【論　文】

A simple framework for planning emergency routes in small townships in response to earthquake disasters

小規模行政区域内の地震時緊急救援道路の検討のための簡易な枠組み

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SUMMARY

The number of deaths related to earthquake disasters might depend on the speed with which people receive medical treatment during emergencies. The rapid transportation of injured people to the closest hospital is important for decreasing the number of fatalities, and the road networks used by emergency transportation vehicles during disasters are key to disaster mitigation. This study proposed a simple framework to be used in discussions of the performance of emergency transportation routes in small townships in developing countries. The framework comprises an estimation method for road damages and connectivity of the road network to hospitals. Although the details of this damage estimation method were not fully examined, a feasibility study of the proposed framework was conducted on small townships in Mandalay, Myanmar. The results found that the proposed framework is simple, but effective for predicting future aspects of disaster mitigation, particularly in developing countries where precise data are not available or not reliable.

Key Words
Rescue route, network, planning, earthquake, Myanma

1. Introduction

Finding ways to decrease the numbers of victims of strong earthquakes is an important concern. The number of fatalities depends on the quality of the medical treatment provided in response to emergencies, and rapid response that transports injured people to hospitals lowers the numbers of deaths. Because transportation of injured people to their closest hospitals is the key factor in reducing the number of deaths, the quality of the roads used for emergency transportation during disasters is important.

Some previous studies, such as Stepanov and Smith(1), Sakuraba et al.(2), and Ohgai and Yamamoto(3), have focused on emergency routes. Stepanov and Smith simulated multiple-objective evacuation routing. Sakuraba discussed the road network accessibility problem and workers/troops' scheduling problems during road rehabilitation. Ohgai estimated the probability of non-arrival and the arrival distances to locations. Although these studies addressed important challenges in the emergency route issue, the complexity of the problem suggests a need for a simple framework within which goals can be set for emergency route planning. In Japan, there are extensive studies on the planning of rescue route and hospitals, such as Banba(4) et al. (2008), Okumura(5) et al.(2009), Ohashi and Fujita(6) (2012), Okumura and Goso(7) (2014). These advanced approaches are based on the experiences of real earthquake damages in Japan. However, these Japanese practices cannot be applicable to the situation in developing countries due to insufficient data resources.

This study proposed a simple framework regarding the capacities of road networks in small townships to function during an earthquake disaster. The proposed framework creates indexes on the performance levels of emergency transportation networks and the damage assessment process for road linkages and connectivity between residences and their local hospitals, which enables an assessment of the performance indexes. In addition, the proposed framework was applied to small townships in Mandalay, Myanmar, to test and demonstrate its feasibility. The idea of the performance indexes is summarized in Section 2, and the estimation process on road network damages is summarized in Section 3. Section 4 describes the planning of road improvements for emergency transportation routes, and Section 5 sets forth the study's conclusions.

2. Performance Index Proposal

2. 1 Importance of travel time to hospital during an earthquake disaster

Several ideas have been suggested for emergency transportation planning, such as planning the routes to supply materials for refugees, which focus on discussing the connectivity of main roads through numerous locations, such as highway connectivity. However, this study focused on roads in small townships because its main concern was not the supply and transportation of materials into affected areas. The main concern of this study was the safe and speedy transportation of injured persons to hospitals for treatment because effective emergency transportation is the most important and most direct way to save lives during an earthquake disaster.

In emergency medicine, the likelihood of death following a traumatic injury increase with time Figure 1. Although the death rate depends on the seriousness of the injuries, it implies that the quality of the emergency roads for transporting injured persons out of affected areas to hospitals and transporting rescue teams into affected areas is important. Therefore, the framework and indexes

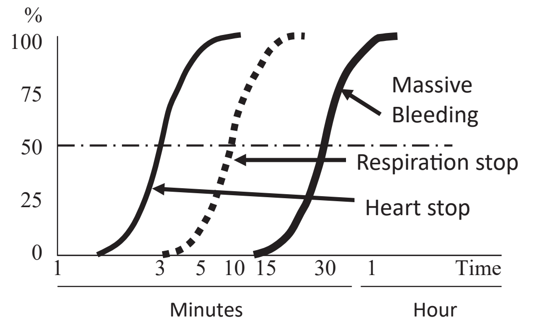

Figure 1. The golden hour principal in emergency medecine(8)

proposed by this study focus on residents' travel time on emergency routes to hospitals.

