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A Contingency Plans Generation System for Urban Storm Surge Disaster Based on Optimization

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***Abstract*—Research on urban storm surge disaster contingency plans generation for personnel evacuation has become an important part of the research in the area of marine disaster prevention and reduction strategy. This paper fits in the research area by introducing the development of a software system that facilitates personnel evacuations during an urban storm surge disaster. The system uses a linear programming model and simplex algorithm and is implemented with ArcGIS and C #. Post development experiments have shown it to be efficient in automatically calculating the affected area, the number of personnel to be evacuated and screening the settlement points of safety. In addition, an optimization calculation generates the maximum number of personnel to be allocated to the safety points as well as the best evacuation routes. The system is simple to operate with a high degree of visualization.**

***Index Terms*—linear programming, personnel evacuation, contingency plan, storm surge, flood**

I. Introduction

Kantorovich is a Soviet mathematician and economist who published a most influential book "The Mathematical Methods in Production Organization and Plan" which proposed the early linear programming ideas[1]. At present, linear programming has become an important branch of operations research and has been widely used for its perfection theory. For example: Zhou & Ang[2] used the linear programming model to measure the energy efficiency performance of an overall economy. Pindyck and Rubinfeld[3] applied linear programming to analyze economic trends; Katagiri and others[4] attempered resources effectively by using fuzzy multi - linear programming. Zhang[5] studied the Social Security Fund Portfolio Optimization using Fuzzy Linear Programming. Linear programming has been the basis of various applications in many fields.

There has been an immense coastal economic development in recent years in China. Unfortunately, storm surge disasters have caused huge losses in this area, much more than those brought by other marine disasters[6]. Storm surge disaster is a natural phenomenon in which the tide level of the affected area significantly surpasses the usual tide level as a result of severe atmospheric disturbances, such as strong winds and sudden change in air pressure that cuases abnormal water movements[7]. The Chinese government at all levels and several scientific research institutions have begun research on urban storm surge disaster contingency plans. The ultimate aim is the safe and rapid evacuation of the affected personnel. Some key elements include the affected area to evacuate, the evacuation personnel number, the type of settlements capacity, the number of relocation sites and evacuation routes etc. The real challenge is how to evacuate the affected personnel to the safest placements in a most effective manner involving the lowest consumption of resources.

This paper describes the realization of a software system to meet the challenge. It is based on optimizing calculation which makes use of a mathematical linear programming model, combined with the related functions of ArcGIS. It resolves the personnel distribution of settlement points with a recommendation of evacuation paths. The system can visually represent the scope and the number of people affected based on the user's selection of the affected regions, types of settlements and security placements. Following a process of optimization calculation, the system will assign the affected staff to various settlements via recommended evacuation routes. Multiple testing of the system has shown very positive results with a user-friendly system interface for easier operation.

II. THE BASIC MODEL AND SOLUTION PRINCIPLE

The system is based on linear programming using a simplex algorithm.

The expression of the linear programming is shown in the following formula.

$$\max \quad \sum_{j=1}^{n} c_j x_j$$

$$\text{s.t.}$$

$$\sum_{t=1}^{n} a_{it} x_t \le b_i \qquad i = 1, 2, \cdots, m_1$$

$$\sum_{t=1}^{n} a_{jt} x_t = b_j \qquad j = m_1 + 1, \cdots, m_1 + m_2$$

$$\sum_{t=1}^{n} a_{kt} x_t \ge b_k \qquad k = m_1 + m_2 + 1, \cdots, m_1 + m_2 + m_3$$

$$x_t \ge 0 \qquad t = 1, 2, \cdots, n$$

Simplex algorithm is the feasible region of linear programming. The basic feasible solution of linear

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programming corresponds to the vertex of the linear programming problem feasible region 1-1. Linear programming simplex algorithm is designed based on the geometry feature of the linear programming feasible region. Thus linear programming problem can be solved by simplex algorithm.

Simplex method is an iterative algorithm. It starts with attempting to find a (initial) basic feasible solution, and then determine whether it is the optimal solution or not based on the optimal theory. If it is the optimal solution, then output the results of the calculation and the calculation stops. If it is not the optimal solution, then try to produce a better basic feasible solution from the current basic feasible solution and then judge whether it is the optimal solution or not by using optimal theory. This iteration is performed until the optimal solution is found. Since the number of the basic feasible solution is finite, and every time the target value is improved, calculation can thus be terminated in limited steps. If the original problem does have an optimal solution, we can get it in limited steps. The amount of calculation is much smaller than that of exhaustive method. If the original problem has no optimal solution, the optimal theory can detect it and the calculation can be terminated to avoid errors and invalid operations.

