A New Scheme for Evaluating Road Projects by Considering Their Effects after Disasters

—Challenges Faced by Japan since the Great East Japan Earthquake of March 2011—

Hitoshi IEDA [a], Tetsuya YAMADA [b], Tohru TAMURA [c], Kiyoshi TAKAHASHI [d]

[a] *Dept. of Civil Engineering, The University of Tokyo, Hongo 7-3-1 Bunkyo-ku, Tokyo 113-8656, Japan, E-mail: ieda@civil.t.u-tokyo.ac.jp*
[b] *Performance Management Office, Planning Division, Road Bureau Ministry of Land, Infrastructure, Transport, and Tourism, 2-1-3 Kasumigaseki, Chiyodaku, Tokyo, 100-8918, Japan, E-mail: yamada-t27m@mlit.go.jp*
[c] *Dept. of Engineering and Policy for Cold Regional Environment, Hokkaido University, North 13 West 8,Sapporo, 060-8628, Japan, E-mail: tamura-t@eng.hokudai.ac.jp*
[d] *Dept. of Civil and Environmental Engineering, Kitami Institute of Technology, 165 Koencho, Kitami, 090-8507, Japan, E-mail: kiyoshi@kitami-it.ac.jp*

Abstract: In Japan, road project assessment has conventionally been based on cost/benefit analysis. However, the roles played by roads have now become more diverse and the current cost/benefit analysis-based assessment method is no longer necessarily appropriate for evaluating their disaster mitigation functionality. Accordingly, Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) drew up A Method for Assessing the Disaster Mitigation Functionality of Roads (provisional draft) for use in evaluation when new projects such as that for the construction of the Sanriku Coastal Road are adopted. The purposes of this study were to review past investigations of methods for assessing the disaster mitigation functionality of road networks to clarify the applicability of the new assessment method developed in Japan, and to identify related problems. Yet, the draft outlined by MLIT in the summer of 2011 is provisional, and improvements, both in theory and practice should still be brought forth.

Key words: Road network, Disaster Mitigation, Road project assessment

1. INTRODUCTION

Although transport facilities were extensively damaged by the Great East Japan Earthquake of March 2011, the road network in the affected area was restored with surprising speed compared to the progress made with other public transport systems. This meant that roads were able to fulfill the significant responsibility of acting as transport networks for stricken areas in a variety of activities such as the evacuation and rescue of civilians and the transportation of support materials. While damage-related service disruption continued at airports, ports and other central facilities of the wide-area transport network and railway links remained severed, expressways were restored quickly and line haul services using express buses were operated in addition to supply transport services. In the intra-region network, national highways and other roads were restored quickly, and acted as the region's key transport network in place of railways destroyed by tsunami waves with no immediate prospect of service resumption. These roads also played an important role in forming an access transport network from highway interchanges after the restoration of ports and airports was finally completed. Thus, in addition to supporting the movement of people and materials in everyday life, road networks also play an extremely prominent role in connecting regional networks when disasters occur. Accordingly, assessment of road networks' disaster mitigation functionality is important when considering road construction and improvement plans.

In Japan, road project assessment has conventionally been based on cost/benefit analysis, which involves evaluating the related costs against the extent of three potential benefits (reduction of driving time, driving costs and traffic accidents). These are calculated using statistics on motor traffic volumes and other variables that can be measured with sufficient accuracy and converted into monetary values. Against this background, Japan's Ministry of Land, Infrastructure, Transport and Tourism drew up *A Method for Assessing the Disaster Mitigation Functionality of Roads* (provisional draft) for use in evaluating the disaster mitigation functionality of roads where the current cost/benefit analysis-based method is not necessarily sufficient. This new approach is expected to be useful in the assessment of new projects for expressways and other roads.

