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Shortest Path Problems for Ambulances in Case of Severe Earthquakes

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1 Introduction

We have many earthquakes in Japan, and there are not a few records of severe earthquakes in the history where many people were injured or died and many houses were destroyed. According to the Coordination Committee for Earthquake Prediction in Japan, severe earthquakes will occur in "near" future with "high" probabilities in the Tokai region where our university is located. This prediction is based on analysis of historical data and geophysical observation data. Local governments have devised many measures to prevent severe damages from these earthquakes. For example, they are making public buildings such as schools quake-resistant, and storing foods and water at designated evacuation places. They are not perfect, however, and if severe earthquakes should occur, many people will be injured and also many roads, buildings and houses will be damaged. In such circumstances, it is important to carry the injured people to hospitals quickly in order to make the number of casualties as small as possible.

When many roads segments are blocked due to the collapse of buildings and houses or fires, as are often the cases with big earthquakes, they will be hindrances to carrying injured people to hospitals quickly. Therefore, we must find the shortest paths to carry injured people to hospitals avoiding blocked road segments which may change from time to time. The first objective of this study is to develop a graphic display system to show the shortest routes to hospitals, according to the changing environments.

In case of disasters, elderly people and infants are likely to be victims who have to be rescued and carried to hospitals. Therefore it is important to secure the roads in the areas where many elderly people and infants live. In other words, it is desirable for the local governments to widen the roads and make houses fireproof and quake-resistant in these areas. Thus the second objective of this study is to prioritize roads which should be secured in consideration of the age distribution of the inhabitants in each area.

2 Construction of the Road Network

We have selected a part of Minami-Ku (South Ward), Nagoya City for our study. This district is designated as one of dangerous regions in Nagoya City by the Disaster Prevention Committee of Aichi Prefecture based on the following four criteria:

1) Predicted magnitude of tremble of buildings

2) Predicted ratio of collapsed buildings

3) Danger of Liquefaction

4) Predicted number of deaths

In this district, there are many densely build-up areas, old houses and buildings, and narrow alleys which may be blocked by collapsed houses and buildings. Also many elderly people live in this district.

2.1 Selection of roads and related facilities

(1) We have selected the roads more than 3 meters in width in this district using Digital Map 2500 Aichi-5 published by Geographical Survey Institute in Japan (GSI). Although many narrow streets are one-way in normal times, we ignore this restriction because we consider the traffic of ambulances in an emergency.

(2) When big earthquakes occur, roads segments are blocked by various causes such as collapse of buildings, houses and bridges, cracks in the ground, and fires. In case of Hanshin-Awaji big earthquake, more than 80% of the deaths are due to collapse of houses and fallen furniture. In this study, we restrict our attention to the blocking of road segments by collapse of buildings and houses. We assume that the three shopping arcades in this district and all the houses in densely built-up areas collapse, and also that the road segments less than 10 meters wide will be blocked if the houses on the both sides of the road segments collapse.

(3) The hospital where all the injured people will be carried to is “Shakai Hoken Chukyo Hospital”, which is designated for use in an emergency in this district. There are two fire stations with an ambulance car, Minami main fire station and Daido branch fire station.

2.2 The structure of the road network

The network is composed of all the road segments selected above as edges and the intersections as nodes. The weight of each edge is the length of the corresponding road segments. The sources of the network are the two intersections nearest to the two fire stations described above, and the sinks are the four intersections adjacent to the hospital. That is, the sinks are nodes nos. 2, 3, 4, and 5 in Fig.1. We add a dummy node no.399 which is connected to the two sources, and another dummy node no.400 connected to the four sinks.

The road network after the segments described above (2.1 (2)) are blocked are shown in Fig.2.

