Optimal route of emergency resource scheduling based on GIS

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ABSTRACT

Rapid emergency resource supply is one of the most issue in effective emergency response and management for crisis and disasters. To support the reasonable emergency resource supply under emergency conditions, emergency material scheduling should take full consideration of time cost, economic cost and the priorities of the resources demand. In this paper, we propose emergency resource scheduling model (ERSM) to determine the optimal route for emergency resource scheduling based on Geographic Information Systems (GIS). The ERSM evaluate optimal emergency rescue route under different emergency conditions based on Analytic Hierarchy Process (AHP) method, which introduced multiple indicators including the traffic road condition, actual travel distance, urgency of disaster relief spot. Meanwhile the solomon insertion-type heuristic algorithm (SIHA) is proposed to identify the optimal route of emergency resource scheduling. Then ArcGIS software with network analysis extension is adopted to display optimal delivery routes. ERSM provides the emergency mangers with optimal route of emergency resource for quick and efficient responses after disaster.

CCS CONCEPTS

• **Computing methodologies** →Planning under uncertainty

• **Information systems** → Geographic information systems

KEYWORDS

Emergency resource scheduling model, Emergency management, Geographic Information Systems, Analytic Hierarchy Process , Solomon insertion-type heuristic algorithm

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1 INTRUCTION

Improving the distribution efficiency of emergency supplies such as life necessities is the main concern in emergency rescue. Such distribution issues are more essential for the delivery staff of emergency resource, who are looking for potential optimal distribution routes. With emergency material reasonable scheduling, emergency management department is able to send the emergency supplies to the emergency rescue site quickly and satisfy the emergency rescue requirements before the disaster increased [1]. Therefore, the focus of this study is on network analysis application based on GIS modeling for determining the optimal route of emergency resource scheduling after the disaster as soon as possible.

In the existing literature, business logistics has been clearly defined as logistics is the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of consumption for the purpose of conforming to customers requirements at the lowest total cost [2,3,4]. However, a clear definition of emergency logistics has not yet been well clarified, the emergency logistics is usually a process of planning, managing and controlling the efficient flows of urgent relief, information and services from the origin point to the destination points to meet the urgent needs of the affected areas under emergency conditions [5]. In general, disasters often cause serious casualties and make many buildings severely damaged, so disaster areas need emergency relief supplies, such as water, food, medicine, shelter, medical equipment, etc., to meet the daily needs of the corresponding survival and reduce the impact of disasters. Emergency material distribution has caused extensive research in recent years. Sheu presents a hybrid fuzzy clustering-optimization approach to the operation of emergency logistics co-distribution responding to the urgent relief demands in the crucial rescue period [6]. Hu and Sheu formulate a multi-objective linear programming model systematically minimizing total reverse logistical costs, corresponding environmental and operational risks in removal of debris [7]. These papers studied the optimal route of emergency resource scheduling ignoring the urgency of demand spots.

The optimal route of material scheduling in the past is based on traditional maps, since Geographical Information System (GIS) provides effective tools to collect, store, display, manipulate, analyze spatial data, and present descriptive information about them on the maps [8] , GIS has been increasingly attention by researchers. The importance about GIS is that, GIS combines digital maps with traditional databases, and provides visual representations of information [9]. Visualization will help people approach problems in the dimensions of space and time and in the form of digital maps rather than dimensionally-restricted data tables and graphs [10]. Winyoopradist and Siangsuebchart developed a model on Network Analyst based on vehicle speed, which depend on road conditions at different times of the day [11]. In route planning systems based on GIS, Gohari developed a model to analyze the shortest paths and took into account several factors, such as the speed limit of a car in a road network [12]. Mohammad Abousaeidi, Rosmadi Fauzi and Rusnah Muhamad proposed regression model and introduced the land use to the optimal route for fresh vegetable distribution [9]. We establish ERSM to meet the fast and efficient emergency resource scheduling based on application of GIS.

The novelty of solomon insertion-type heuristic algorithm (SIHA) used in material distribution consists in incorporating not only the distance but also the time dimension in the heuristic process [13]. Due to it has the advantages of easy implementation and obvious application effects, SIHA is suitable for emergency material scheduling.

This paper quantifies the urgency of demand and puts forward the ERSM, which combines urgency of demand spots, road distances, traffic conditions with GIS. The object of this paper is to introduce the GIS to present the optimal route of emergency resource scheduling with consideration of distance, traffic conditions, urgency of demand spots.