The simplex algorithm procedure works as follows:

Step one: convert the form of linear programming into binding standard linear programming problem by adding a free variable;

Step two: select the non-basic variables which can increase the objective function as entering variable;

Step three: select leaving variable which is the basic variable that has the most constraints in order to meet the constraints when the entering variables and leaving variables interchange places;

Step four: pivot transformation, that is, add value to entering variables in order to make it become the basic variables, and then modify leaving variable so as to become as non-basic variables by reducing the value of element where the row of non-basic variables is included in the column of entering variables to zero, in order to interchange the entering variables and leaving variables places;

Step five: repeat the first step to further improve the objective function value, until all non-basic variable coefficients of the objective function coefficients row. This shows that the objective function value could not be increased, and the objective function value is the maximum.

III. LINEAR PROGRAMMING MODEL OF PERSONNEL EVACUATION

As the standard form of linear programming is the problem of solving maximum and the optimization of personnel evacuation is the calculation of minimum resources consumption, the model should be properly transformed into a standard form for resolution. Reverse solving the minimum Min(z) can be transformed into solving Max (-z) issues. At last the minimum is obtained by taking reverse of the final result while the unknown value does not change. As for this issue, all the factors are positive. After Max(-z) transformation all the coefficients are negative. And so it can not be solved. Therefore, this study uses the variables substitution technology in this model so that all the negative coefficients are transformed into positive coefficients before reaching a resolution.

Regarding the specific issues of the city storm surge disaster personnel evacuation, the objective function can be realized as follows:

$$\mathrm{Min}(z) = a_1 * x_1 + a_2 * x_2 + \cdots + a_i * x_i + \cdots + a_n * x_n \quad (1)$$

(xi is the actual number of people for the ith settlement, ai is the resource consumption of the ith settlement, the range of i is from 1 to n)

First of all, Formula (1) will be converted to a standard form of linear programming as follows:

$$\mathrm{Max}(-z) = -a_1 * x_1 - a_2 * x_2 - \cdots - a_i * x_i - \cdots - a_n * x_n \quad (2)$$

Then, using variable substitution technology the coefficient of Formula (2) will be converted from negative to positive as shown in the following formula:

$$\mathrm{Max}(-z) = a_1 * x_1{}' + a_2 * x_2{}' + \cdots + a_i * x_i{}' + \cdots + a_n * x_n{}' - (a_1 * b_1 + a_2 * b_2 + \cdots + a_i * b_i + \cdots + a_n * b_n) \quad (3)$$

xi'= bi- xi,

(bi is the largest capacity of the ith settlement)

Formula(3) is the final standard form of linear programming. After working out the x1', x2', …, xi', …, xn' by simplex method, the actual number of people for each settlement x1, x2, …, xi, …, xn can be worked out by Formula (4), and that is the final answer of the question.

In a word, the linear programming model of personnel evacuation is:

$$\mathrm{Max}(-z) = a_1 * x_1{}' + a_2 * x_2{}' + \cdots + a_n * x_n{}' - (a_1 * b_1 + a_2 * b_2 + \cdots + a_n * b_n)$$

s. t. :

$$x_1 \le b_1;$$
$$x_2 \le b_2;$$
$$\cdots\cdots$$
$$x_n \le b_n;$$
$$x_1{}' + x_2{}' + \cdots\cdots + x_n{}' = b_1 + b_2 + \cdots\cdots + b_n - c;$$
$$x_i{}' \ge 0 (i = 1, 2, \cdots, n)$$

xi' is the transformation of the actual number of the settled people, ai is the resource consumption of the ith settlement, bi is the largest capacity of the ith settlement, c is the actual number of people who need to evacuate.

Ⅳ. SYSTEM DESIGN AND REALIZATION

A. Copy Design of contingency plans generation system

Before and after the storm surge disaster, affected personnel should be allocated adequately. This requires accurate and current information on the affected area, the evacuation number and the evacuation path. The system can take the user's selection of the affected regions and type of the selected settlement sites as input data. It then employs optimization calculation to generate the number of the affected personnel, number of settlement spots, the capacity of settlement and the number of people to each settlement using minimum resources. Finally recommended evacuation routes are shown to further facilitate efficient evaluation.

B. Contingency plans generation system structure

The structure of personnel evacuation contingency plans generation system is shown in Figure 1.

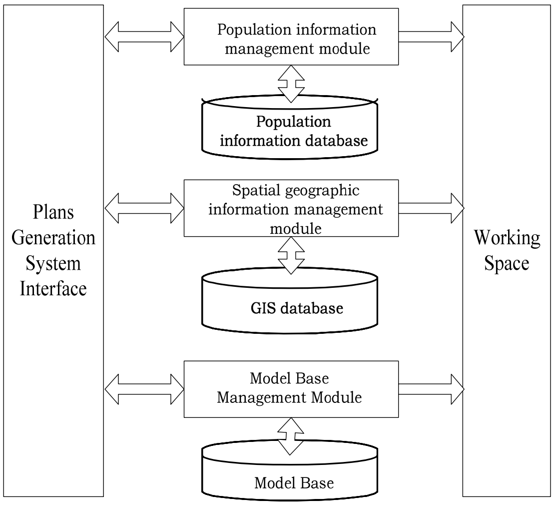

Figure 1. System structure

The function of various parts in Figure 1 is described below:

- Population information management module: It is mainly used to store, manage and extract the population information, as well as the capacity information of the settlement point.
- Space geographic information management module: It is mainly used to store, manage and extract information in the GIS geo-spatial information database.
- Model-base management module: It is mainly used to store, manage linear programming models.
- Plans generation system interface: It is the place to set various parameters and to manage the interface of the entire system.
- Working space: It is the workplace for optimization calculation.

