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Development of an Adaptive Evacuation Route Algorithm under Flood Disaster

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Synopsis

The Adaptive Evacuation Route Algorithm (AERA) is proposed in this paper considering the effect of the dynamic change in water depth on people's evacuation behavior under a flood disaster. Based on the idea of Dijkstra shortest path method, this algorithm pursues the goal of minimizing total evacuation time. This approach is realized on spatial-temporal GIS software-DiMSIS and tested in Nagata area located in Kobe city. The result of the experiment shows that AERA can be used to provide optimal evacuation route under dynamic situations.

Keywords: Evacuation route, Flood, Shortest time, DiMSIS

1. Introduction

Flood disaster is often characterized by dangers that strengthen and spread over time (Opasanon S., 2004). Such dynamic situational changes over time might make the shortest route not always the optimal and safest one. From field surveys of real cases such as the Niigata flood disaster in 2004 (Gunma University, 2004; Intensive Heavy Rainfall Disaster Policy Committee, 2004), many people know where the refuge is but they do not know how the situation will progress with certainty and which route is safe under the emergency situation. Static hazard maps may not always help them when an actual disaster happens. Instructions that do not consider the evolution of damage over time and threats of probable additional destruction and deterioration can result in suboptimal decisions that can lead to unnecessarily imposed risk and unnecessarily lost lives (Miller-Hooks and Krauthammer, 2002). In addition, people's evacuation behaviors such as evacuation time and walking speed also have effect on the optimal strategy. Therefore, in determining the evacuation route, it is important to explicitly consider the time-varying nature of node and people's reaction to evacuation in such circumstances. It is necessary to provide dynamic information and instructions to help people to make the right decision. As Akagiri Takekazu(2003) mentioned, the future version of hazard maps is to judge flood related various situations such as flow speed, risk index, and for this purpose both inside water and outside water conditions should be analyzed by a simulation model. With such a simulation model used, an advanced version of hazard map should provide dynamic information such as the time the flood will arrive etc.

There have already some related research, for example, Cova and Johnson (2003) applied a linear program to address the problem of finding optimal lane-based evacuation routing plans. The primary objective is to minimize the total distance and the secondary objectives is to minimize vehicle merging-conflicts and to prevent crossing-conflicts at intersections. In this research, the constraint method for multi-objective programming was employed. J.MacGregor Smith (1998) proposed a multi-objective model to solve the problem of congestion along the evacuation route. Qingsong Lu et al.(2003) proposed two heuristic algorithms named Single-Route capacity constrained planner and Multi-Route capacity constrained planner to incorporate the constraints of the routes. These researches focus on the traffic difficulties (e.g., congestion) that might arise during an urgent evacuation (Frank Southworth, 1991). But for flood disaster, the main hazard is water depth along the route when walking is selected as the preferential transportation way. Some approaches are proposed in the literature to solve related water depth problems. Tamotsu Takahishi et al. (1989) proposed their evacuation route algorithm that took the effect of information of river back breach and depth of water on the way into account. Based on Warshall-Floyd shortest route method, the research seeks the minimum distance as the first objective by transforming the constraints by flood into corresponding increased distance along the evacuation route. Tachi K. et al. (2001) implemented Arcview to support the selection of the evacuation route. Shinji IIDA et al. (2002) considered the contribution of both inside water and outside water when calculating inundation depth and adopted reduction ratio of walking speed to evaluate the effect of inundation on movement. In this research, Arcview was also used to carry out network analysis. Unfortunately, it appears that no exact algorithm has been proposed for efficiently determining optimal evacuation paths, where the uncertain, dynamic and time-varying conditions inherent in emergency circumstances are explicitly considered (Sathaporn Opasanon, 2004).

This paper presents an evacuation route algorithm adaptive to specific dynamic situations under the flood disaster. Walking speed difference among people, and the effect of water depth on walking speed and evacuation start time are considered in this research.

The method is expected to use for strangers who are not familiar with the local environment. In this case, it can provide them with a safe way to shelter. In addition, the method can help to make disaster evacuation planning for the local area by providing a safe route to shelter under a given inundation situation.

