Optimize the Planning of Ambulance Standby Points by Using Getis-Ord Gi* Based on Historical Emergency Data

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Abstract: In this paper, we first find the hot spots of emergency call events from a large number of historical pre-hospital medical data, and then plan ambulance standby points to shorten the time to the emergency scenes. The Getis-Ord Gi* method for calculating the local spatial autocorrelation index is introduced as a screening tool for ambulance standby locations. First aid call data are selected according to different time granularities, and the results of ambulance standby point planning with annual cycle are obtained by analyzing hot call areas extracted under different time granularities. By adjusting the significance level of hot call areas extracted, different numbers of ambulance standby points and their importance can be obtained. In the case study, we figured out 6 standby points with a significance level of 95%, for 12 ambulances. This method has been applied in the medical emergency service in Minhang District, Shanghai.

1. Introduction

The most important part of the pre-hospital medical emergency system is to make sure that the ambulance can get to the patient address in time, trying to give patients emergency treatment on the spot and then transport them to appropriate medical institutions. Among them, the time from receiving the call to the arrival of the ambulance on the scene is an important consideration for evaluating the operational efficiency of the emergency system. The corresponding indicators including the average arrival time, the 15-minute arrival rate, the 20-minute arrival rate, etc. The factors which can shorten the on-the-way time and increase the emergency arrival rate mainly consist of the allocation of ambulance standby points and the dispatching algorithm of ambulances. The former factor refers to the number of ambulances and the position of standby points; and the latter refers to the optimal assignment of ambulances to the calling locations, based on the current available ambulances, traffic conditions, and the algorithms that balance the system optimization and user optimization, which have been widely investigated in literature [1-8]. This paper focuses on the former, trying to improve the arrival rate through optimizing the allocation of ambulance standby points. Particularly, since the number of ambulances is usually fixed in the real world, the core of the research is to figure out how to optimize the plan of ambulance standby points so as to maximize the proximity from standby points to call addresses to shorten the travel time.

In literature, the research on the selection of ambulance standby points is mainly based on spatial coverage model. From the perspective of population distribution, the service areas of current
Ambulance standby points are evaluated [9-15], and the standby points, first aid sites or emergency hospitals were planned according to this model [16-18]. This paper attempts to extract the optimized ambulance standby points by analyzing a large number of historical data. The main reasons are as follows: first, compared with other data, historical data of emergency calls are more relevant to ambulances which can reflect the direct demands for ambulances; second, in the past few years, the medical emergency service has made great progress in the application of information and communication technologies, and it has been applied to daily operations such as dispatching ambulances and tracking status of emergency tasks, which greatly improves their efficiency. At the same time, a large amount of structured data has been collected, which can also be used for further analysis; third, although the place and time of occurrence of emergency events is somehow random, it usually follows a law of statistically significant probability distribution at a time granularity. Thus, based on historical emergency calls, hotspot call regions of ambulance standby points can be arranged appropriately to shorten the distance between standby points and emergency sites.

In the above process, since the characteristics of space and time are inherent in pre-hospital medical emergency work, technology for analyzing spatio-temporal big data based on geographic information science can be considered as the fundamental method. In particular, we use the Getis-Ord Gi* for calculating local spatial autocorrelation index [19] for figuring out ambulance standby points. This paper takes the data from Minhang District of Shanghai as an example, and presents the methodology.

2. Principle

It is remarkable that service areas of standby points need correspond to the hot spots of emergency calls. By this means, the objective is to find such areas. Additionally, the locations of emergency calls are discrete, which means that there is an inconsistency in spatial analysis unit between discrete historical call locations and continuous hotspot call areas. To handle this, we convert discrete points into a continuous grid network, consisting of a large number of square grid cells of the same shape, each with an attribute value representing the number of calls inside grid cells. Multiple adjacent grids may form a hotspot area.

