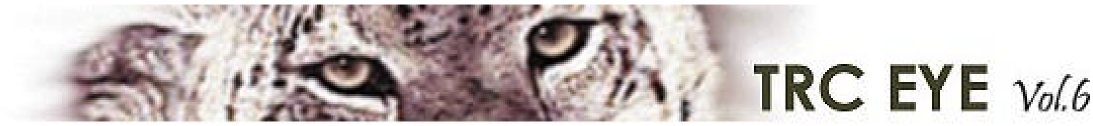

Estimation of assembling time for emergency action

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Abstract

In order to establish headquarters for seismic countermeasure, it is important to secure the personnel as well as the facilities. In many earthquake scenarios those two items are assumed sound after an earthquake, though the facts may be different. Therefore, it comes necessary to estimate the realistic status of those items for the effective actions. This paper describes the estimates of assembling time of personnel. The evaluation of assembling time possesses the following tasks, to estimate regional damage, to estimate individual damage such as bridge collapse, to estimate passage time of each arc, and to search the optimal route from each starting point to destination. Given a scenario earthquake, the regional damage and the individual damage are evaluated in a probabilistic way so that the damage rates are obtained. Passage time of each arc is evaluated reflecting the damage rates. Based on the passage time of each arc, the optimal route can be searched. Combining this assembling time with the information of the personnel's location, the relationship between the time elapsed after an earthquake and the number of the personnel will be obtained. This method can be used more widely by being combined with the existing GIS system.

1 Introduction

In many earthquake scenarios, it is assumed that the headquarter facilities and the personnel required are sound. This assumption, however, may bring the improper emergency action, as suggested in the Great Hanshin Earthquake. For example, Kobe branch office of Kansai Electric Power Company was damaged a lot, so that they had to organize their headquarter for seismic countermeasure in an unexpected place, yielding some delay in establishing it. After Kobe earthquake, a lot of strengthening work have been done for the existing buildings. On the other hand, the estimation for the availability of personnel and/or the upgrading the assembling system have not been considered seriously, though it is very important from the viewpoint of disaster prevention.

It is, therefore, necessary to consider the assembling of personnel reflecting the actual damage, which means the damage of assembling route and that of personnel himself. So far, a lot of knowledge and data regarding to the damage estimation have been accumulated. This method integrates them, so that the realistic estimation of the assembling status after the occurrence of an earthquake become possible. For example, the followings are obtained as necessary information for estimation; damage probability of each personnel at the place where he is, a time for commencement of movement, the nearest destination of each personnel, the optimal assembling route, and so on.

This paper also introduces the system newly developed for the purpose above, and also shows that it is used with the existing GIS system.

2 Framework of estimation

Figure 1 illustrates the framework of the estimation. The estimation consists of three components; evaluation of damage, search of the optimal route, and calculation of assembling. The first component estimates regional damage conducting seismic hazard analysis and fragility analysis. The second one evaluates the passage time of each arc meaning the road connecting the nodes, and finds out the optimal route from the starting node to the destination node using Dijkstra's method. The last one evaluates the assembling time for each mesh.

The feature of this system is that it combines the damage, such as collapse of buildings and fire expansion, and the passage velocity. This treatment can make it possible to plan more realistic seismic countermeasure.

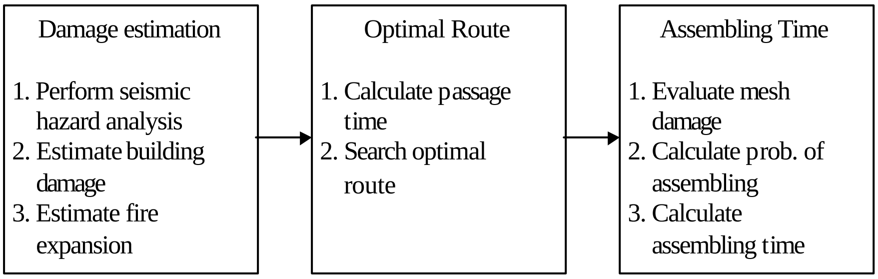

Figure 1: Framework of estimation

3 Method

3.1 Passage time of Arc

Figure 2 illustrates the concept of evaluation of the passage time. The passage time T of an arc is calculated by the following equation,

$$T = \sum_{i=1}^{n} \frac{L_i}{v / C_i} + T_{\sup} \tag{1}$$

where L_i is a length of segment i, C_i is a delay factor of segment i, and v is a velocity. $T_{\sup}$ is a supplement time corresponding to the individual factor, such as bridge collapse. n is the number of segments in the arc.