2.2 Travel time

This study's focus on transporting injured people to hospitals assumed that they would most likely be physically carried to a spot as close as possible to the road network linked to the closest hospital and that the injured persons would be transported from there to the hospital in vehicles. The problem with emergency routes in townships concerns the viability of the road networks during earthquake disasters. Figure 2 illustrates the travel situation of victims injured in their residences who travel the emergency route to the closest hospital. The main concern is the total travel time (walking to the emergency route and driving from that spot to the hospital).

In reality, the total time is not simple as shown in Figure 2. For example, Ohashi and Fujita(6) (2012) considered the time for ambulance arrival to the site and for staying at the site. However, some of the time consumption is not only related to the condition of road network but also the management issues such as the number of ambulances and the locations of the ambulance waiting. Table 1 shows the summary of the possible time consumption, and to make the problem simple, the authors only chose the walk travel time and driving time, since these two times clearly related to the road network issue. In addition, considering the limitation of the number of ambulances, the authors assumed any car nearby the injured person will work to rescue.

Table 1. Summary of possible time consumption

Possible time consumption	Related factors
Time to find the injured person	Neighborhood rescue works, Number of firefighters/volunteers.
Time to rescue the injured person	Damage level of buildings, experience of finders/firefighters.
Time to call ambulance/vehicles	Number of ambulance, neighborhood cars.
Time to walk to the road	Road network damage, road blockade.
Time for vehicles staying on the site	Possible urgent treatment to injuries.
Time for vehicles go to hospital nearby	Road network damage, Traffic condition.

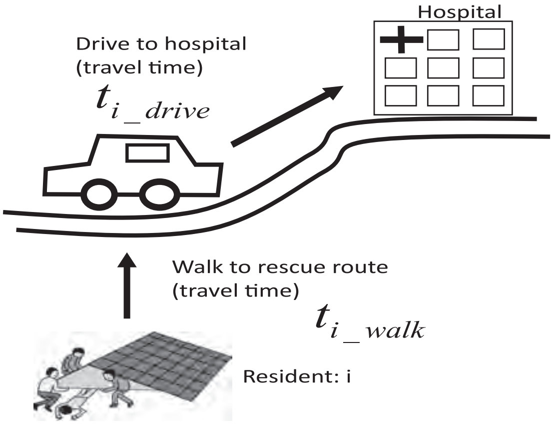

Figure 2. Travel time from a residence to an emergency route to a hospital

Thus, the time for the ambulance coming is neglected.

Transportation capabilities during earthquake disasters depend on numerous factors, such as the number of available ambulances (which is negatively related to the wait time) and the possible vehicular speeds on damaged roads. To calculate its performance index, this study assumed that an injured person would be physically carried to the emergency route at a walking speed of 4 km per hour and driven from that spot to the hospital at a vehicular speed of 60 km per hour. For the calculations, all other variables were ignored for simplicity. For example, in Japan, the effect of the traffic congestion is quite critical. However, the estimation of the congestions is quite difficult and often ignored in this kind of simulation (i.e. Okumura et al.(5), 2009). In addition, it is related to the number of vehicles in the town. In developing countries, the number of the vehicles are still limited and most of the vehicles might work to rescue injured persons. From this viewpoint, as the first step of the study, we disregard the effect of traffic congestions.

Although other variables might be important to accurately estimating the death rate in a disaster area, the simplification used here might not influence the results of an assessment of the performance of a given emergency route or road network. In other words, this study's simplified calculations of travel time sufficiently inform discussions on preparing infrastructure to handle earthquake disasters, such as retrofitting roadside structures; the problems related to emergency response management, such as preparing ambulances, are not considered.