Guidelines such as the American Association of State Highway and Transportation Officials' *A Guide to Highway Vulnerability Assessment* (AASHTO Task Force) were referenced for the development of a simple and practical assessment method. There were three key points in the preparation of *A Method for Assessing the Disaster Mitigation Functionality of Roads* (provisional draft): (1) assessment of existing road networks to ensure a) that regions will not become isolated due to external disaster forces, and b) that regions are linked with main disaster mitigation bases and are highly restorable; (2) the use of indices unrelated to road traffic volumes and populations around roads; and (3) the use of indices reflecting the external influence settings of individual areas by regional development bureaus to guarantee local security (rather than uniform indices applied nationwide).

2. LITERATURE REVIEW

This section summarizes past studies on the connective reliability and vulnerability of road networks. Connective reliability has been the subject of extensive research in the last three decades as a measurement that indicates the status of connection between nodes (i.e., whether there is at least one usable route between them) based on probability. The main work here involved the study of a method that can be used for intensive calculation whose complexity increases exponentially with the size of the network. As connection at a certain service level was then considered rather than simple connection with a trafficable link, the study progressed to investigate travel time reliability. The concept of vulnerability (which is similar to connective reliability) must also be considered, although there is no established definition of it. Against this background, Taylor (2006) defined the subjects of vulnerability studies as "incidents that have significant impact on a sparse network although the probability of their occurrence is very low" based on a series of studies (e.g., D'Este/Taylor (2001, 2003)), and placed importance on the structural vulnerability of networks. Berdica (2002) defined vulnerability as "a susceptibility to incidents that can result in considerable reduction in road network serviceability." Jenelius et al. (2006) introduced the concepts of importance and exposure. The term *importance* here concerns one link, as opposed to a scenario in which damage to multiple links is included in the exposure. The concept of vulnerability differs from that of connective reliability in that the vulnerability of networks is examined without consideration of probability.

According to AASHTO's *A Guide to Highway Vulnerability Assessment*, analysis should be based on evaluation of the individual structures (such as bridges, roads and interchanges) that constitute a network. The main subject of assessment here is the disaster mitigation performance of links and nodes. The guide contains explicit descriptions on the assessment of priorities for counter-terrorism measures and procedures for examining the details of defense measures (Steps 1 to 6) for facilities constituting national highways and expressways (e.g., bridges, tunnels) in the United States. A number of the points raised also apply to Japan, such as the fact that political decisions are based on comprehensive systematized assessment methods.

Step 1: Critical Asset Identification

・ Creation of a comprehensive list of critical assets (e.g., bridges, tunnels)
・ Systematization of critical asset factors and establishment of value depending on the importance of each factor

Step 2: Vulnerability Assessment

・ Systematization and assessment of the vulnerability factors of assets

Step 3: Consequence Assessment

・ Classification based on the critical asset and vulnerability factors of each asset
・ Consideration for the consequences of attacks on the riskiest assets (using the outcomes of Steps 1 and 2)

3. OBJECTIVE

In Japan, road project assessment has conventionally been based on cost/benefit analysis, which involves evaluating the related costs against the extent of three potential benefits (reduction of driving time, driving costs and traffic accidents) calculated using statistics on motor traffic volumes and other variables. However, as this approach is not necessarily adequate for evaluating the disaster mitigation functionality of roads, the Ministry of Land, Infrastructure, Transport and Tourism developed a new road assessment method.

The purposes of this study were to review past investigations of methods for assessing the disaster mitigation functionality of road networks (including the AASHTO Guidelines), to clarify the applicability of the new assessment method developed in Japan, and to identify related problems.

4. PROPOSAL OF THE NEW ASSESSMENT METHOD

Based on a review of past studies, the following two points were considered essential in the formation of new assessment indices:

(1) Applicability to assessment of individual links *and* the entire network

The method must be suitable not only for assessing the disaster mitigation functionality of the entire network but also for assessing individual links in consideration of its use in evaluating individual road project sections.

(2) Ease of practical application

For application to actual road assessment, the method should be as easy as possible for local development bureaus and other organizations to apply based on existing data (e.g., DRM, road traffic census results). Accordingly, simple hazard level setting based on road condition data (showing considerations such as whether sections have been improved) available from road traffic census results must also be possible.