The delay factor newly introduced in this method corresponds to the fact that the velocity of the personnel changes according to damage of segment. This factor will be determined by the engineering judgement, considering the structural damage along the arc, the fire expansion, and the width of road. It can be noted that the fire expansion is also the function of the damage of wooden structure.

The delay factor C is evaluated by the following equations,

$$C = C_1 \cdot (1 - R_f) + C_2 \cdot R_f \tag{2}$$

$$R_f = \frac{n_f}{N} \tag{3}$$

where C_1 is the delay factor in the case that no fire expansion exists and C_2 is the delay factor in the case that fire expansion exists, respectively. n_f is the number of wooden buildings on fire and N is the number of buildings in the mesh considered. Both C_1 and C_2 are assumed to be given by the following equations,

$$C = a \cdot D^b + c \tag{4}$$

$$a = C_{100} \tag{5}$$

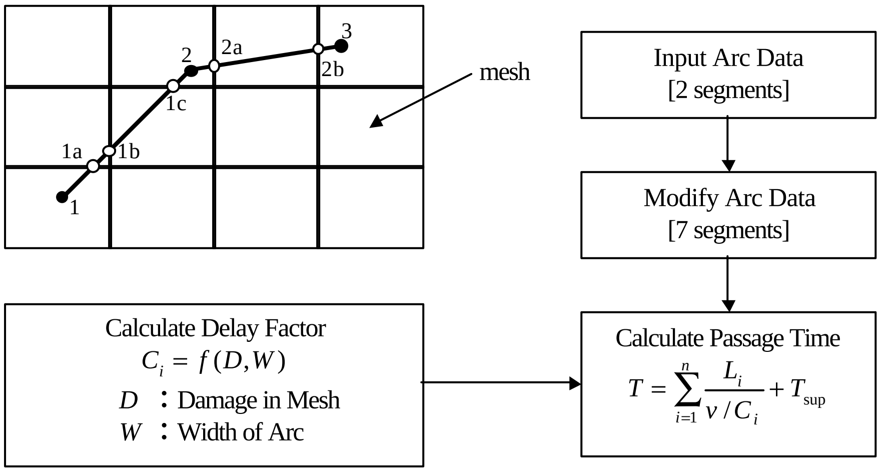

Figure 2: Evaluation of passage time of arc

$$b = \frac{\ln(C_{50} - C_0) - \ln(C_{100} - C_0)}{\ln(50) - \ln(100)} \tag{6}$$

$$c = C_0 \tag{7}$$

where C_0, C_{50} and C_{100} are coefficients corresponding to the damage rate of 0%, 50% and 100%, respectively. D is the damage rate, which is calculated by the following equation,

$$D = D_w \cdot R_w + D_{nw} \cdot (1 - R_w)/2 \tag{8}$$

$$R_w = \frac{n_w}{N} \tag{9}$$

where D_w is a damage rate of wooden building and D_{nw} is that of non-wooden building. n_w is the number of wooden buildings and N is the number of buildings in the mesh considered.

Coefficients C_0, C_{50} and C_{100}, which are given as inputs in the analysis, control the relationship between the damage rate and the delay factor as shown in Fig. 3. Also indicated in Table 1 are the values employed in this system, which are obtained based on the expert's opinion. It may be noted that these coefficients must be assigned for the combination of the status of fire expansion and width of arc.

Table 1: Example of delay factors (in the case of walk)

Width of Arc (m)	In case of no fire expansion			In case of fire expansion		
	C_0	C_0	C_{50}	C_{100}	C_{50}	C_{100}
13 -	*1.0*	*1.0*	*1.0*	*1.2*	*1.2*	*1.2*
5.5 - 13	*1.0*	*1.0*	*1.1*	*1.4*	*1.4*	*1.4*
3 - 5.5	*1.0*	*1.0*	*2.0*	*5.0*	*5.0*	*5.0*
0 - 3	*1.0*	*1.0*	*3.0*	*9.0*	*9.0*	*9.0*