2.3 Performance indexes

This study proposed several types of indexes to measure the performance of emergency routes using calculated travel time from a residence to the closest hospital. The first index is the average time taken to transport the victims as follows.

$$T = \sum_i \left(t_{i\_walk} + t_{i\_drive} \right) \Big/ N \tag{1}$$

Where T is the average time, (i) is the origin of transportation (residence), $t_{\mathrm{i\_walk}}$ is the travel time from the origin (i) to the emergency route, $t_{\mathrm{i\_drive}}$ is the travel time while on the emergency route to the hospital, and N is the total number of residences.

As another index, we can define the coverage ratio of travel time. With the allowable travel time of 15 minutes (according to the golden hour principle, in cases of massive bleeding, some people would die) or 30 minutes (in cases of massive bleeding, about 50% of the people would die), the coverage ratio would be as follows.

$$R = N_a / N_t \tag{2}$$

Where N_a is the number of residents who can arrive a hospital during a given travel time and N_t is the total number of residents.

Using these indexes (average time = T and coverage ratio = R), many concerns could be addressed, such as appropriate locations for emergency routes, priority road improvements, and so on.

2.4 The method employed to obtain the performance indexes

The method used to obtain the values of the proposed performance indexes is summarized in Figure 3. First, for earthquake disasters, the location of an earthquake's epicenter and its magnitude are assumed. Recently, detailed modeling of the fault rupture process, including the non-uniform rupture level on the fault plane, has made it is possible to estimate the shaking periods at given locations.

However, a point source model and simple attenuation using an assumed earthquake magnitude and the distance between a given location and the epicenter could be a simpler method. Then, the damage done to the road network can be evaluated. Road networks experience numerous types of earthquake damage, such as manhole cover uplift at soil-liquefaction sites and road destruction caused by building collapse, fallen bridges, and so on. The probabilities that these types of damage would occur could be statistically estimated as a damage rate, computed as the number of damages per unit distance (i.e., number of damages/km).

In this study, the connectivity of a given road network after an earthquake disaster was determined by estimating this road damage rate. This is the method used on the roads that connect to the hospitals. Finally, the travel times from all possible locations where injured people could be (i.e., residences) to the closest hospitals were calculated. GIS easily provided the estimates.

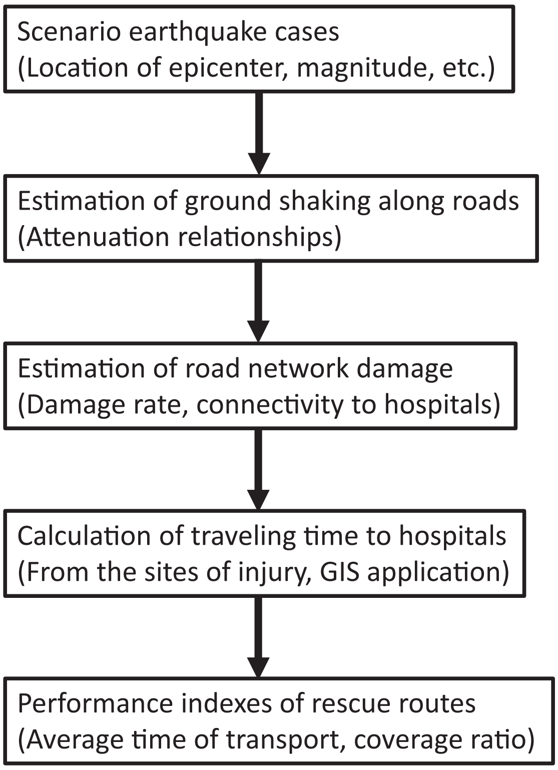

Figure 3. Estimation process of performance indexes

3. Estimating Road Network Damages

3.1 Estimating seismic intensity

For simplicity, this study used attenuation relationships to estimate the extents of seismic shaking along the roadsides in the townships[i.e. 5)]. There are several types of attenuation relationships, and the differences in attenuation relationships are due to the differences in background data, such as regional differentiation, types of fault rupture processes, periods of observation, and so on.