2 METHODOLOGY

The optimal route evaluation criteria system is shown in Fig. 1. Choosing the optimal route of emergency resource scheduling consider traffic road conditions, travel distance, urgency of disaster relief spot. There are many criteria to evaluate road conditions, such as traffic index of the prevailing road, the degree of damage to the road. Also, there are many criteria to evaluate the urgency of disaster relief spot, such as the size of affected area, the number of casualties and the degree of damage to infrastructure. Determining the optimal route of emergency material scheduling scheme is a complex process, all these factors should considered.

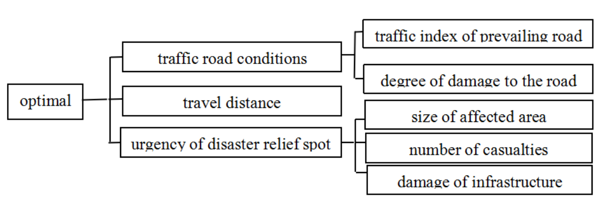

Figure 1. Optimal route evaluation criteria system

2.1 AHP Method

The identification of the appropriate proportions of influencing factors is a complex process, the Analytic Hierarchy Process (AHP) method establishes a series of scales from comparisons. In AHP a matrix, such as Eq. (1), is generated as a result of pairwise comparisons.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

In the formulation, a_{ij} indicates how much more important the ith objective is than the jth objective. For all i and j, it is necessary that a_{ii}= 1 and a_{ij}= $1/a_{ji}$. The possible assessment values of a_{ij} in the pairwise comparison matrix and their corresponding explanation are shown in Table 1.

The AHP group decision-making developed can be defined as follow:

Normalized column vector:

$$\tilde{w}_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij}$$

Summarize the by row: $\tilde{w}_{ij}$

$$\tilde{w}_i = \sum_{j=1}^{n} \tilde{w}_{ij}$$

Normalized row vector:

$$w_i = \tilde{w}_i / \sum_{i=1}^{n} \tilde{w}_i$$

$$w = (w_1, w_2, \cdots, w_n)^T$$

Calculate the biggest characteristic root of the judgment matrix:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i}$$

The consistency degree of the judgment matrix

The consistency ratio:

$$CR = \frac{CI}{RI}$$

where the consistency index (CI) is defined as:

$$CI = (\lambda_{\max} - n) / (n - 1)$$

If CR ≤ 0.10, the degree of consistency is satisfactory. Otherwise, the element value of the judgment matrix should be adjusted.

Calculation of total ordering in the layer

The single order of criterion layer to target layer:

$$w = (w_1, w_2, \cdots, w_n)^T$$

Table 1. Scales in pairwise comparisons

a_{ij}	Definition
1	i and j are equally important
3	i is slightly more important than j
5	i is more important than j
7	i is obviously more important than j
9	i is absolutely more important than j
2,4,6,8	the importance of i and j is between the two adjacent degrees

2.2 Establish the model

2.2.1 Modeling assumptions.

There is only one emergency resource distribution spot, and there are several demand spots for emergency resource.

The delivery tools of emergency resource distribution spot to the various emergency resource demand spots are the same.

The material of emergency resource distribution spot is sufficient to satisfy the needs of all demand spots.

2.2.2 Model

Model establishment not only contains spatial data, such as travel distance, traffic road conditions, but also consider non-spatial data, like the urgency of disaster relief spot. With the help of GIS technology combined with spatial and non-spatial data, emergency resource scheduling can be conducted and optimal routes based on the study requirements can then be selected. The first phase of the study requires the use of GIS tool to create a spatial database that contains detailed digital information about the routes. The information of travel distance for all roads is derived from digitizing the road networks as spatial data set. In the present study, delivery time is regarded as a dependent variable that depends on the road condition. The traffic index is a conceptual index that reflects the smoothness or congestion of the road network, we obtain the real-time average speed of a road through the observation of the real-time traffic index of the prevailing road in the moment before the disaster. The degree of road damage also affects the average speed after disaster, it has been shown that the speed loss (Eq.2) caused by road damage is related to the area of road surface damage, pavement width and depth of road surface damage. The distance traveled in an emergency situation is transformed to the normal travel distance during the same running time by comparing the average speed after disaster with the average vehicle speed under normal circumstances in a certain road.

$$\Delta v = \frac{v_0}{8.14} e^{0.01S + 0.049H + 0.803 f(D)} \quad f(D) = \begin{cases} 1.8 - D & 0 \le D \le 1.8 \\ 0 & D > 1.8 \end{cases}$$

(2)