This paper consists of five parts: in the first part, we review the previous research of route selection under dynamic situations; a subsequent section presents the detailed model formulation; in the third part, we applied the algorithm in Nagata, Kobe city; finally, the paper concludes with a discussion of the results and areas for further research.

2. Adaptive evacuation route algorithm

AERA algorithm can be decomposed into five main steps.

1) Initialization

Let a dynamic network $G = (V, A, \{(0,1,2...T)t_0\})$ be a finite graph, where V is the set of nodes that include three parts:

S : set of source nodes, $S \subset V$

D : set of destination nodes, $D \subset V$

I : set of intermediate nodes, $I \subset V$

A : set of arcs and $\{(0,1,2...T)t_0\}$ is discrete time and t_0 is the time interval of calculation of water depth in the network. Besides coordinate, each node has a pair of labels called T_j and P_j. T_j is the minimum time from origin point s to point j. P_j is the previous point of the shortest time way from s to j.

2) To calculate the initial distance L_0 and time T_{init}

In this research, we classify the network as the sub-network and main network. The main network means the evacuation route designated by the government and the sub-network means other roads in the local network. So there are three cases of spatial relationships between the position of evacuees and main network nodes as shown in Fig.1.

- If the point is in a sub-network, then the start point is the nearest and accessible node in the main network.
- If the point is on a route, then the start node is the nearest node on this route
- If the point is the same as a node, then the start node is itself, then $L_0 = 0$

Considering in most cases the position of evacuees is not far from the node on the main network, we select the nearest node as the start point on the optimal evacuation route. Taking Fig.1 as an example,

$L_0 = \min(L_{p-1}, L_{p-2}, L_{p-3}, L_{p-4})$ $T_{init} = L_0 / SP_0$, where

SP_0 is the normal walking speed of people. Then, mark the origin node as k.