3.2 Damage rate of the roads

Several previous studies have addressed road damages caused by seismic shaking. For example, the damage rate assessed using the JMA (Japan Meteorological Agency) seismic intensity(9) is shown in Table 2. Prefectural governments in Japan often use this table for their seismic damage assessments. The following equation(9) was used to compute JMA seismic intensity when the Peak Ground Velocity (PGV) had been computed from the attenuation relationships.

$$I = 2.68 + 1.72 \log PGV \qquad (3)$$

Where,

I = JMA earthquake intensity
PGV = peak ground velocity (cm/s)

Table 2.　Road damage rate estimates based on seismic intensity(10)

Seismic intensity	Damage rate (no./km)	
	National highway controlled by country	Prefecture roads, city roads
$I < 4.5$	–	–
$4.5 \le I < 5.0$	0.035	0.016
$5.0 \le I < 5.5$	0.11	0.049
$5.5 \le I < 6.0$	0.16	0.071
$6.0 \le I < 6.5$	0.17	0.076
$I > 6.5$	0.48	0.21

3.3　Connectivity to hospitals

The connectivity of roads to hospitals shall be considered. The damage rates in Table 2 are the estimated numbers of damages per km, and damages to all of the roads were calculated using the damage rate and the lengths of the roads. The authors assume the connectivity will be lost when the expected number of damage to a hospital is 0.50 or more. This threshold of damages is the same as a .50 probability of damage occurrence on the way to the hospital.

3.4　Travel time to hospitals

It is challenging to estimate the locations of injured people. However, this study took a simplified approach and assumed that injured people are at their residences when earthquakes hit at midnight. Thus, residences were used as the locations of the injured people requiring transportation to the hospital. Under that assumption, total transportation time was calculated, in which transportation originates at a residence and ends at the closest hospital. The proposed performance indexes were obtained using the calculated travel time.

4. The Case of Mandalay, Myanmar

4.1　Earthquake scenarios

A case study on small townships in Mandalay, Myanmar, was conducted as a feasibility study on the proposed framework. Mandalay is the second largest city in Myanmar, with a population exceeding 1.2 million according to the 2012 census. The city is close to an active fault (Sagaing Fault) as shown in Figure 4. The fault is 8 km from Mandalay, which has historically suffered from many of its ruptures.

To conduct the feasibility study, the first step considered three earthquake scenarios, which are summarized in Table 3. Case A is the Shewe Bo earthquake (M = 6.8) that hit in November 2012, from which Mandalay experienced no significant damage.

The results on Case A are for cases without damages, meaning there are no damages by

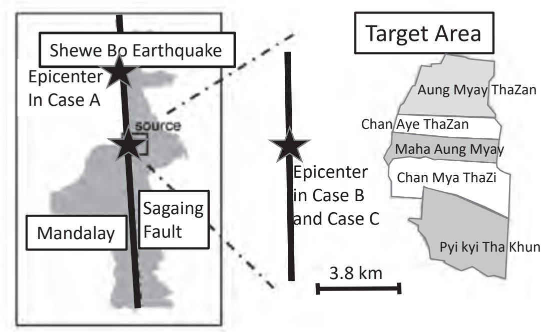

Figure 4. Mandalay and Sagaing Fault area

Table 3. Scenario earthquake cases

Case	Location（Epicenter）	Magnitude
Case A	Same with Shwe bo earthquake（120 km North of Mandalay, depth 14 km）	Same with Shwe bo earthquake（M = 6.8）
Case B	Severe one（Closest point to Mandalay, depth 14 km）	Same with Shwe bo earthquake（M = 6.8）
Case C	Severe one（Closest point to Mandalay, depth 14 km）	Severe one（M = 7.9）

Figure 5. Major road networks in Mandalay and the nearby hospitals used in the study

the earthquake. Case B has the same magnitude as Case A, but the epicenter is the closest point to Mandalay on the Sagaing Fault. Case C is the worst-case scenario, in which a large magnitude earthquake occurs at the closest point to Mandalay.