Δv	the speed loss caused by road damage
v_0	the speed before road damage
S	the area of road damage
H	the depth of road surface damage
D	the lane width
$f(D)$	the adjustment formula of lane width

The urgency of disaster relief spot is related to the size of affected area, the number of casualties, and the degree of damage to infrastructure. The urgency of disaster relief spot is a relative variable, which is determined by comparing two spots. The area of the affected area are obtained by using remote sensing technology, which can be used to display the affected area by adding buffers in ArcGIS. The number of casualties should be counted and updated in real-time by region. Water and electricity are the infrastructure necessary for human survival, so the degree of damage to the infrastructure are measured based on the time of cutting off the water supply and power. Gathering the statistics of these information about all emergency resource demand point when the disaster occur, and determining the minimum affected area, the least number of casualties, and the shortest time of cut off the water supply and power respectively. These values are the standard values that measure the urgency of disaster relief spot. Each emergency resource demand spot is compared with these standard values to obtain relative urgency of disaster relief spot (Eq.3).

$$\tau_i = \beta_1 \frac{A_i}{A_{min}} + \beta_2 \frac{N_i}{N_{min}} + \beta_3 \frac{T_i}{T_{min}} \quad (3)$$

τ_i	the urgency of disaster relief spot i
β_1	the proportion of affected areas obtained by AHP
A_i	the area of the affected area at spot i
A_{min}	the minimum affected area
β_2	the proportion of number of casualties obtained by AHP
N_i	the number of casualties of at spot i
N_{min}	the least number of casualties
β_3	the proportion of time of cut off the water supply and power obtained by AHP
T_i	the time of cut off the water supply and power at spot i
A_{min}	the shortest time of cut off the water supply and power

Taking into account all the influencing factors, such as the traffic road condition, actual travel distance, urgency of disaster relief spot, the final model formula can be constructed (Eq.4).

$$L_{ij} = \alpha_1 l_{ij} + \alpha_2 \left(\frac{l_{ij}}{\overline{v}_2 - \Delta v} - \frac{l_{ij}}{\overline{v}_1} \right) * \overline{v}_1 + \alpha_3 \frac{\sum_{j=1}^{n} (\tau_i - \tau_j) * l_{ij}}{\sum_{j=1}^{n} (\tau_i - \tau_j)} * (\tau_i - \tau_j) \quad (4)$$

L_{ij}	distance index between i and j
$\alpha_1, \alpha_2, \alpha_3$	the proportion of travel distance, transport road conditions, and urgency of disaster relief spot obtained by AHP respectively
l_{ij}	actual travel distance between i and j
$\overline{v}_2$	real-time average speed in the moment before disaster
$\overline{V}_1$	average speed under normal circumstances
Δv	the speed loss caused by road damage
τ_i, τ_j	the urgency of disaster relief spot i,j

Solomon insertion-type heuristic algorithm (SIHA) select the best disaster relief spot to insert its best available insertion position from all unspecified spots. Thus each time it insert the spot and the insertion position is the current optimal, it will improve the quality of the solution. The optimal insertion position is determined by distance. Assuming that the unloading spot d is inserted between the spots m and n. When the spot d inserted may cause changes in the distance and time, which is

c_{11} (Eq. 5),c_{12} (Eq. 6). Combining c_{11} and c_{12},we acquire the c_1 (Eq. 7). The insertion position of minimum c value is the optimal insertion position. If insert a spot to the current path get a greater benefit than to insert to a new path, this spot is optimal. The optimal spot is decided by c_2 (Eq. 8), which c_2 minimum spot is the optimal spot.

$$c_{11}(m,d,n) = d_{m,d} + d_{d,n} - d_{m,n} \tag{5}$$

$$c_{12}(m,d,n) = b_{n,d} - b_n \tag{6}$$

$d_{m,n}$ the distance between spots m and n

$b_{n,d}$ the new time for service to begin at customer n given that d is on the route

$$c_1(m,d,n) = \gamma_1 c_{11}(m,d,n) + (1-\gamma_1)c_{12} \qquad 0 \le \gamma_1 \le 1 \tag{7}$$