In consideration of these points, *A Method for Assessing the Disaster Mitigation Functionality of Roads* (provisional draft) addresses I) evaluation concerning improvement of disaster mitigation effects between major cities/bases (Model I), and II) evaluation concerning disaster mitigation for the entire network (Model II).

(1) Model I: qualitative assessment of disaster resistance and multiplicity

Due to isolation or the need to take large detours when a disaster happens, major local cities may have difficulty in performing rescue activities and transporting emergency materials over a wide area. Accordingly, Model I evaluates the extent to which isolation and detours are eliminated by road (link) improvements depending on the importance of the cities to be linked.

In this model, the assessment of intercity links is based on qualitative indices from the viewpoints of disaster resistance and multiplicity as described below.

Disaster resistance: Main routes (i.e., those providing the shortest travel time or distance between certain cities) with no sections that may become impassable in the event of a disaster are assessed as disaster-resistant. Sections that may become impassable include those where tsunami damage, landslides caused by earthquakes or local downpours, avalanches, etc. may occur.

Multiplicity: Disaster-resistant routes with a detour ratio of no more than 1.5 times the distance of the route itself are assessed as having multiplicity. For the detour ratio, the smaller of the time/distance values is used.

From these two viewpoints, each intercity link is rated A (highest), B, C or D (lowest) in terms of disaster resistance and multiplicity, and road improvement is started from those rated D.

(2) Model II: quantitative assessment of travel times

It may take longer or become impossible to reach the nearest prefectural capital, highway interchange or adjacent municipality from a local municipal office due to isolation or the need for detours in the event of a disaster. Accordingly, Model II quantitatively measures the degree of improvement in disaster mitigation over the entire network based on the degree of travel time reduction brought about by road (link) improvement.

In this model, the current travel time t_j for movement from a municipal office j to the nearest prefectural capital or the backbone highway and adjacent municipality is calculated, and the normal travel time without link improvement T^i_{01} is defined as follows:

$$T^i_{0_1} = \sum_j t_j \delta_j \qquad (1)$$

δj = 1 if the route from *j* passes through *i*, and 0 if it does not.

Similarly, assuming road closure due to the possibility of tsunami damage, rock falls, landslides or avalanches, and the presence of roads with non-seismically reinforced bridges, the degree of weakness α of each network is found as shown below, where T^i_{02} and T^i_w are the travel time in the event of a disaster in cases with and without improvement of Link *i*, respectively. In other words, α^i indicates the travel time increase in disaster conditions over that in regular driving.

(With improvement)

$$\alpha^i_w = \frac{T^i_w}{T^i_{0_1}} \qquad (2)$$

(Without improvement)

$$\alpha_0^i = \frac{T_{0_2}^i}{T_{0_1}^i} \tag{3}$$

Priority determined in descending order of α_0^i

Using these two values, the degree of improvement in the network *K* is defined as follows:

$$K^i = \frac{\alpha_0^i}{\alpha_w^i} \tag{4}$$

Priority determined in descending order of K^i

5. EXAMPLES OF APPLICATION TO ROAD PROJECT ASSESSMENT IN THE AREA OF THE GREAT EAST JAPAN EARTHQUAKE

The indices were examined with focus on realism and speed for the Tohoku area stricken by the Great East Japan Earthquake of March 2011. In September 2011, six months after the disaster, assessment based on the results of analysis conducted using the two models described in the previous section was reviewed by the Road Subcommittee of the Panel on Infrastructure Development for the adoption of the project for the construction of the Sanriku Coastal Road and other new initiatives in order to contribute to the recovery/restoration of stricken areas, and approximately 1 trillion yen in roads over a 10-year period was approved. This section summarizes examples involving the application of the two indices.