4.2 Major road networks in Mandalay, Myanmar

There were five targeted townships in Mandalay used in the study, which have hundreds of roads of various widths. However, we assumed that, in the event of an earthquake, most of the narrow roads would be impassable because of debris from damaged buildings, vehicles, and so on blocking the road. Therefore, the study focused on the major roads, defined as four or more meters wide. The estimation used 384 road links. Figure 5 shows the roads and the locations of the nearby hospitals.

4.3 Seismic intensity and damage rate

For simplicity, we neglect the site amplification of ground motions at the first step. This is mainly due to the insufficient information of site ground conditions in developing country. Thus, Peak Ground Velocity at base layer（PGV600）obtained by an attenuation relationship(11) is considered as the PGV at the ground surface. For the next step, the soil class and more realistic seismic

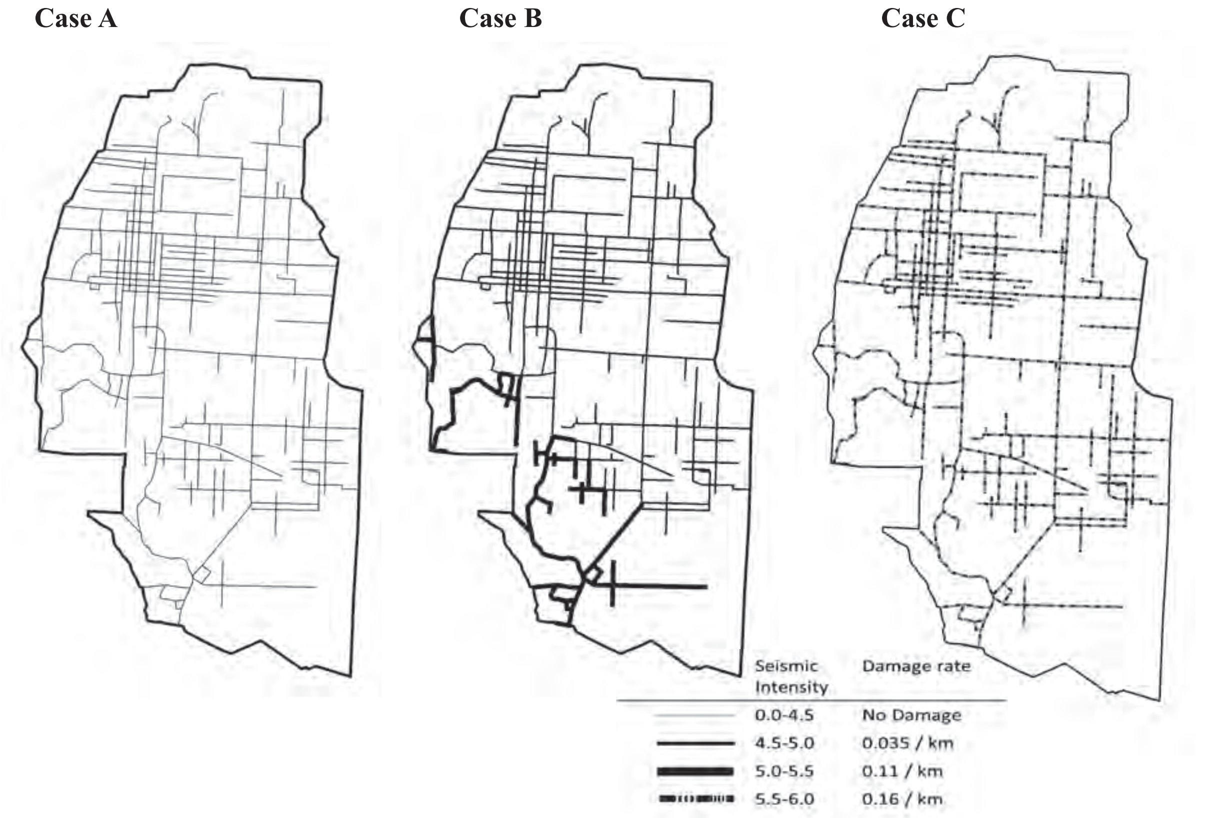

Figure 6.　Seismic intensities and estimated damage rates of the road networks across three scenarios

shakings were classified.