One important parameter for constructing a grid network is spatial granularity, which is the side length of each grid cell. The size of spatial granularity has a significant impact on analytical results. If the granularity is too small, the attribute values of grids might be too small (such as only 0 or 1), lacking of spatial diversity. On the other hand, if the granularity is too large, the spatial variation of point distribution might be hidden. Based on our experiments, a spatial granularity of around 500 meters can be considered as an appropriate size in urban area.

Temporal granularity, which is related to the planning period of standby points, is another important concern. For example, if the ambulance standby points are planned on a quarterly basis, the temporal granularity is quarterly, too. Of course, taking the operability into consideration, the planning of standby points should not be changed frequently. Based on existing literature, the spatial distribution of emergency calls usually follows a yearly change cycle. In the following experiments, we illustrate the changes for different temporal granularities.

Getis-Ord Gi* is used to select hotspot areas based on a grid network, which is an indicator of local spatial autocorrelation. By adjusting the parameters of analysis, different levels and quantities of hotspot areas can be obtained, and their centroids can serve as ambulance standby points.

Overall, the methodology consists of three steps: first, to uniform the unit of spatial analysis and to determine the temporal granularity, historical data of emergency calls are converted into cells of a grid network; second, Getis-Ord Gi* is employed to identify hotspot areas in the grid network; third, ambulance standby points are extracted according to the hotspot areas. Among them, the implementation of the first two steps is described in the following sections. The third step is introduced in the experimental section.
3. Constructing a grid network

As shown in Fig. 1. First, with a certain temporal granularity, selected emergency calls are located in space. Second, a grid network is constructed covering the study area with a given spatial granularity, i.e., the side length of each grid cell. Third, the set of points is superimposed with the grid network, and the number of points covered by each grid cell is calculated, which is the attribute of the unit.

4. Hotspot area identification

A hotspot area is composed of a plurality of adjacent grid cells with varying numbers, each of which has a high attribute value, i.e., the number of historical emergency calls in this study. We calculate the value of Getis-Ord Gi* for each grid cell to quantify the strength of local spatial autocorrelation of the grid cell to find out hotspot areas. Local spatial autocorrelation refers to the correlation of a grid cell with its surrounding cells on the same attribute. If a grid cell is surrounded by a group of cells with high attribute values, positive local spatial autocorrelation is observed, and its corresponding Gi* is greater than zero.

The formula for calculating Gi* is given is Equation 1-3, where \( w_{i,j} \) is the adjacent weight between the grid unit \( i \) and the grid unit \( j \), whose value is 0 or 1, which means that the two grid units are not adjacent or adjacent (i.e., they share the same edge or vertex). This value can also be the reciprocal of the distance between two grid cells. \( x_j \) is the attribute value of the \( j \)-th grid cell and \( n \) is the number of grid cells.

\[
G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S} \left[ \frac{n \sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2}{n-1} \right] \quad (1)
\]

\[
\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)
\]

\[
S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)
\]

The values of Gi* equal to z-Scores of the standard normal distribution. Therefore, it is easy to make hypothetical test on local spatial autocorrelation with a certain significance level. If the null hypothesis is refused, the grid unit can be considered to be a hotspot area with its neighbors. In practice, different numbers of hot spots can be obtained by changing significance level. By comparing the Gi* values of grid cells in each hotspot area, it is possible to sort hotspot areas by significance. Then, we can allocate available ambulances to those areas with high ranks.
5. Case study

5.1 Data description
The historical emergency call data in 2017 from Minhang District, Shanghai, are used in our experiments, which consists of 39,499 records. Each record has an address to indicate the calling position. Based on it, all records are located on a map. As shown in Fig. 2, the black solid polygon is the boundary of Minhang District and the white dots represent the locations of emergency calls.

![Figure 2](image)

**Figure 2.** The study area and the spatial distribution of emergency calls in 2017.

5.2 Extracting hotspot areas
A grid network is constructed and the spatial granularity is 500 meters. We choose a significance level of 99.99% to extract hot spots for the set of calls with temporal granularities of a year, half a year, and a quarter, respectively. The results are shown in Fig. 3, where grids are hidden if their attribute values are 0. A black rectangle represents a hotspot grid cell.