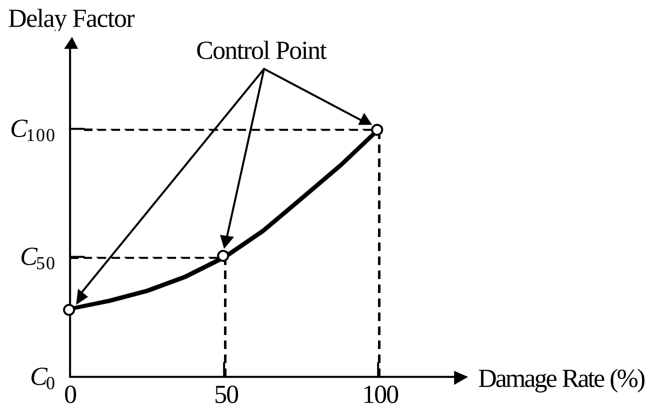

Figure 3: Relationship between damage rate and delay factor

3.2 Optimal route

The optimal route is searched using Dijkstra's method, which is frequently used in the similar problems. This method gives the optimal routes for every nodes simultaneously with the information about the time required to the destination and that about the node to go next. This time is abbreviated as T_{m-i} for node i.

In the case when there may exist plural destination, this system can propose the nearest destination by comparing the result for each destination. Namely, each personnel can know where to go for each scenario earthquake as the prior information.

For the convenience, the procedure of Dijkstra's method is illustrated. Figure 4 shows the example with the destination node [8]. Figure 5 shows the process of determining the optimal route by searching the shortest node step by step. In Fig. 5, black nodes are determined node, which have information regarding to the node to go and the time required. White nodes are free nodes connected to the determined node. Solid lines are the route identified by this procedure.

At first, nodes [4], [7] and [9] are selected as free node connected to the determined node [8]. By comparing the required time, the nearest free node [9] is picked up as a determined node.

Next, nodes [4], [7] and [10] are selected as free node connected to the determined node [8] or [9]. Node [7] is picked up as a determined node.

The same process is carried out until the last determined node is identified.