There were no large differences in estimated seismic intensities among the three cases because the distances from the major roads to the earthquake epicenters were almost the same. Figure 6 shows the estimated damage rates of the target roads for the three scenarios. To this point, the estimations assumed that the major roads were in the same road class as national highways.

4. 4　Connectivity to hospitals

The framework assumed no vehicular connectivity via roads to hospitals when expected number of damage were 0.5 or more. Figure 7 shows the connectivity of the major roads to the hospitals under the conditions of the three earthquake scenarios. Case A was the situation in which no earthquake damage occurred. Case C presents the most disastrous road damages and the highest road damage rate, and the extent of its connectivity of road to hospitals was less than in Case B.

4. 5　Travel time and performance indexes

In the first step, the framework assumed the residences in the targeted townships were uniformly distributed. Under that assumption, the total times for transportation to hospitals were computed when transportation originated at a residence and ended at the closest

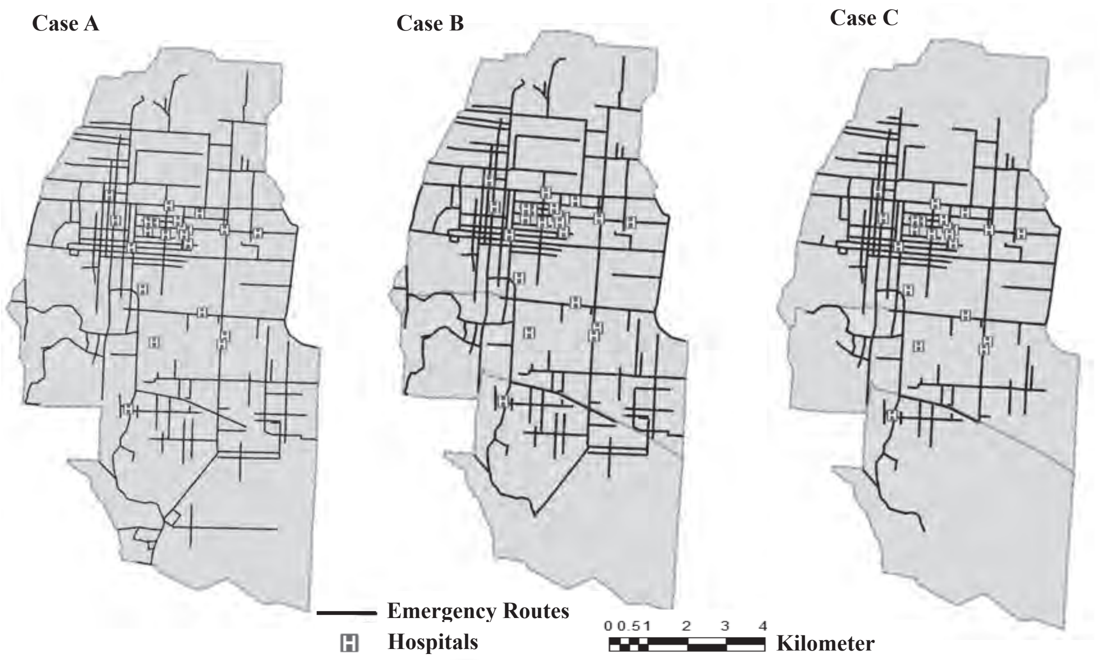

Figure 7.　Estimated extent of connectivity of the road network in three scenarios

hospital. A detailed explanation of this case study is available from the references below(12),(13). The total times from residences to hospitals are shown in Figure 8. Using these data, the proposed performance indexes were evaluated.

The average total transportation times under the three scenarios are summarized in Table 4. Based on the estimated extents of damage to the road network, the total transportation times were 7.53, 9.46, and 13.34 minutes for Case A, Case B, and Case C, respectively. These estimated transportation times were used to compute the death rates related to the extents of road damage.

The coverage ratios of travel time of residences to the closest hospitals are shown in Table 4. It can be used as a detailed background data to estimate the death rates increase that would relate to road damage.

