Application of multi-objective shortest path and Allocation Analysis of Flood Prevention

Abstract

Since the aftermath of typhoon Herb in 1996, all sorts of flood and drought followed in 2002 have claimed lives and countless property, which have imposed serious economic damage on the country. The collection of flood information is the basis for establishment of flood prevention system. It is anticipated that flood information management system will include flood insurance, flood warning, damage notification and incorporation with GIS in the future to provide further capabilities.

This research makes use of the ArcGIS and mathematical programming, in accordance to the properties of a flood disaster, aiming pragmatically at the balance between the relief of a disaster and the shortest time for conveying the equipments, to construct the optimal model of the equipment's transportation and the mobilization of the emergency. The system could trace and manage more efficiently at the equipments in urgent of repair, reconstruct the state of the recovery.

I. Preface

These years, the greenhouse effect and El Niño is expanded and leads the occurrence of typhoons, downpours and droughts constantly and heavily. In response to the drought happened last year, the Ministry of Economic Affairs and its affiliated organizations took a measure of water restrictions phase by phase and utilize the mechanism of man-made rain to ease the drought. Moreover, two floods and eight typhoons resulted in severe damages to drainage channels, embankments, bank revetments, reservoirs, dams, and power plants. The budget of reconstruction is estimated about NT$5.5 billions. It shows that Taiwan now faces severer flood and drought problems.

Disaster management, featuring cross-region, discipline, domain, as well as specialty, integrates disaster prevention resources and use information technology to manage these resources efficiently. Basically, disaster prevention resources are dispersed on different governmental organizations; therefore, it is a primary to strengthen horizontal connection between governmental and non-governmental organizations. So, mutual support and sharing of business, information, knowledge, experience, and resources is also a critical key to disaster prevention.

In order to fulfill above-mentioned purposes and reinforce the allocation mechanism, this study employs Geographic Information Systems (GIS) and analysis programming to establish an optimal path according to the flood characteristic and its potential influence for equipment allocation and mobilization to facilitate decision makers arranging the allocation priority effectively.

II. Shortest Path Algorithm

The Shortest Path Problem, a very classical algorithm in the graph theory research, is a problem of finding a path between two vertices. The specific form of algorithm can divide into four parts:

1. Determining the start point: means finding the shortest path through a given start node.
2. Determining the ending point: means finding the shortest path through a given ending node. In view of undirected graph, this problem is equal to the problem of determining start point; however, in directed graph, this problem is contrary to the problem that reverses start points.
3. Determining both start and ending points: means finding the shortest path between two vertices through the given start and ending points.
4. Overall situation: computing all shortest paths in a graph.

A solution to the shortest path problem is sometimes called “Shortest Path Algorithm”. The most common algorithms for solving this problem are:

1. Dijkstra's algorithm — solves the single-source shortest path problem for a directed graph with nonnegative edge weights. It features start point-centered expansion toward the end point. Dijkstra's algorithm can compute an optimal solution of shortest path for every two nodes; however, because of going through many nodes while computing, the efficiency is lower. Beside, it fails to process negative cost graphs.
2. A* search algorithm — an improvement of Dijkstra's algorithm, which is commonly used to solve the shortest path problems of game. A* search algorithm adopts a special Heuristic Estimate method to eliminate obviously wrong paths and then swiftly compute an optimal one. Compared with Dijkstra's algorithm that ensures to find the shortest path, A* search algorithm is more efficient.
3. Bellman-Ford algorithm — an efficient algorithm to solve the single-source shortest-path problem that means finding the shortest paths from a specific source vertex to every other vertex in a weighted, directed graph.
4. Floyd-Warshall algorithm — solves all pairs of shortest paths. It is able to process directed graph or negative value correctly. Floyd-Warshall uses different observation to find a new recursion. The edges may have negative weights, but no negative weight cycles. The time complexity is $\Theta(V^3)$.

5. Johnson's algorithm — uses reweighing to eliminate the paths with negative value to make the graph adaptive to Dijkstra's algorithm for the sake of higher efficiency.