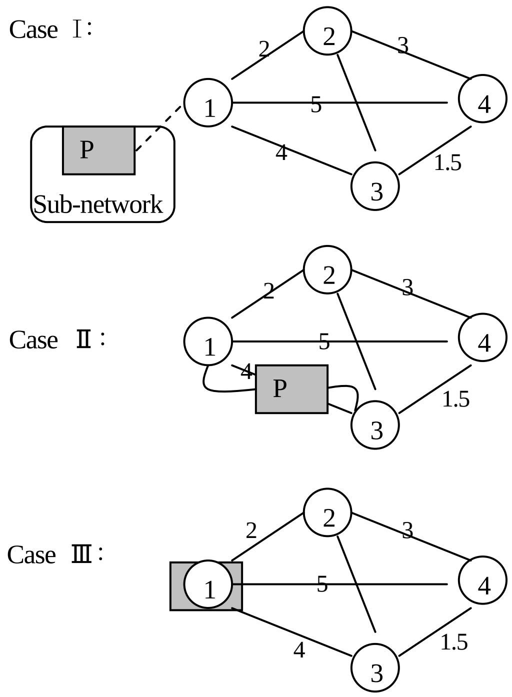

Fig. 1 Relationships of start point and node

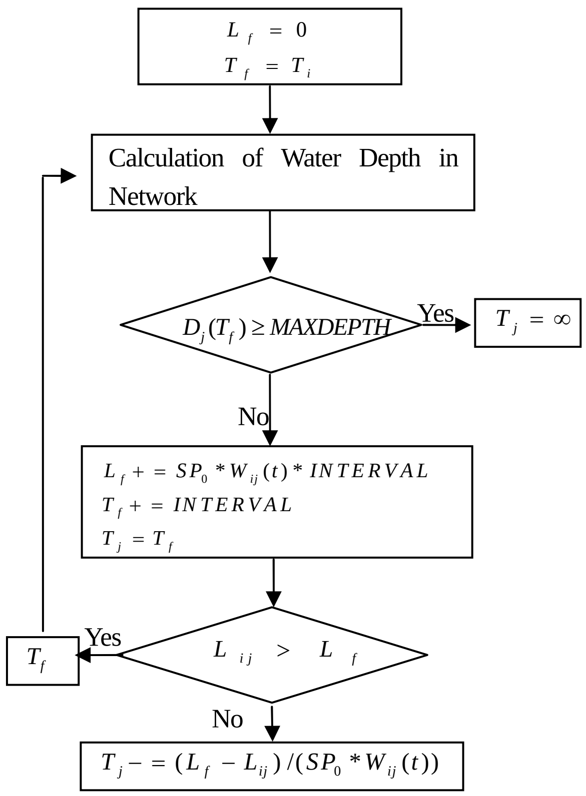

Fig. 2 Calculation of consumed time to another node

3) To calculate the consumed time

- Calculating the time from node k to those nodes j which directly connect with k and not marked yet. Considering almost all roads in the real case are with double directions in feature, we treat the undirected graph as a graph with double directions in this algorithm.
- The consumed time is $T_j = \min\{T_j, T_u + T_{uj}\}$, T_{uj} is the time consumed from u to j. If T_j is replaced, then put a label (T_j, u) on V. Fig.2 depicts the calculation process from node i to node j.

In Fig.2, T_i : start time of calculation that also means the consumed time for node i.

$D_j(T_f)$: water depth of node j at time T_f.

$MAXDEPTH$: the maximum water depth people can walk through.

T_j : consumed time to node j.

L_f : the distance people walked in multiple interval period of time.

$W_{ij}(t) = 1 - h_{ij}(t) / MAXDEPTH$ (T.Takahishi,1989)

$h_{ij}(t) = (D_i(t) + D_j(t)) / 2.0$

$W_{ij}(t)$: walking speed discount ratio from node i to j at time t

$h_{ij}(t)$: water depth of edge ij at time t

$D_i(t)$: water depth of node i at time t

$D_j(t)$: water depth of node j at time t

SP_0 : Initial Walking Speed

Some previous approaches implemented the data of water depth only at integral intervals but it will result in relatively large error of calculation when an edge is very long in distance and it takes a lot of time. In order to avoid this problem, in this research we assume that water depth will spread evenly in an interval. Linear interpolation method is used to calculate water depth at any time in an interval for nodes. The formula is given as follows

$$D_{temp} = D_i(t_n) + [D_i(t_n+1) - D_i(t_n)]* \\ [T_{cur}/(INTERVAL*60.0) - t_n]$$

$D_i(t_n)$: water depth of node i at interval t_n.

T_{cur} : the current simulation time.

When all nodes that directly connect with the current "seed point" are marked, it is time to select the new "seed point" among them.

4) To continue with the new node

- To compare the consumed time among all nodes that are not marked yet and select the one with minimum value as new node.
- Mark this new node and reset the start time equal to its responding minimum time.
- If the water depths of all nodes that are not marked yet exceed the threshold then it means the designated point is not accessible. If the new "seed point" is the same as the destination node, then the algorithm ends and we obtain the optimal route with the minimum consumed time, otherwise go to step 3.

5) To calculate the total consumed time

- $T_{total}(s,d) = T_{init}(s) + T_{used}(s,d)$

3. Performance evaluation

3.1 Case area introduced

This algorithm is realized on spatial-temporal GIS software, DiMSIS. We select Nagata in Kobe city with area size about 0.25km^2 as the case area shown in red circle in Fig.3. This area includes the "chos" within the scope that Shinyo elementary school, the designated shelter, can cover as shown in Table 1.

