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METHODOLOGY FOR ASSESSMENT OF EVACUATION SYSTEM USING GIS

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This paper discusses assessment using GIS, one of the non-structural disaster mitigation measures, namely evacuation, explained by means of an application to Kami-furano town's evacuation system. GIS database consisting of topography, roads, houses and evacuation center was created. Assignment and routing were carried out considering the household distribution, proximity to evacuation centers and road network capacities. Three new parameters were defined namely, Static Evacuation Time (SET), Dynamic Evacuation Time (DET) and Congestion Delay (CD). SET is the evacuation time if only farthest resident evacuates. DET is the evacuation time if all evacuate simultaneously. Congestion Delay is the difference between DET and SET, and provides a measure of dynamic effects such as capacity limitations, crowding, etc.,. Estimates of these parameters were obtained through traffic simulation. DET and Congestion Delay can describe the status of an evacuation system and its infra-structure more clearly.

Keywords: Large-Scale GIS Database, Traffic Simulation, Static Evacuation Time, Dynamic Evacuation Time, Congestion Delay

1. INTRODUCTION

Predictable disasters such as floods, volcanic eruptions account for majority of disasters in the Asian region causing heavy life and property damages. Occasionally the scale of the loss of life because of these disasters, results in the generation of memorable public concern. Another problem that arises concern is occupation of flood plains because of increasing demand for land, leading to increased flood disaster exposure. Quality of life in the Asian region is improving gradually and improved disaster mitigation measures will become a necessity in the near future.

A range of structural and non-structural mitigation measures aimed at civil protection are used currently. Structural mitigation measures include measures such as sabo-dams, dikes and other constructions. However, successes of these measures are only marginal, chiefly due to exorbitant cost of construction and poor spatial / temporal reliability of prediction. Also the protracted lead times involved in construction of these facilities demand alternate non-structural mitigation measures. Emergency evacuation in conjunction with advanced forecasting, monitoring and warning are essentially becoming important to offset the marginal success of structural measures. Evacuation has been used as a mitigation measure for a long time.

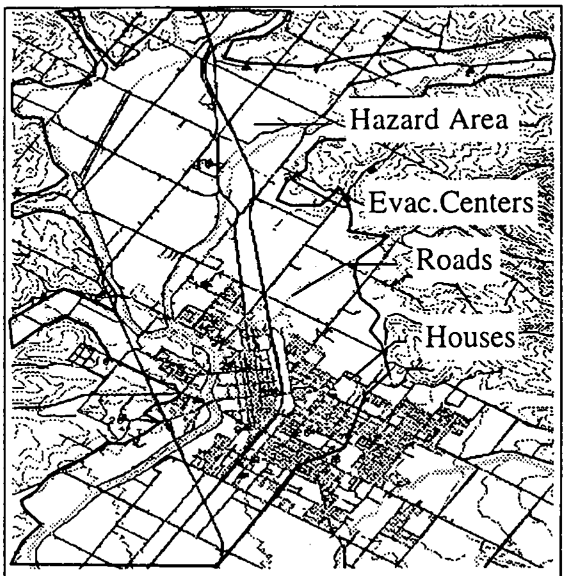

Figure-1: Base map of Kami-furano Town

Kami-furano town of Hokkaido, located on the base of Mt.Tokachi volcano, experienced a mud-flow disaster in 1926 resulting in loss of 144 lives. Another mud-flow disaster is anticipated in the imminent future and mitigation measures to contain the damage is in progress. The town office has demarcated hazardous area and has assigned 35 locations as evacuation centers. Upon occurrence of Mud-flow in the mountains, evacuation order will be issued and residents will evacuate to an evacuation center. There are nearly 5,500 residents within the hazardous areas. The town has setup wireless broadcast system in each household to transmit evacuation order. The town conducts evacuation training exercises that are carried out once every year. The base map of Kami-furano is as shown in figure-1.

Even though evacuation has existed as a non-structural mitigation measure for some time now, no effective methods exist to evaluate how an emergency evacuation will be during a disaster. Research was conducted to develop a method suitable for an evacuation system, such as that of Kami-furano, which can help in assessment and improvement. Findings of this research are presented in this paper.