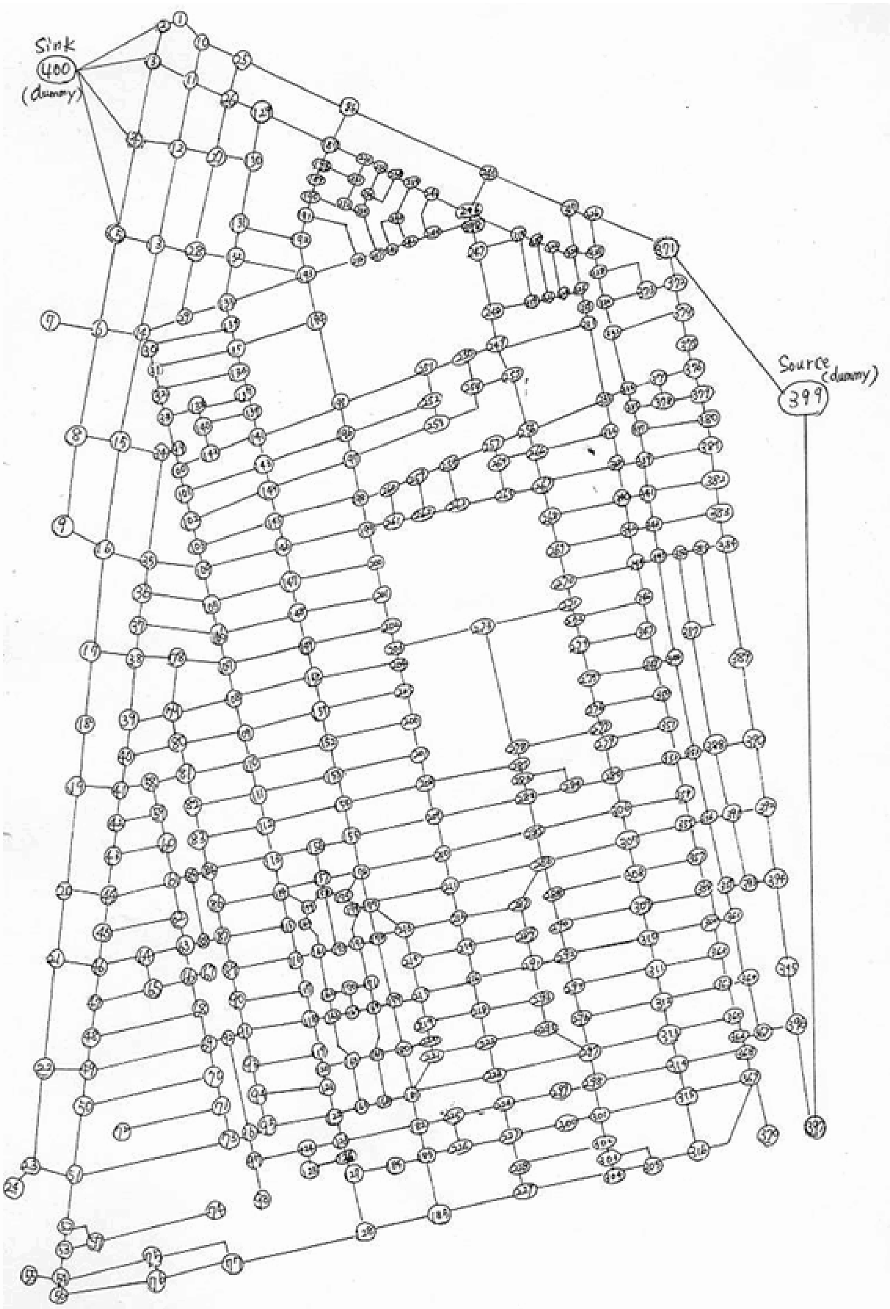

Figure 1: The road network in normal times

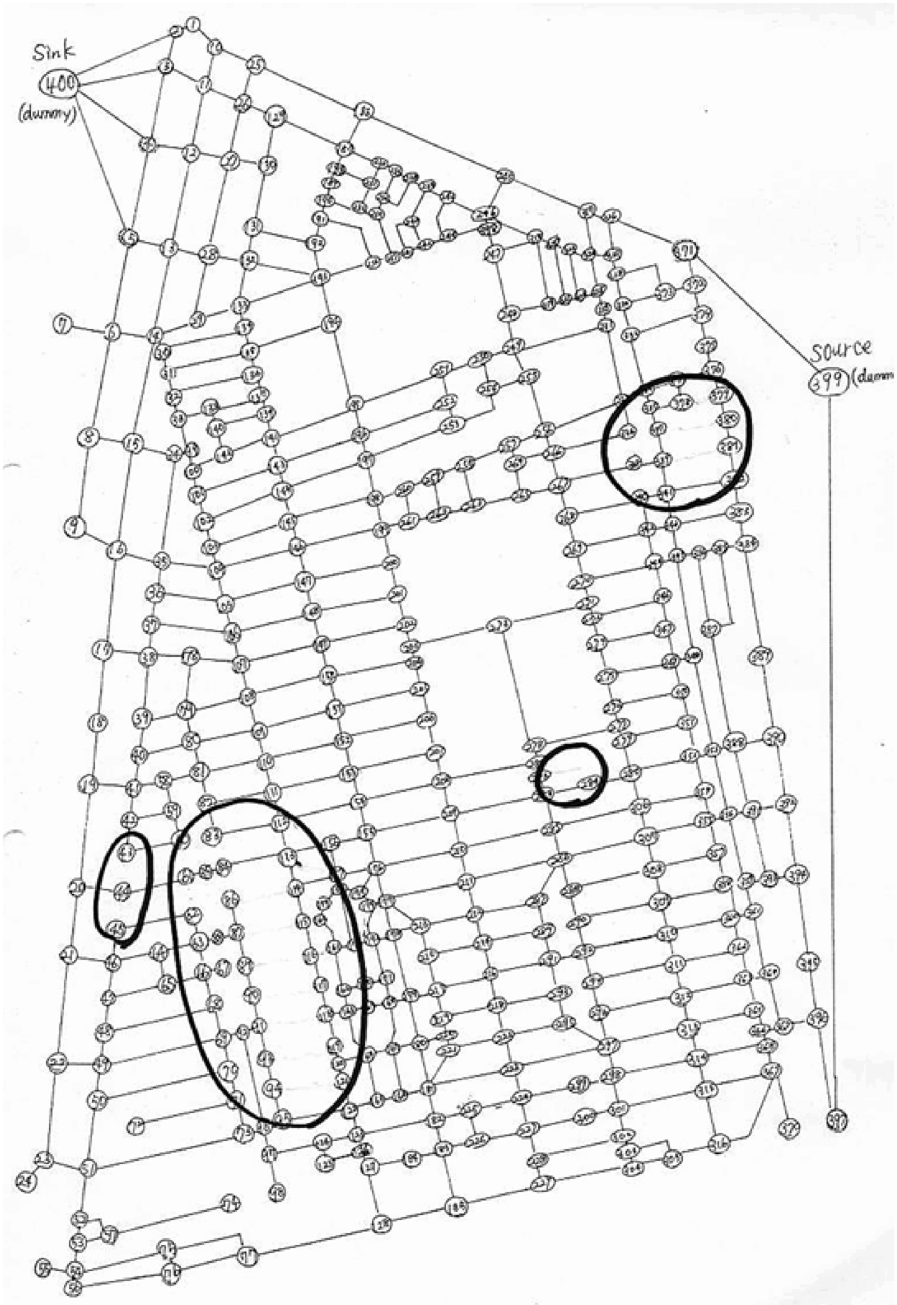

Figure 2: The road network after the segments are blocked

3 Outline of the Graphic Display System

We have developed a graphic display system using a GIS (Geographic Information System: Arc GIS 8.3 by ESRI Japan) and VB (Visual Basic by Microsoft). The purpose of the system is to show the shortest routes from the fire stations to the intersections (nodes) nearest to the injured people, and then the routes to the hospital. The system is constructed along the following lines.

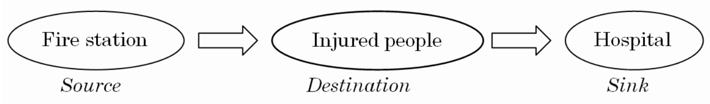

Figure 3: Route of ambulance car

1) The map of the selected district is introduced into a file of GIS. The fire stations and the hospital are clearly marked.

2) The road network is constructed. The weight of an arc is the length of the corresponding road segment. The weights of all the arcs are inputted into Excel as the adjacent matrix.

3) We use Dijkstra's algorithm to find shortest routes and code it with VBA (Visual Basic for Applications) of Excel. When we input the node number of the destination into the program, the shortest path is outputted as the sequence of node numbers on the path.

4) With VB, the shortest path obtained above is displayed on the map on GIS. When some segments of the road network are blocked, we modify the adjacent matrix accordingly.

4 Shortest Path Networks and Priorities of Road Segments

4.1 Shortest path network for ambulances

The shortest path network for ambulances is the collection of the shortest routes for all destinations. Using the system we have developed, we made two shortest path networks for ambulances, one for the road network without blocking (B) and the other for blocked road network (A). Comparing these two networks, we observe the following.

- Even in the network A, the network is connected, i.e. there are no isolated nodes.
- Most shortest paths are almost linear.
- There are some road segments which are not included in any shortest routes in A and B.
- Some roads segments which are not included in any shortest routs in B are used as paths of shortest routes in A.
- In the network A, it takes more time for ambulances to move in the south and north direction than in the east and west direction.