Table 1 "Cho" List of case area

1	Udezukacho 1-4 chome
2	Kubocho 1-4 chome
3	Futabacho 1-4 chome
4	Shiodacho 1-4 chome

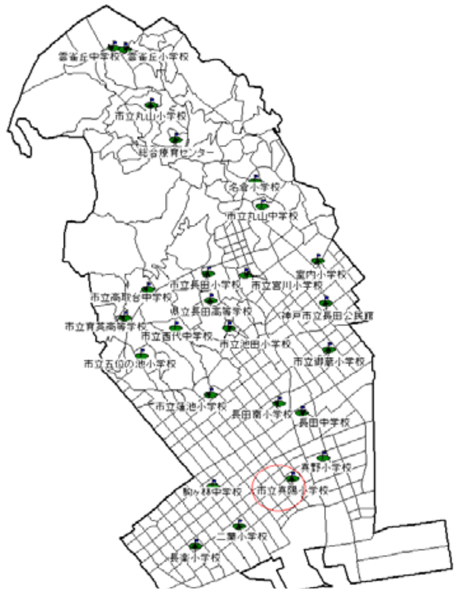

Fig. 3 Case area map

3.2 Application

As shown in Fig.4, the basic data preparation consists of two parts: one part is geographic data; the other part is flood data. The geographic data source is composed of layered basic geographic information such as buildings and road network that serves as the potential evacuation route. In this algorithm, the original flood data may vary regarding inside water and outside water. The following work is to calculate the water depth of each node over the whole network. Table 2 shows the structure of the experiment result. In this table, "DepthN" represents the corresponding water depth of each node at N multiple interval time period. In this case study, typical scenarios of hazard maps for the Nagata area are selected and the time interval is set to be 5 minutes. The main communication interface of this approach by use of a spatial-temporal GIS, DiMSiS is also being developed as illustrated by Fig.7. The red circles on the map in

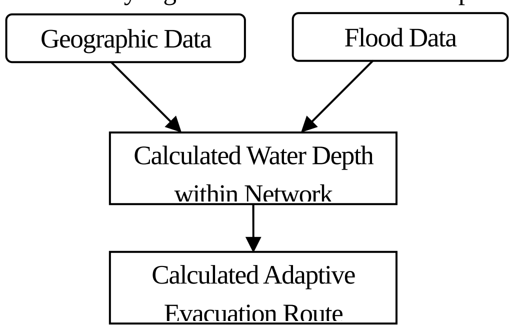

Fig. 4 Work flow of this experiment

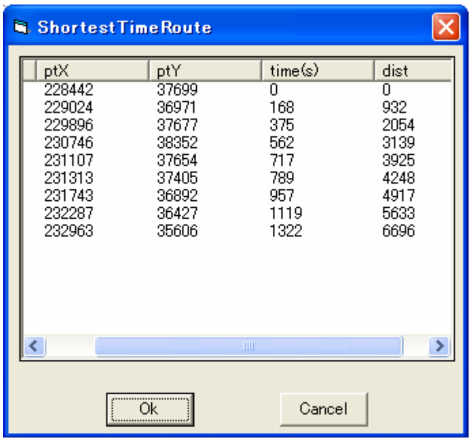

Fig. 5 Simulation Result for old person in case one

Fig. 6 Message given in case two

Fig.7 represents the start point and destination point respectively and the frame in the left-bottom side lists the route information from the start point to the destination point.

In the application, we compared the simulation result in two cases. One is that the evacuees are young person and old person with walking speed respectively as 1.1m/s and 0.8m/s. They started evacuation at time 0 from the same start position to the same destination. We found that it took 932s for young person and 1322s as shown in Fig.5 for old person. The second case is that with the same walking speed, they started evacuation with 15 minutes later than that in the first case. Then we found that the young person can safely arrive to shelter but the old person was encountered in flooding water. The message is given in Fig.6. From the experiments, we can find that a small magnitude of the difference in evacuation behaviors among human group especially those vulnerable people might lead to totally opposite result to expected one. So this algorithm also provides one way to motivate people to adapt their evacuation behavior to dynamic situation based on simulation results.

4. Conclusion and future work

In this paper, the evacuation start time was defined to mean the time elapsed from the start of simulation. An adaptive evacuation route algorithm has been proposed to solve the problem of optimal evacuation route in the dynamic network. Through the experiment in the Nagara area, Kobe, Japan this approach has been used to provide the optimal evacuation route with minimum consumed time under dynamic situations. Although the algorithm has been used for flood disaster, it is expected to apply also to other disasters like tsunami and landslide with similar dynamic situations.

In this method, the dynamic process of water depth is assumed to be well known. In reality, however, it is difficult to forecast how the flooding water will spread so it is necessary to select more scenarios from flood disasters when implementing the algorithm in different local areas. For instance, we may need to include a scenario such that an intensive heavy rainfall happens, and the evacuation start time will have great influence on the optimal evacuation route.