C. System flowchart

The flowchart of the contingency plans generation system is shown in Figure 2.

The system also builds an urban water dynamic model which can simulate the potential impact of a disaster in order to validate the information of a safe settlement. The information includes the names of settlement points, their locations, distance from the affected region, and the largest personnel capacity. After each simulation, the information of settlement points will be written automatically to the population information database in order to facilitate optimized calculation.

Optimized calculation includes two aspects. The first is personnel assignment optimization to each settlement point. The optimization algorithm starts with establishing the mathematical model of linear programming before using C# language to implement the simplex method. The reusability of code is enhanced through packaging the class for maximum. The internal function of class is defined in a static manner so that it is not necessary to repeat the statement on the class each time it is used. The second is GIS path optimization. It mainly uses the shortest path optimization function of GIS itself.

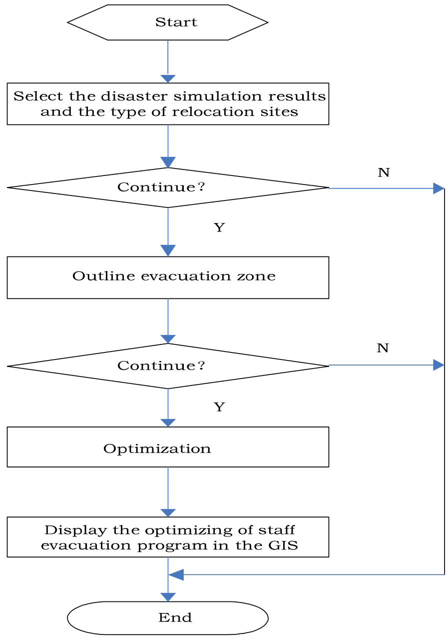

Figure 2. System flowchart

D. Key technologies in system development

The system employs three technologies, namely dynamic array, variable substitution and database transaction processing solution.

The dynamic array technology is used when the optimization based contingency plans generation fails to generate an accurate number of settlement points. Each time the data in relation to the current secure settlements as well as the number of people to be safely settled is extracted from the dynamic database, it is then stored to the dynamic array that should be passed to solving function in the way of parameters.

Variable substitution technology is used to solve the calculation issue of a non-standard optimization model. This has been introduced in detail in section 3.0 of the paper.

Database transaction processing solution is used to solve the problem of inconsistency in database records in a dynamic update especially in situations when a large quantity of data requires an update. The solution is to use database transactions based on relations in the process of realization. After a transaction is committed, we can guarantee that the state of the database and its business rules are consistent and no data will be lost or destroyed.

Ⅴ. SYSTEM TESTING

Multiple tests have been conducted using a hydrodynamic model for simulation showing affected regions in a GIS. When the user designates a withdrawal region using a mouse, a process of optimization calculation is triggered and GIS can automatically indicate the number of personnel that should be evacuated, and recommend optimal placements together with the specific routes leading to them. A view of the system is shown in Figure 3:

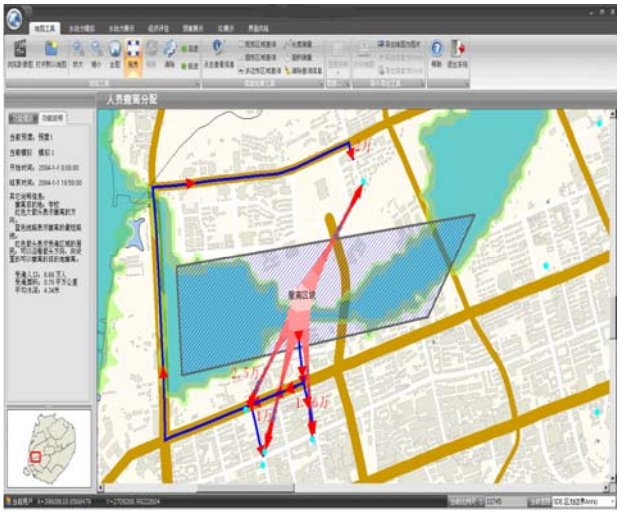

Figure 3. The running effect of the system

In Figure 3, the irregular shape in the middle shows the affected area that need to be evacuated. The green dots are the settlement points. The red arrows point to the specific settlement points. The blue lines are the optimal evacuation routes to the various settlement points.

Ⅵ. CONCLUTION

Contingency plans generation for personnel evacuation based on optimization can solve the personnel evacuation issue before and after disasters. The research remains in the category of Intelligent Decision Support System (IDSS). In future research, street names will be delineated as a unit for evacuated areas in order to improve the accuracy of evacuation paths.

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