Table 3.　Results of the estimated total travel time to hospitals from residences（averages）

Cases	Average travel time（min.）
Case A	7.5311
Case B	9.4605
Case C	13.335

Table 4.　Coverage ratio of travel time

Total time（min.）	Case A	Case B	Case C
0 ～ 5	0.41	0.41	0.38
5 ～ 10	0.35	0.33	0.23
10 ～ 20	0.18	0.15	0.17
20 ～ 30	0.03	0.04	0.10
30 ～ 40	0.02	0.03	0.06
40 ～ 50	0.01	0.02	0.03
50 ～ 60	-	0.01	0.02
>60	-	0.01	0.01

5. Discussion on Rescue Route Planning

Although many factors, such as site

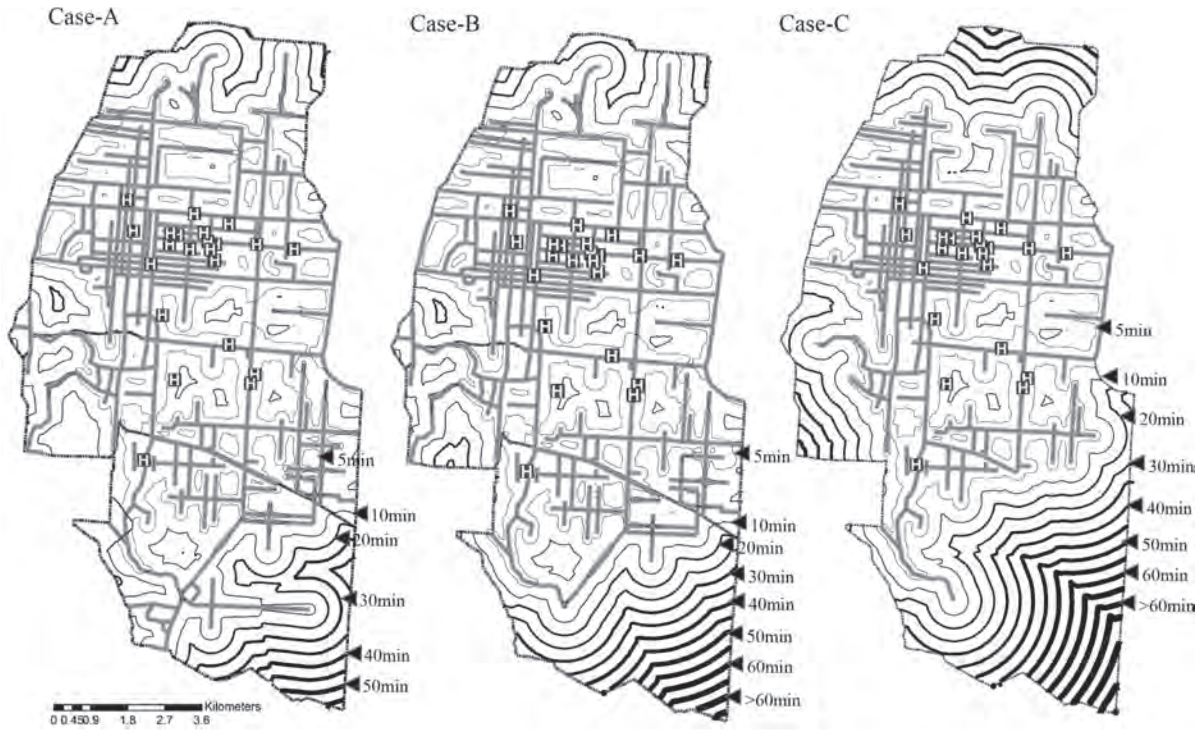

Figure 8.　Estimated total times from residences to the closest hospitals in three scenarios

amplification of ground motions and population distribution, need to be considered by future suggest that the proposed framework might give a good index to use for planning emergency transportation routes. For example, Figure 8 (above) shows the areas in need of critical attention. The residents of East Chan Aye Thar Zan (northern part of the target region) and Myothit (southern part of the target region) would use relatively more time traveling to hospitals during earthquake disasters. Thus, the estimations identify the areas that need attention and set quantitative targets to be met through urban planning. Figure 9 shows the locations recommended for improvements to the road network. Improvements at 80th street and 66th street are recommended for East Chan Aye Thar Zan, and improvements at 78th street and 62nd street are recommended for Myothit.