III. K-shortest Path Algorithm

K-shortest Path problem is the extension of shortest path problem. Shortest path problem means finding the shortest path between every two vertices; in addition to finding the shortest path, K-shortest path algorithm also provides a second short path. K-shortest path can be classified into directed solution, namely directly calculating two vertices' K-shortest path in the network; oppositely, the undirected solution needs to obtain the shortest path first and further calculate the path from the second to K path according to the previous result.

K-shortest Path Algorithm was proposed by Hoffman in 1959 but the most common algorithm was proposed by Yen in 1971 that has been regarded as a basis of related algorithm or applications.

Algorithm	Author	Era
Hoffman and Pavley's algorithm	Hoffman and Pavley	1959
Dreyfus' algorithm	Dreyfus	1969
Yen's algorithm	Yen	1971
Calculating kth shortest paths	B. L. Fox	1973
DoubleSweep algorithm	Shier	1976
Martins' algorithm	Martins	1984
Simplified Double-Sweep Method	Rink, Rodin, Sundarapandian	2000

This study, based on "Calculating kth shortest paths" presented by B.L. Fox in 1973, integrates both Breadth-first search and Insertion Sort methods to develop the following K-shortest Path Algorithm.

Step 1：Obtain a point near the start point, sorting by cost and then save to network analysis matrix.

Step 2：Exclude analyzed point, and then obtain the least-cost node from the network analysis matrix. Sort the cost of neighboring points, saving to save to network analysis matrix.

Step 3：Repeat Step 2 until the cost of latest point's first path more than the cost of end point's K-shortest path.

The advantages of the invention are

- providing multi-shortest path for users to select.
- high performance and the complexity is nLog(n) that can compute many shortest paths in shortest time. For example, it takes only millisecond to compute 6000 paths.
- integrate transportation problem and K-shortest path problem to resource allocation.

IV. Location-allocation

The transportation problem is the following:given a set of suppliers each with supply Si, a set of demand points each with demand Dj, and the unit cost cij of shipping from supply point i to demand point j, find the shipment pattern(shipments from the supply points to the demand points) such that all demands are satisfied and the total cost is minimized.

V. Optimal analysis module for mobilization

In order to transfer the equipment to disaster areas, the system integrates an optimal analysis module for mobilization. It provides a reference for the distribution of equipment and shortens the time for most the executives to schedule the equipment and paths of mobilization.

First of all, the problems needed to be solved are as following:

The equipment (named as M) is stocked in several warehouses (named as W). At the same time, several places (named as N) need these equipments. The number and types of stocks in every warehouse are apparently different. Furthermore, each place needs different types and number of the equipment. There is more than one path from each warehouse to each disaster area. Therefore, we hope we can transport different kinds of equipment to each disaster area with least cost.

The flood might block the traffic; thus, the route of transporting the equipment might alter, too. Moreover, the location and condition of the disaster, the number and types of the equipment are all the factors that affect the distribution of the equipment and mobilization. Therefore, this module was formed based on the information about warehouses, types and number of rescue equipment and network maps in the database of the flood prevention. And the area, location, number and types of rescue equipment are the factors. The following flowchart shows the module:

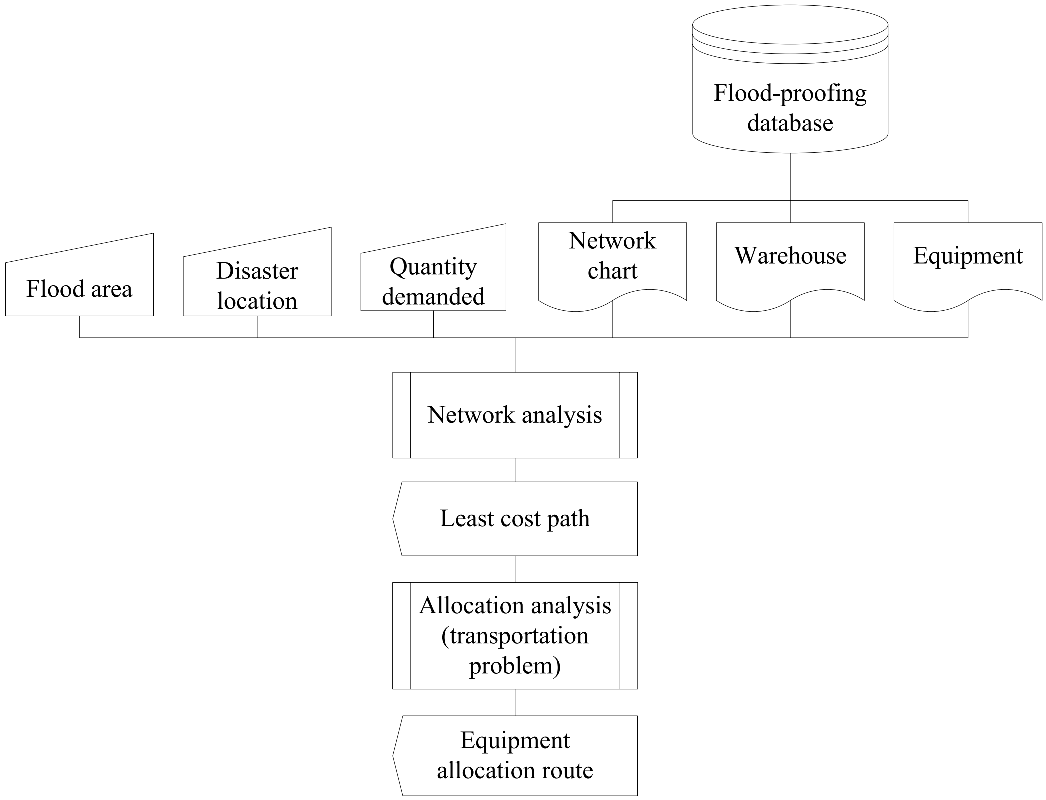

Fig. 1 Flowchart of optimal analysis model for disaster prevention equipment allocation

Hence, the way to get the solution is divided into two steps:

1) shortest path analysis - listing the shortest paths from warehouses to disaster areas and the cost.

2) treating the result of first step as transportation cost and then allocating resources.

Shortest Path Problem usually applies to vehicle navigation system and all kinds of disaster rescue systems. It not only means the shortest distance geographically, but also extends to other measurement units, including time, expense, route, capacity and so forth. Therefore, the core algorithm for computing the shortest distance, minimum time, or lowest expense, is the shortest path algorithm.

When the shortest path and cost is known, the following problem is how to allocate rescue equipment. Providing that the allocation of equipment is independent and the unit cost of transportation is the same, the allocation of *m* can be expressed as

$$\min\left\{\sum_{w}\sum_{n} X_{n,m}^{w} C_{n}^{w}\right\}$$

subject to

$$S_m^w \geq 0, \quad \forall w$$

$$D_m^n \geq 0, \quad \forall n$$

$$C_n^w \geq 0, \quad \forall w, n$$

$$\sum_{w} X_{n,m}^{w} = D_m^n, \quad \forall n$$

$$\sum_{n} D_m^n \leq \sum_{w} S_m^w$$

where

S_m^w = quantity of *m* stored in *w* warehouse

D_m^n = quantity of *m* in the *n*

C_n^w = least cost from *w* warehouse to *n* disaster area

$X_{n,m}^{w}$ = quantity of *m* equipment stored in the *w* warehouse transporting to *n*

This research applied least cost method to find the initial solution and then solve the optimal solution by Simplex method. The flowchart of transportation problem analysis model is shown below.