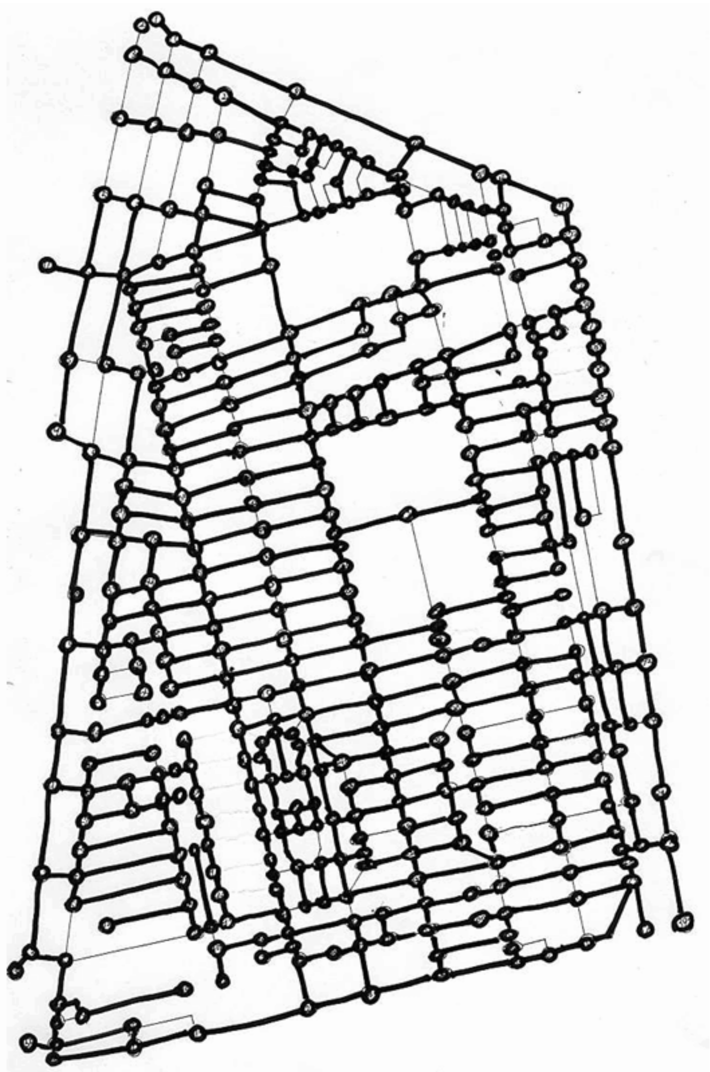

Figure 4: Network A

4.2 Prioritization of blocked road segments for restoration

Now we turn to the second objective of this study. We consider two factors for this purpose.

First, we pay attention to the differences between the lengths of corresponding shortest paths in A (Fig.4) and B (Fig.5). These lengths and differences are computed by Dijkstra's algorithm. When there is a big difference, it is important to restore the road segments contained in the shortest path in the network B.