2. LITERATURE REVIEW

Emergency evacuation is the preventive process of moving civilian population from the hazardous area to safe locations,

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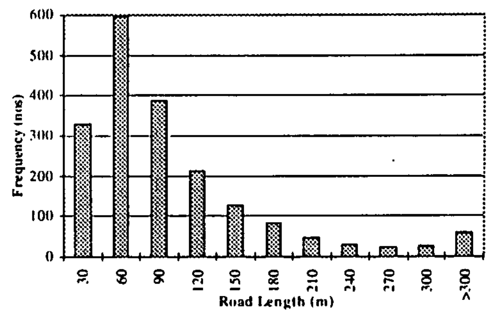
before the harmful effects of disaster can create damage. Evacuation time estimates, sometimes also referred as clearance time or EET, is generally used as a measure of effectiveness 2),3),4) to evaluate the evacuation system. Evacuation time is the duration between issue of evacuation order and last person reaching safety and can be thought of as sum of the preparation time and the travel time, preparation time being the time between issue of command and departure from house and travel time being the time between departure from house and reaching safety. The inter-relationships between evacuation center locations, residential distribution, public infra-structure, social condition and evacuation plan and their influence on evacuation time is termed an evacuation system.

To study an evacuation system, most researchers have developed a computer simulation model and have attempted to estimate evacuation times, notable among them being I-DYNEV, IEMIS/I-DYNEV, EVAS, MASSVAC. These models address disasters that affects wide area such as nuclear discharge, chemical release, dam failure flooding and have used car as the transportation mode 2),3) in their evaluation. IEMIS/I-DNEV has attempted a probabilistic approach for preparation time, based on a cyclone disaster case history, while MASSVAC has used an arbitrary logistic function. Equilibrium traffic assignment model is used in I-DYNEV while Probabilistic multi-path assignment model was used in MASSVAC. EVAS has used shortest path routing based on static evacuation times. In all these models, input data has been aggregated to course resolution, perhaps to overcome computational and data management problems.

Most Japanese researchers have attempted to document the scenario of evacuation rather than evaluate it. Among the few who evaluated, Takahashi et.al have simulated evacuation by walk for Ogura basin embankment failure and Kami-furano town mud-flow disaster. They have considered only 141 road links in their Kami-furano town evacuation simulation model. There are roughly 9000 road links in Kami-furano town and a higher data resolution is required for practical evacuation system evaluation.

2. MODELLING

From a consultant's viewpoint, assessment of town's evacuation system will require high resolution input data of the evacuation system. Detailed consideration of entire town will require huge volume of input data and will increase the computational load tremendously. GIS system was used to create a 1:2500 resolution topographic digital map of roads, houses, evacuation centers and hazardous zone. Houses and evacuation center were represented as nodes while roads were represented as network. Each house and evacuation center were linked to network by means of a short road-link. Information on road class, summer/winter status, intersection priorities, population statistics, evacuation center capacities, etc., were assembled from various sources such as town office records, road maps, residential maps and aerial photographs and these data were input as attributes of the geographic feature.



Graph - 1: Frequency distribution of road length

A walking speed of 1.2m/s was used to simulate evacuation by walk, based on the results of a walking experiment undertaken during last evacuation training at Kami-furano. It was assumed that all residents will walk at the constant speed of 1.2m/s irrespective of age or family composition. Takahashi et.al have used 1.4 m/s in their simulation of Kami-furano town's evacuation model.

Road length > critical length

$$V_{avg} = V_{max} - \frac{V_{max}^3}{6L}\left(\frac{1}{a_1} + \frac{1}{a_2}\right)$$

Road length < critical length

$$V_{avg} = \frac{2}{3}\sqrt{\frac{2L}{\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}}$$

Fig-2: Average speed as function of road length and road class (V_{max}, a_1, a_2 are functions of road class)

Short road segments are common in Kami-furano as can be seen from the road-length frequency distribution (graph-1). Literature to estimate speeds for such short lengths could not be sighted and hence experimental investigation was undertaken. Three distinct phases were noticed when road lengths were greater than critical road-length, namely acceleration, steady-state and deceleration phases, and 2 distinct phases, acceleration and deceleration, were observed if shorter than the critical length. Taking this fact into account average speed was expressed as a function of road-length and road class (fig-2), and was used to assign the speeds to each road. SET and DET calculations were based on this average speed. Also no appreciable change was noticed between day and night driving in roads with street-lights, while changes were observed in roads without street light. Average speed variation with drivers was not very significant.

Evacuation process is unsteady and incomplete since information such as where each resident will be during the time of evacuation order, the transportation mode, route and evacuation center he will choose are unknown a priori. For the purpose of computer modeling these information's are necessary and hence the following scenario was assumed. "All residents in hazardous area will evacuate immediately on receipt of evacuation order. They will evacuate to the nearest evacuation center and will use the shortest path route using the transportation advised by the town – walk or car. When walking, all family members will walk together and in the case of car, each family will travel in one car." Even though car based evacuation is rare in Japan, considering the sparse distribution of residents and broad roads of Kami-furano town, car based evacuation was also considered.