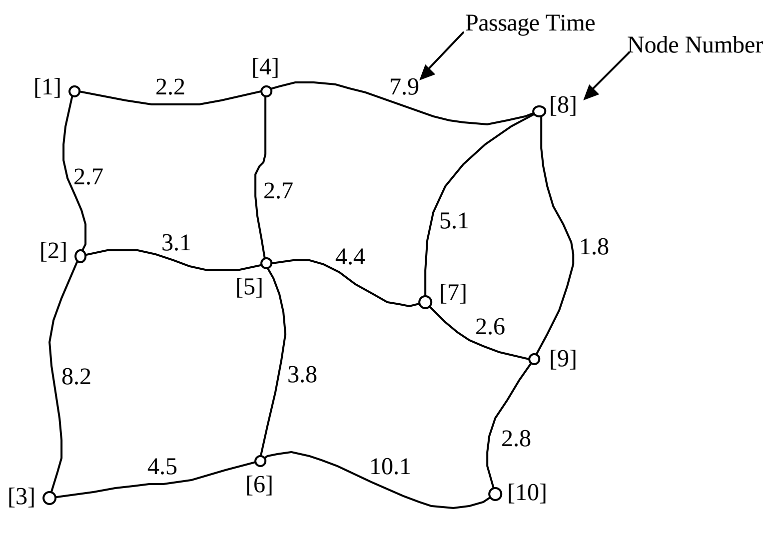

Figure 4: Example route for illustration

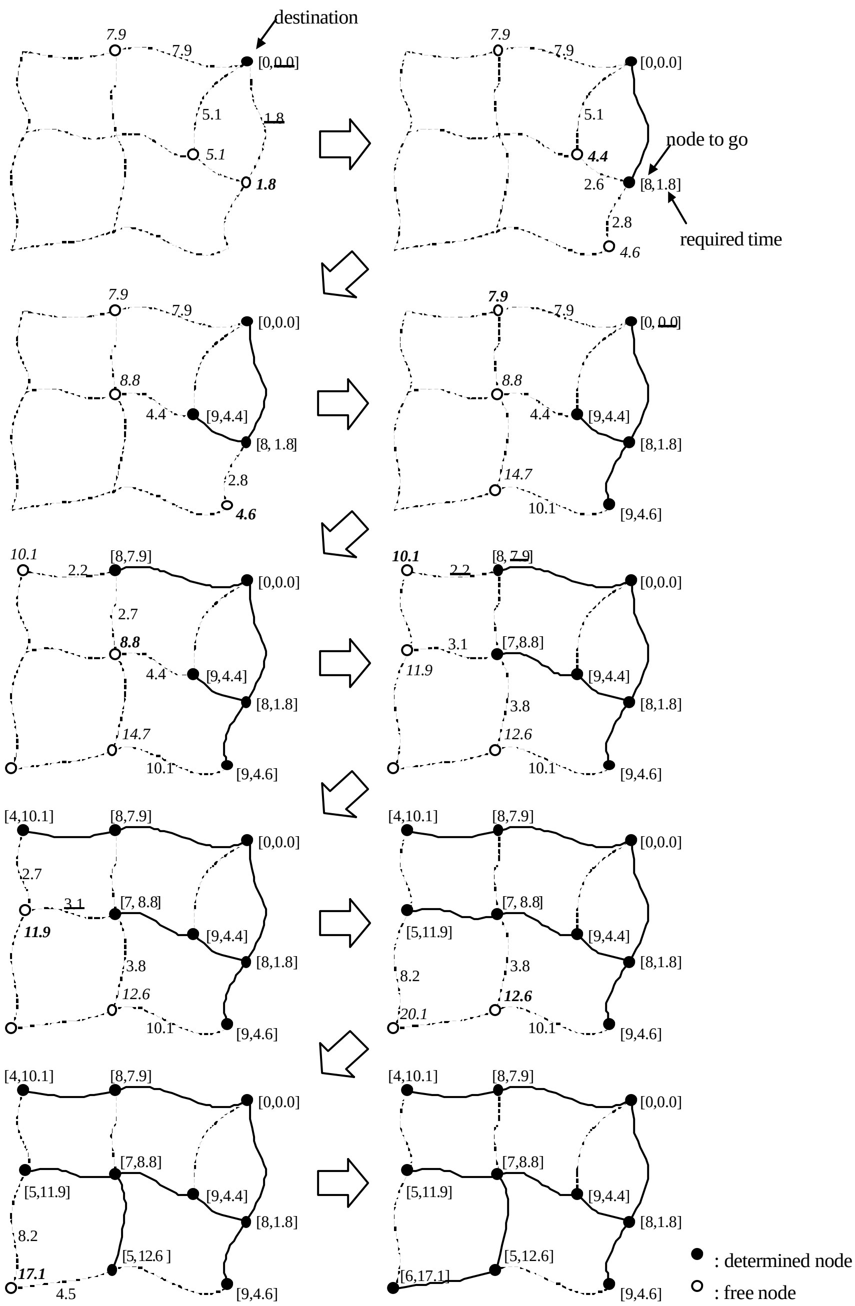

Figure 5: Process for searching the optimal route

3.3 Damage in mesh

Using damage rate in mesh, following items are estimated in this system; a damage rate of personnel, an assembling probability and a time for commencement of move.

A damage rate of personnel D_p is calculated using the following equation,

$$D_p = D_w \cdot R_w + D_{nw} \cdot (1 - R_w) \tag{10}$$

$$R_w = \frac{n_w}{N} \tag{11}$$

where D_w is a damage rate of wooden building and D_{nw} is that of non-wooden building. n_w is the number of wooden buildings and N is the number of buildings in the mesh considered. It must be noted that the individual data regarding to the personnel's are not considered in the calculation, since they are not available generally. Therefore, if the data were available, more accurate estimation could be done.

The assembling probability P_a is calculated using D_p in the equation (10) as follows,

$$P_a = 1 - D_p / 2 \tag{12}$$

The above simple relationship is derived the existing study by authors. In reality, the assembling time differs due to the individual situation, such as the time when an earthquake occurs, damages of personnel himself and/or his family, and so on. It is unfortunately the fact that enough data to reinforce the above assumption have not been obtained yet.

The time for commencement to move means the necessary time to secure the safety of relatives, to give first aid treatment to the injured, and so on. As stated in P_a, there are few date concerning the time. Therefore, the following equation based on the other study is employed in this system to obtain the time for commencement T_c,

$$T_c = 5 \cdot \sqrt{D_p - 0.1} \quad D_p > 0.1 \tag{13}$$

$$T_c = 0.0 \quad D_p \leq 0.1 \tag{14}$$

3.4 Time estimation

The total time from the occurrence of an earthquake to the arrival can calculated by the following equation,

$$T_k = T_{c-k} + T_{m-i} + T_{n-ik} \tag{15}$$

where T_k is the total time of mesh k. $T_{c\text{-}k}$ is the commencement time of mesh k given by the equation (7.1) or (7.2). $T_{m\text{-}i}$ is the required time of node i, which is estimated with the optimal route by the Dijkstra's method. $T_{n\text{-}ik}$ is the time required from the centre of mesh k to the nearest node i.