![Grids](image)

(a) throughout the year  (b) first half of a year  (c) second half of a year
(d) first quarter  (e) second quarter  (f) third quarter
Figure 3. Results of hot spots extraction with a significance level of 99.99% at different temporal granularities

As is shown in Fig. 3, the extraction results of hot spots are different under different temporal granularities. The results of one year and six months (Fig.s 3a, 3b and 3c) are almost the same, while the results of the four quarters are remarkably different, especially in the third quarter (Fig. 3f). This can be understood as the cycle of emergency calls in the district changes every half a year or one year. This is consistent with the characteristics of emergency call service, which may be affected by season to a great degree. When planning future ambulance standby points based on historical data, it is necessary to consider corresponding temporal granularity. For example, in this case, to plan the ambulance standby points for the whole year of 2018, we need refer to the result of Fig. 3a, while if one wants to plan for a certain quarter in 2018, the result of corresponding quarter in 2017 should be considered.

5.3 Planning ambulance standby points
The following three steps are used to plan ambulance standby points. First, determine the number of standby points, by adjusting the level of significance to obtain hotspot areas that is no less than the number of standby points. Second, sort hotspot areas according to significance level, and select the top hotspot areas to locate standby points. Third, the number of ambulances in each standby point can be configured according to the significance level of hotspot areas where it is located. The higher the significance level, the more ambulances should be placed.

As shown in Fig. 4, to plan the ambulance standby points for the year 2018, we set a significance level of 95%. With the temporal granularity of one year, we can get 6 hotspot areas. Compared to Fig. 3a, since the significance level is decreased, the number of hotspot areas identified is increased. The order of importance from high to low is A>B>C>D>E>F.
Figure 4. Hotspot areas with a 95% significance level at a temporal granularity of one year.

Table 1. Standby points planning results.

| Hotspot area | Standby point position         | Number of ambulances |
|--------------|--------------------------------|----------------------|
| A            | Ruiqing Road, Heqing Road      | 3                    |
| B            | Lianhua South Road, Jindu Road | 3                    |
| C            | Xinsong Road, Xin West Road    | 2                    |
| D            | Pingyang Road, Wanyuan Road    | 2                    |
| E            | Hongsong Road, Huanghua Road   | 1                    |
| F            | Wubao Road, Wuzhong Road       | 1                    |

The obtained hotspot areas are superimposed with the road network, and the central position of the area is selected as the standby point. Meanwhile, the number of ambulances of each standby point is configured according to the importance of the hotspot area. The final planning result is given in Table 1. The positions of standby points might be adjusted according to the actual land use situation.

6. Conclusion

In the pre-hospital medical emergency system, shortening the time from receiving emergency call to the arrival of ambulances on the scene is important to improve the efficiency of the emergency system. Based on a large number of historical emergency calls, hotspot call areas can be found, which can be used as the basis for planning ambulance standby points to achieve the goal of shortening the traveling time. According to the above principle, this paper proposes a method of planning ambulance standby points, which consists of three steps: first, construct a grid network to form a continuous surface representing the changes of emergency calls over space. Second, applying Getis-Ord Gi* to identify hotspot area in a grid network. Third, plan ambulance standby points according to hotspot areas.

In experiments, we take about 40,000 records of emergency calls in 2017 in Minhang District of Shanghai as the study case. Select 500 meters as spatial granularity and one year as temporal granularity. Adjust the significance level to demonstrate how to plan standby points of ambulances.

The method proposed in this paper is operable. Based on a large number of historical emergency calls, it can accurately extract hotspot areas. Meanwhile, the way to planning the standby points can be dynamically adjusted according to the latest data. This method has already been applied to the medical emergency services of Minhang District in Shanghai.

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8. References

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