Computational load was reduced by dividing the model into traffic assignment, routing and traffic simulation modules and by using the GIS. Capacitated LP Assignment and Shortest path Routing models were used for traffic assignment and routing as in the case of EVAS system. Human judgment was used to further improve the assignment and routing if necessary. Traffic simulation was performed to account for the dynamic effects.

3. ASSESSMENT METHODOLOGY

Just evacuation time alone does not provide sufficient information on evacuation infra-structure. For example, a large evacuation time may mean that the residents are far away from evacuation centers or alternatively may mean high congestion because of poor infra-structure. Better parameters need to be defined that can express the condition of evacuation system more clearly.

In our study, we calculated two types of evacuation times instead of just one, namely Static Evacuation time (SET) and Dynamic Evacuation Time (DET). Static Evacuation time is the evacuation time if only one person evacuates, thus ignoring the influences of other evacuees. Dynamic Evacuation time is the evacuation time if all evacuees evacuate simultaneously. SET and DET are schematically explained in figure-3. SET and DET were estimated by traffic simulation. In calculating DET, fatigue and crowding were considered for walking, as explained in the paper by Takahashi et.al,. Road capacity limitation was considered for car, as described in Highway Capacity manual 5). "Congestion Delay (CD)" which is the difference between DET and SET, represents the time contributed because of the dynamic effects.

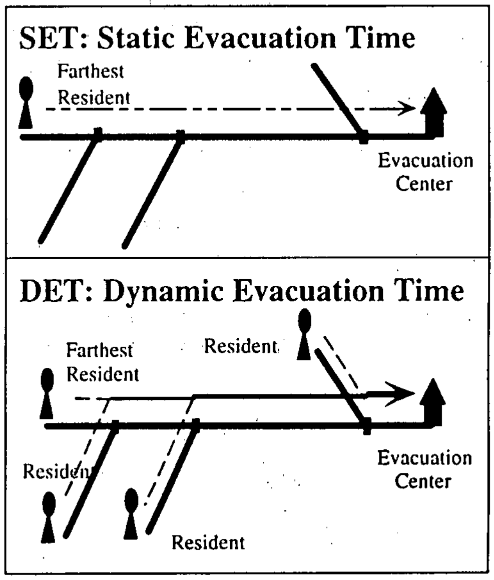


Fig-3: SET/DET Schematic Diagram

The condition of an evacuation system can be classified into 4 types based on the estimates of DET, CD and allowable evacuation time, and is schematically expressed in table-1. Type-2 indicates wide separation of evacuation centers and evacuees and can be remedied by construction of more evacuation centers or experimenting with alternate transportation methods. Type-3 indicates capacity limitation and can be improved by re-routing, re-planing or infra-structure capacity expansion.

Table-1: Types of evacuation system

DET	C.D / DET	Condition of Evacuation System
Low	Low	1: Superior Evacuation System
High	Low	2: Resident ~ Evacuation Center distance large
Low	High	3: Infra-structure Capacity in-sufficient
High	High	4: Inferior Evacuation System

3. CASE STUDY RESULTS

Results of the Computer Model were compared with evacuation training conducted on Feb'96. Questionnaire was distributed and details on the starting time, ending time, mode of travel, route taken were collected. Assignment and routing agree to a large extent with that generated by the computer. Figure-4 shows the residents who assembled in Evacuation center no-18 (only those who participated are shown) and the corresponding assignment and routing generated by the computer model (shows all assigned), by means of gray thin lines. The assignment of computer and actual agrees, except for 2 residents. The dark think lines indicate the route taken by the residents. This too matches to the one generated by computer. Direct comparison of evacuation times was not possible because of unknown preparation time. However, the speed of walking was estimated based on the experiment on the evacuees during the evacuation training. The evacuation time calculated based on speed and route length agrees with that calculated by the computer.