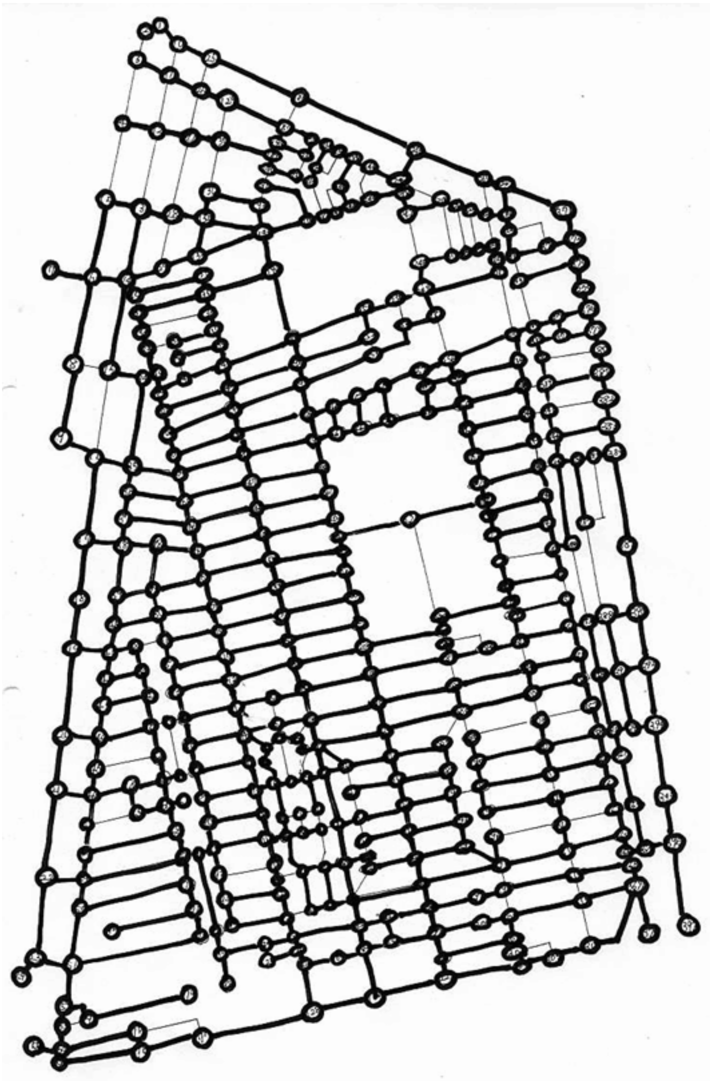

Figure 5: Network B

Second, we pay attention to the weak for refuge at the time of big earthquakes. Among the weak we consider elderly people and infants. For example, in case of Hanshin-Awaji big earthquake, about half of the dead people were above 65 in age. Therefore we should give priorities to road segments in the areas where many elderly people and infants live. To this end we use statistics on age distributions of inhabitants in each town in the district, where "elderly people" are defined to be people above 65 in age and "infants" are below 15 in age. We compute the ratio of the elderly people plus infants to the population in each town, and classify all the towns into 10 classes based on the ratios computed. This classification is shown on the map made with GIS. This shows that in many areas in this district the ratio is more than 30%, and the ratios become even 35% in the areas where many road segments are blocked.

4.3 Some measures against big earthquakes

Computational results obtained in the previous subsections can be also used to take measures *before* big earthquakes should occur: they can be used to specify the road segments to be strengthened.

We have considered two factors in 4.2: one is the length of the shortest path and the other is the ratio of the weak. We suppose the latter is more important for the purpose of reducing the number of deaths in case of big earthquakes. Therefore we first order the destinations of the shortest paths affected by the blocking of road segments according to the classification based on the ratio of the weak. The classification was made so that each class should contain the same number of nodes. For the nodes contained in the same class, we compare the differences between the length of the shortest paths before and after the blocking of road segments, and give a priority to the node with the larger difference. This means that the roads segments contained in the shortest path leading to such a node and the neighboring houses and buildings are to be reinforced with priority.

5 Concluding Remarks

We have developed a graphic display system to show the shortest path for ambulances in some district of Nagoya City when some road segments are blocked by a big earthquake. We have also proposed priorities of road segments to be reinforced before big earthquakes should occur in order to reduce the number of anticipated victims.

There are some problems with this system to be solved in future. First, the efficiency (speed) of the system is not very good, because we use three softwares, i.e. GIS, VB, and Excel, and move data among them. To overcome this shortcoming, it may be better to construct the whole system with one software, e.g. GIS. The second problem is the accuracy of the data used. It was very difficult to obtain data from the local government about individual houses and buildings in the district, so we assumed all houses and buildings in the densely-populated areas will collapse. If we can get more precise data, we can improve the system. Further we hope we can enlarge the area of study and propose better measures against big earthquakes.

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Table 1: Priorities of blocked roads

Priority of restoration	Node no. of the destination	Class no. of ratio of the weak	(1) Shortest distance before the earthquake	(2) Shortest distance after the earthquake	The difference (1)–(2)
1	22	9	1723 m	1792 m	69 m
2	21	9	1544	1595	51
3	351	8	998	1083	85
3	381	8	726	811	85
5	61	8	1331	1391	60
6	380	8	726	774	48
7	379	8	681	705	24
8	44	8	1382	1401	19
9	84	8	1266	1282	16
10	276	8	1039	1041	2
10	277	8	995	997	2
10	278	8	995	997	2
10	279	8	995	997	2
10	280	8	907	909	2
10	281	8	951	953	2
10	282	8	951	953	2
10	283	8	907	909	2
10	284	8	907	909	2
10	340	8	793	795	2
10	342	8	869	871	2
10	352	8	907	909	2

References

[1] Nagoya City: Statistical Sketch of Nagoya, 2004, `http://www.city.nagoya.jp/`

[2] Geographical Survey Institute: A geographical information system, `http://www.gsi.go.jp/GIS/index.html`

[3] ESRI Japan: `http://www.esrij.com`