The search of the nearest node is simply done by calculating the distance between the centre of mesh and the node. The estimation of $T_{n\text{-}ik}$ is carried out using the same way for the calculation of passage time of arc.

4 Examples

4.1 Seismic hazard

As shown in Fig. 6, scenario earthquake is characterized by some parameters such as magnitude, azimuth, dip angle fault length, etc.

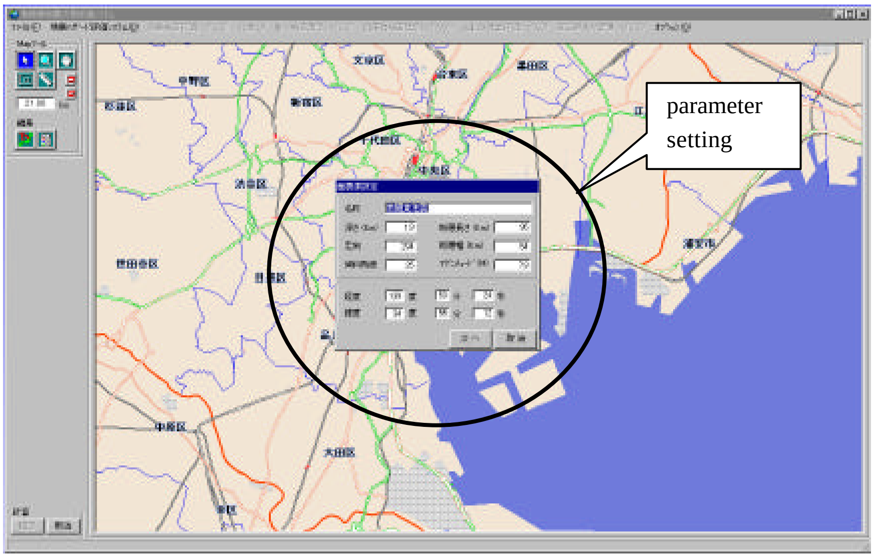

Figure 6: Characterization of scenario earthquake

Figure 7 shows the JMA intensity in Tokyo area. This intensity is obtained from the zero period acceleration and JMA magnitude. The approximate relationship among them is given by the following equation,

$$I = 1.86 \cdot \log_{10} A + 0.15M - 0.37 \qquad (16)$$

where I is JMA intensity , A is zero period acceleration and M is JMA magnitude, respectively.

4.2 Damage of building

Before calculating the damage rate, structural type and the number of building in area must be assigned. Structures are divided into two (2) types; one is wooden building and the other is the RC building. Each building is characterized its story number and age.

Figure 8 indicates the damage rate of RC building in the center of Tokyo.