In previous studies, there are many kinds of approaches to give the priority of the improvement with advanced simulation techniques (i.e. Okumura et al(5)., 2009). However, many information is needed to do advanced method such as the road network data including narrow streets is not well prepared in developing countries such as Myanmar. The expectation on these analyses may be different either. The accuracy on the estimation of causality may be important in this kind of analysis in developed countries, such as Japan. However, not only the accuracy of the estimated index but also the simple information to show the priority and improvement will be more effective in adequate policy making in developing countries.

A detailed approach to improving road performance under conditions of seismic activity is a challenging engineering problem, and further studies using road damage case histories should be conducted. Furthermore, the damage rate estimation (Table 2) is for the Japanese case, so modification to fit the Myanmar case is necessary. However, for simplicity, this study assume that the damage rate would be one-half of the values shown in Table 2 if the road performance is improved by additional construction activity such as seismic retrofit of the building along the road.

Table 5. Coverage ratio after recommended road improvements in percentage

Total time (min.)	before (Case C)	80th Street	66th street	78th street	62nd street
0 ～ 5	37.6	38.0	37.8	37.6	38.6
5 ～ 10	22.7	23.3	23.1	22.7	24.3
10 ～ 20	16.5	16.4	16.7	16.5	16.9
20 ～ 30	9.3	9.0	9.4	9.3	9.3
30 ～ 40	5.8	5.2	5.3	5.8	5.4
40 ～ 50	3.2	3.1	3.1	3.2	2.3
50 ～ 60	2.2	2.2	2.1	2.2	1.6
>60	2.8	2.8	2.6	2.8	1.5

In practice, municipalities have more than the four road improvement options shown in Figure 9. However, these options were chosen because the roads were about same length (about one km), and, therefore, the improvement costs were about same, meaning that only the increase in performance was compared. Table 5 summarizes the coverage ratios of travel time accounting for the effects of these improvements for Case C. The results indicate no effect for the improvements to 78th street. The most significant performance increase was for 62nd street. If the relationship between the death rate and travel time to the hospital (Figure 1) were accurate, the effects of road improvements would be indirectly observed as a decrease in the death rate. Thus, the proposed framework might be a powerful tool for appropriate planning of emergency rescue routes in small townships.

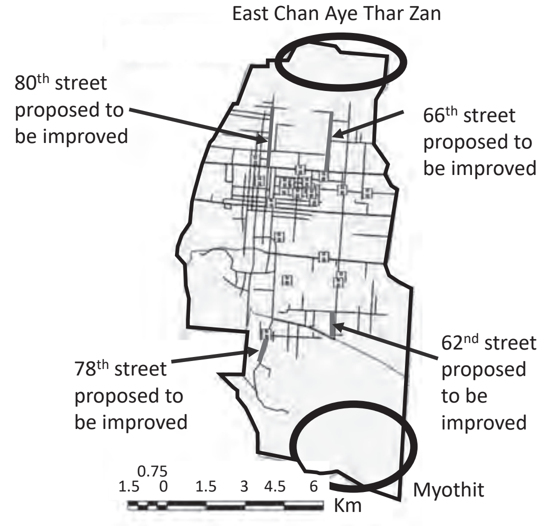

Figure 9. Road locations recommended for improvements in Mandalay, Myanmar

6. Conclusions

This study proposed a simple framework to assess the performance of emergency transportation routes in small townships during earthquake disasters. The framework consists of estimating the road damages and connectivity of the road network. Although the details of the damage estimation method were not fully examined, the feasibility study of the proposed framework in small townships in Mandalay, Myanmar, found that it might be a powerful tool for effective planning of emergency transportation routes in small townships. Future studies should consider additional variables, such as site amplification of ground motion, population size and distribution, and nuanced road damage, with which road performance improvement measures might be derived.

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