Moreover to account for essential features of the adaptive evacuation route, besides water depth, the hazardous places along the route are also important factors which have effect on people's evacuation behavior. We will extend our research to discuss such a problem in near future.

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Table 2 Structure of Water Depth Data

ID	ptX	ptY	Depth0	Depth1	Depth2	Depth3	Depth4	DepthN
1	232963	35606	0.22	0.23	0.24	0.27	0.31	0.42
2	233781	36255	0.34	0.35	0.37	0.4	0.42	0.48
3	228269	36377	0.24	0.25	0.28	0.32	0.36	0.46
4	229024	36971	0.23	0.24	0.26	0.29	0.34	0.37
5	231434	33948	0.21	0.24	0.26	0.40	0.46	0.75
6	231220	34221	0.37	0.39	0.39	0.41	0.45	0.60
7	230592	36838	0.22	0.34	0.34	0.34	0.34	0.57
8	229716	36090	0.21	0.35	0.55	0.65	0.70	0.72
N	230559	35035	0.21	0.57	0.35	0.35	0.4	0.57

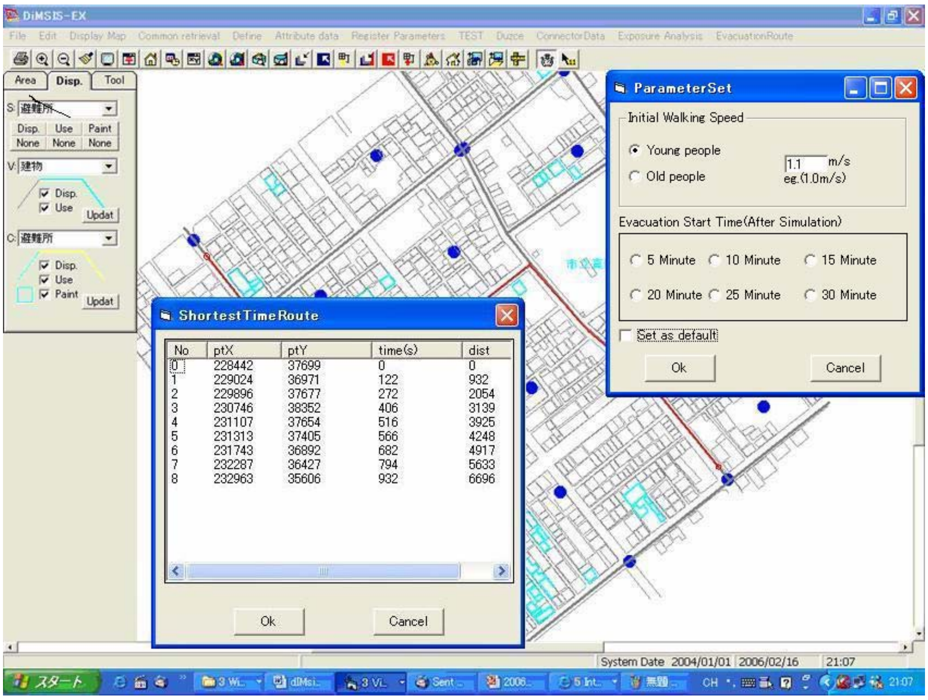

Fig. 7 Main interface of ASRA on DiMSIS

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水害における適応型の避難経路アルゴリズムの開発

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要旨

この研究では、水害で人々の避難の振舞いへのダイナミックな水深の効果を考えて、適応型の避難経路アルゴリズム (AERA)を提案する。ダイクストラ最短経路方法の考えに基づいて、このアルゴリズムは総避難時間を最小にするという目標とする。時空間地理情報システム-DiMSISに基づいて、対象地域を神戸市長田区とし，アプローチの適用を試みる。実験の結果は、ダイナミックな状況の下の最適の避難経路を提供するのにAERAを使用することができるのを示する。

キーワード: 避難経路、洪水、最も短い時間、DiMSIS