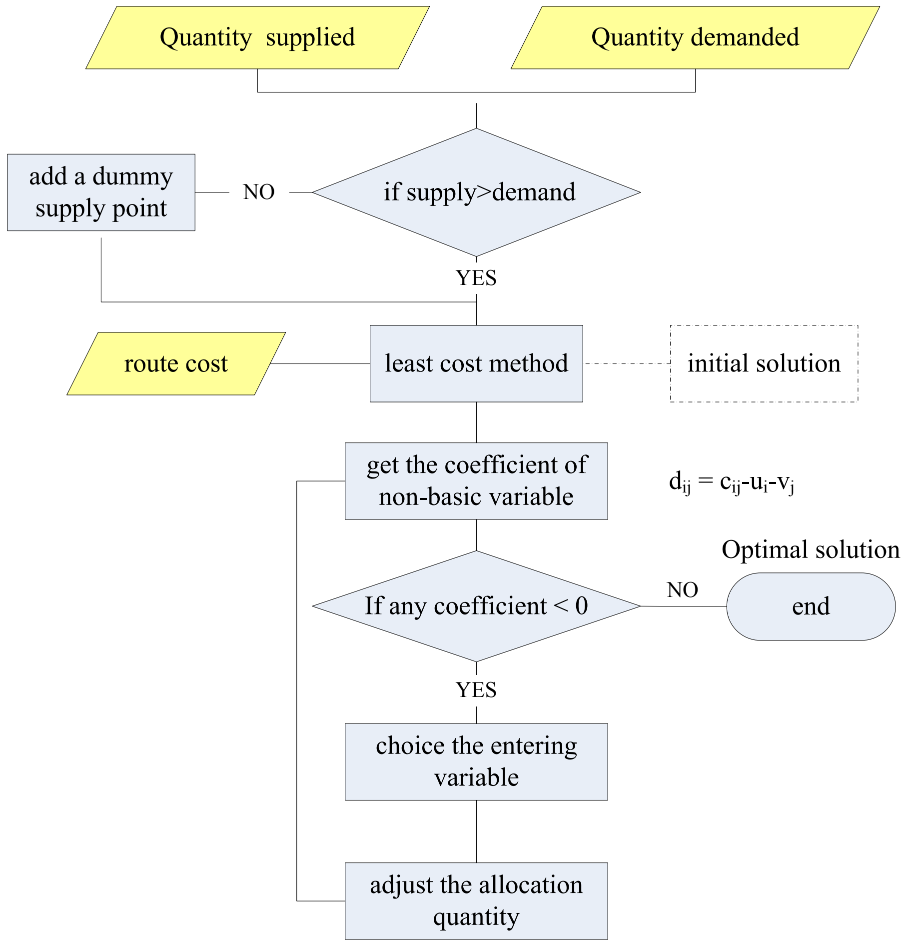

Fig. 2 Flowchart of transportation problem analysis model

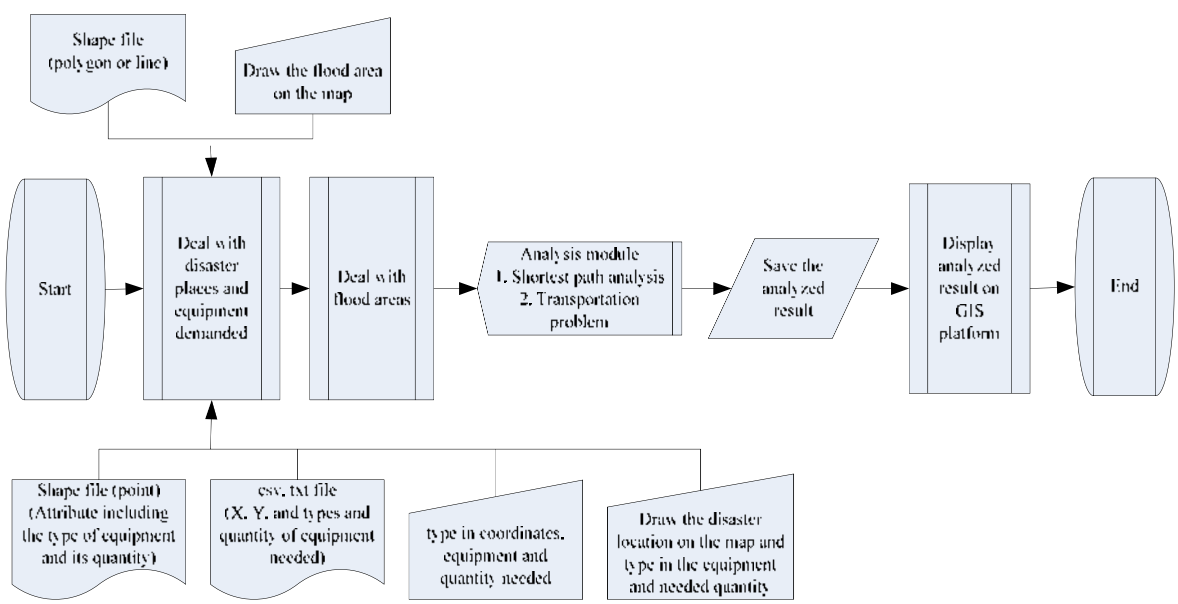

Fig. 3 Flowchart of decision making analysis for disaster-prevention equipment allocation route

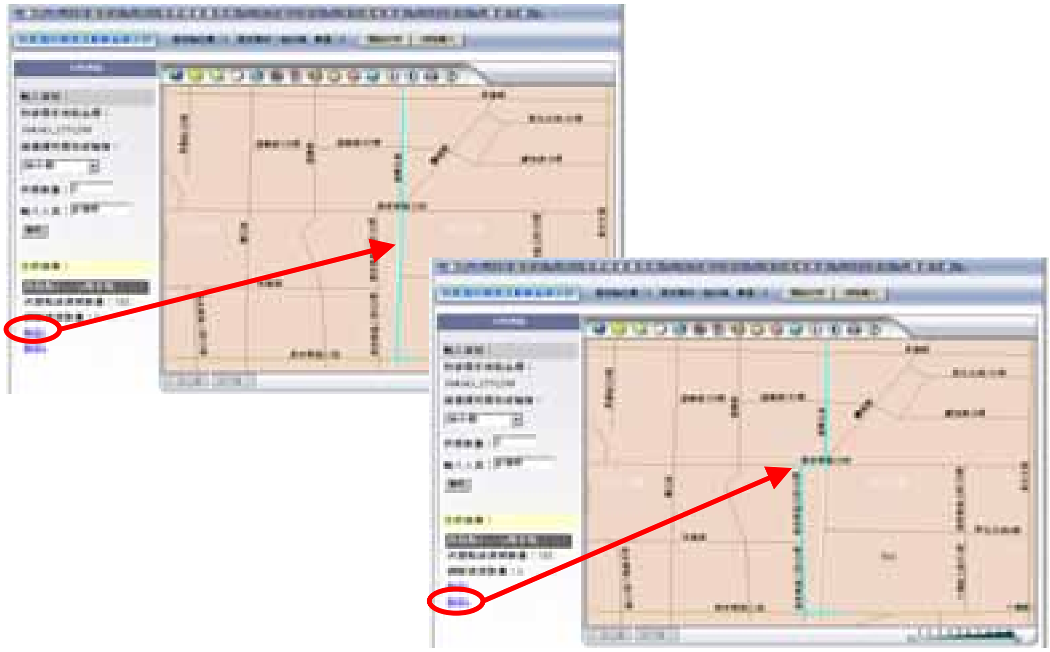

Fig. 4 Analysis result of disaster-prevention equipment allocation route

VI. Conclusion

This study practices resources allocation of transportation problem and solve the multipoint-to-multipoint problem of equipment deployment. This system is capable of swiftly providing an optimal solution for every point and computing the amount of resources allotted from each supply point to demand point according to the cost between supply and demand points. Also, the provision of second short path enables decision makers and rescuers to get more choices.

The study result can apply in the fields of tourism, transportation, and governments relating to disaster rescue, such as PDA system, navigation system, disaster response system, and so on.

VII. Reference

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