$$c_2(m,d,n) = \mu d_{0,d} - c_1(m,d,n) \quad \mu \ge 0 \tag{8}$$

3 CASE STUDIES

This model is suitable for finding the optimal route for emergency resource scheduling after a disaster, such as hurricane, tsunami, earthquake. Shenzhen is located in the southern coast of China, and it often have typhoon by the impact of geographical location. The fourth typhoon Nida attacked Shenzhen in august 2016, because the timely warning and emergency supplies prepared, it did not cause too much loss. As the road surface gathered water caused by typhoon bring a lot of inconvenience to the people travel. Therefore, this model is used to study the optimal scheduling route of Nanshan Water Group in Nanshan District for the road surface gathered water spot. The locations of supply spot and demand spots are shown in Fig. 2. There are only one supply spot and fifteen demand spots, the Water group assign five vehicles for transport. The experts combine the Analytic Hierarchy Process (AHP) method and the historical experience to determine the proportion of each influencing factor(Table 2). The real-time traffic index obtain from the website of Transport Commission of Shenzhen Municipality, and road damage can be observed through the road traffic monitor. The speed loss can be easily acquired. Considering the traffic road conditions and the urgency of disaster relief spot and using ArcGIS network analysis(Fig. 3) to insert the model, we acquire the OD cost matrix and know the distance between the emergency resource supply spot and demand spots. Solomon insertion-type heuristic algorithm (SIHA) is proposed to identify the optimal routes. The optimal routes are shown in Fig. 4, the shortest total distance is 83178.04 miles.

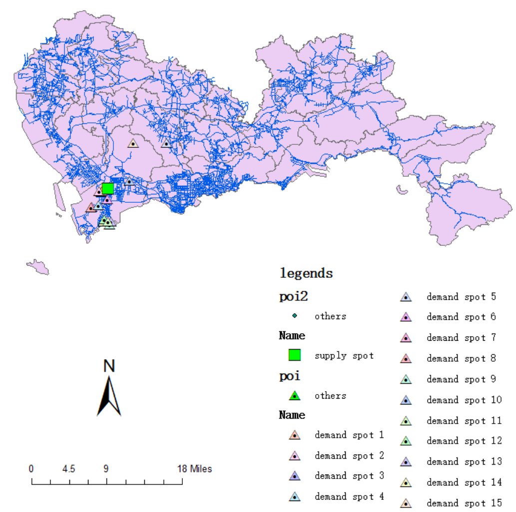

Figure 2. Locations of supply spot and demand spots

Table 2. Proportion of influencing factor

α	Value	β	Value
α_1	0.0752	β_1	0.2583
α_3	0.1830	β_2	0.6370
α_3	0.7418	β_3	0.1047

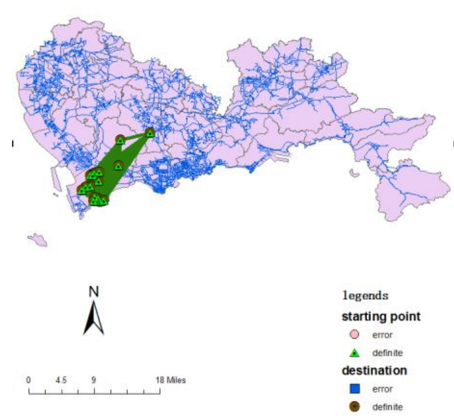

Figure 3. Network analysis within the study area

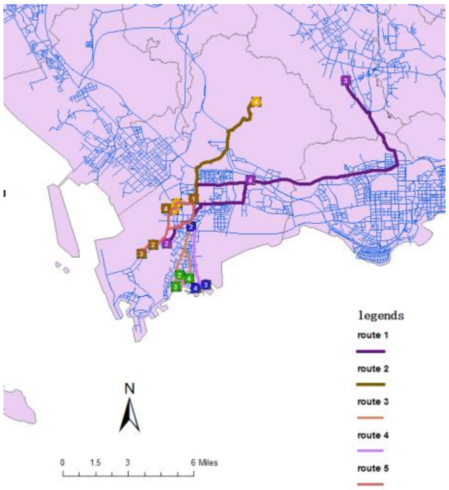

Figure 4. Optimal route of emergency material scheduling

4 CONCLUSION

A GIS-based decision support system was applied to determine the optimal route of emergency material scheduling. The model quantify the urgency of the disaster relief spot by contrasting with the standard values, meanwhile considering the traffic conditions and travel distance in detail. The ERSM can be widely used for a variety of post-disaster emergency supplies scheduling to support the reasonable emergency resource assignment in disaster management. According to the damage experience of different disasters, experts can flexibly calculate the proportion of each factor using the Analytic Hierarchy Process (AHP) method. Solomon insertion-type heuristic algorithm (SIHA) and network analysis help users identify the optimal routes. ArcGIS provides visualization output of optimal routes. This result assist the emergency manager to make a decision with full consideration of travel distance, traffic conditions, the priorities of the resources demand.

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