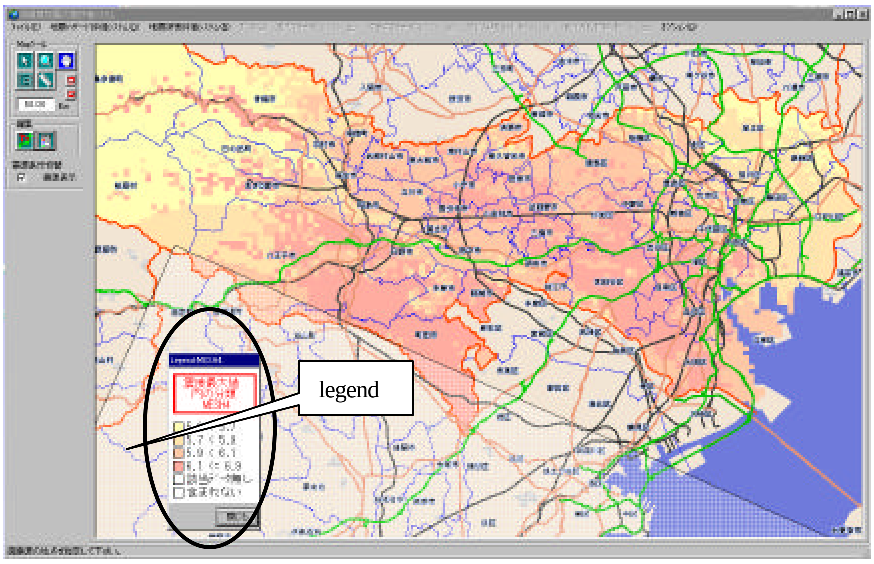

Figure 7: JMA intensity in Tokyo area

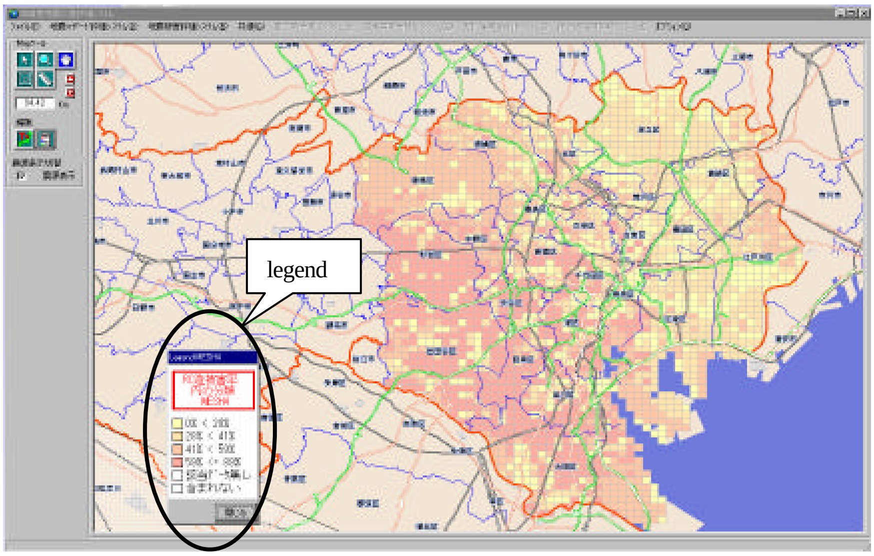

Figure 8: Damage rate of RC buildings

4.3 Assembling route

Figure 9 shows the optimal assembling route to the destination, which reflects the damege rate, road width and etc.

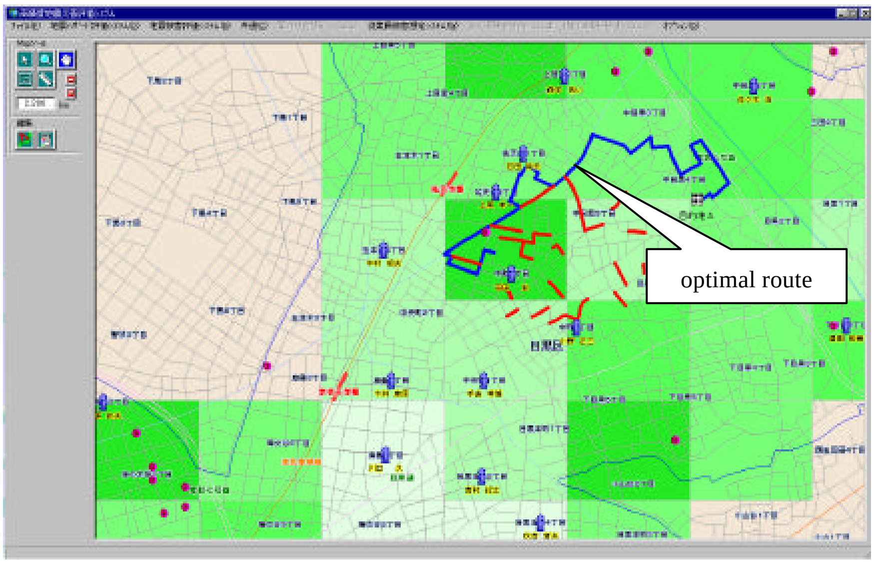

Figure 9: Optimal route

5 Conclusion

This paper describes the estimation of the assembling time map, which will be helpful for the realistic action for seismic countermeasure.

Furthermore, a lot of application using same procedure can be possible for the emergency action. For example, the strategy to transport emergency materials such as, water and food, may be made. Also, estimation of the optimal evacuation route may be useful for government.

This method still has a lot of assumption due to the fact that the available data are not in hand. However, authors think that the first priority is to build up the framework and the second priority is to brash up the system by modifying the methodology and by collecting data.

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