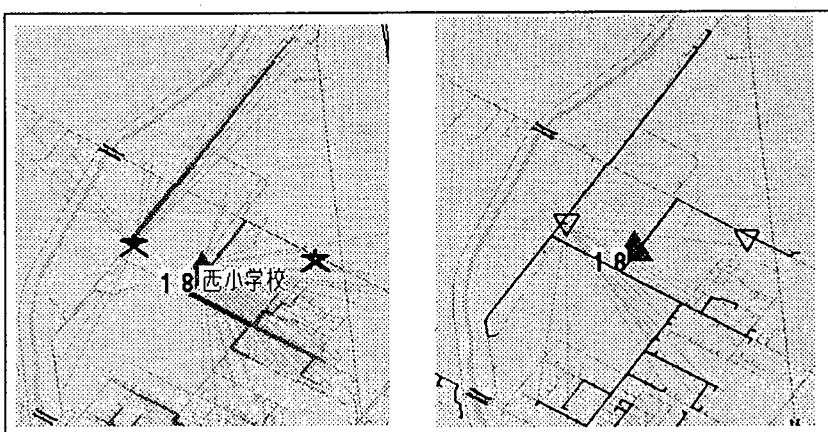


Fig-4: Comparison of computer generated assignment (left) and evacuation training (right)

Using the computer model, evacuation simulation was performed for all evacuation centers and for various scenarios. Car parking capacity estimated by site investigation and was considered for the car based evacuation. Two cases are presented here for discussion, namely -- Case-A: Evacuate to the nearest evacuation center and Case-B: Evacuate to the nearest evacuation center outside hazard area. Simulation was carried out for walk and car. Table-2 summarizes the results of the

Table-2: DET and Congestion Delay in minutes.

Case Number	DET	CD
Case-A-Walk	0:27	0:00
Case-B-Walk	0:22	0:16
Case-A-Car	0:33	0:00
Case-B-Car	0:20	0:15

simulation. In the case of walk, evacuation times are large, while the congestion delay is small indicating the condition where the evacuees and evacuation centers are widely spaced. In the case of Car, the evacuation times are around 20 minutes and the congestion delay is high, indicating insufficient infra-structure for car based evacuation.

3.1 Improvement of Evacuation System

DET and congestion delay provide information on condition of evacuation system. Evacuation system can be improved further if congestion areas can be identified. A GIS system based visual simulation program was developed that could provide information on where and how congestion takes place by visually simulating the evacuation process. Screen images of this visualizing process is as shown in figure-5. Even though evacuee's movement is temporally variable, an idea can be obtained based on the visualization and overall evacuation plan can be improved by altering assignments, routing and/or infra-structure capacity expansion.

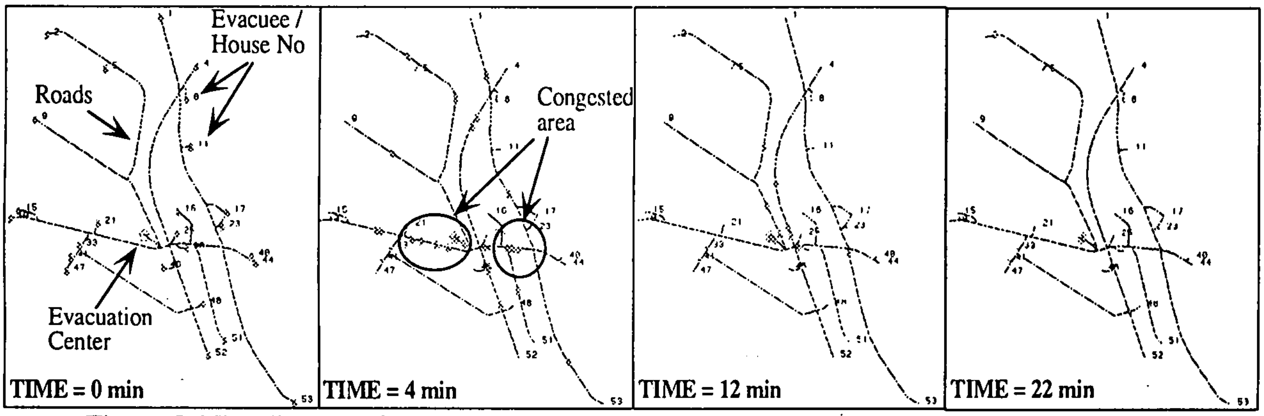


Figure-5: Visualisation of evacuees through road network near Ohara Jisaki evacuation center

4. CONCLUSION

Conventionally only the DET (called either as evacuation time or EET or clearance time) was used for evaluation of evacuation system. Calculating DET and CD provides better information on the condition of the evacuation system and can be used positively in improving the evacuation system. Advanced traffic assignment and routing model can be used if necessary to further improve the reliability of assignment and routing. CD and visual simulation provide valuable information about the infra-structure of the evacuation system that can be useful in congested places such as inner-Tokyo. Application of GIS database greatly enhanced data management making it practical to apply to a real evacuation system.

Even though this procedure was applied to mud-flow disaster problem, we can apply it to assess evacuation systems of other predictable disasters also. Wide area assessment as well as impact of dynamic effects on important infra-structure can also be carried with our model.

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