1) Realistic hazard level setting

In the future, it will be necessary to consider more realistic setting of hazard levels (e.g., what kinds of roads are expected to be closed in the event of a disaster) based on experience gained from the Great East Japan Earthquake and other disasters. The example here involves an area that actually sustained tsunami-related damage in relation to the Great East Japan Earthquake.

2) Disaster mitigation effect represented as links on a network

- Disaster mitigation between major cities/bases

Model I was used for the assessment. Figure 1 shows the assessment values seen before road improvement in some of the analysis target regions, and indicates many Rank-D links (exhibiting neither disaster resistance nor multiplicity). Next, the post-improvement values were calculated to determine how the ranks had changed. Table 1 shows a comparison of ranks for the Ofunato-Kesennuma section, and indicates a change from D to B. Road improvement was considered effective for such sections where the rank improved.

- Disaster mitigation for the entire network

Model II was used for the assessment. Table 2 shows the travel time difference between driving in normal conditions and in the event of a disaster (weakness level) and the degree of improvement in travel from municipalities around the link to the prefectural capital (Morioka) or adjacent municipalities as found from model calculation for three sections in the target regions. The table shows that the improvement effect was high for all three sections. The changes in the degree of improvement in the Karakuwakuta-Rikuzentakada and Utazu-Motoyoshi sections are especially significant.

	Disaster resistance	Multiplicity
A	Yes	Yes
B	Yes	–
C	No	Yes
D	No	No

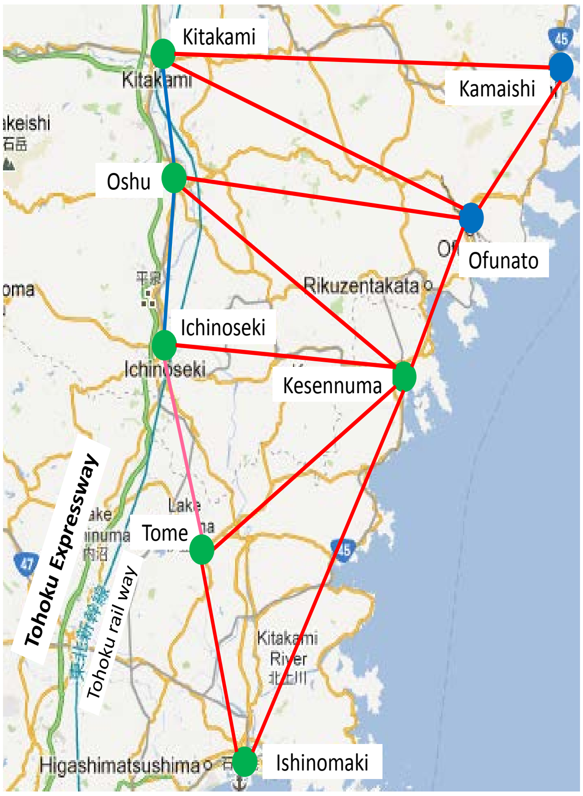


Fig. 1 Image of links between major bases

Table 1 Change in assessment value before and after road improvement

Current status	→	(Target) after improvement	Assessment:
D	→	B	very good

Table 2 Travel time difference and degree of improvement

Section	Weakness (before improvement)	Weakness (after improvement)	Degree of improvement
Yoshihama - Kamaishi	The travel time was two to three times the normal	The travel time was 0.7 times the normal	The travel time was reduced to 0.3 times by improvement
Karakuwakita - Rikuzentakada	The link sustained tsunami-related damage and became impassable (∞)	The travel time was 0.8 times the normal	The link became passable after improvement (∞)
Utazu - Motoyoshi	The link sustained tsunami-related damage and became impassable (∞)	The travel time was 4.5 times the normal	The link became passable after improvement (∞)

6. NATIONWIDE APPLICATION

Japan's Ministry of Land, Infrastructure, Transport and Tourism applied Models I and II to the Tohoku, Chubu, Kinki and Shikoku regions to assess the disaster mitigation functionality of road networks. The hazard level here was set based on tsunami hazard maps created by individual municipalities, and the analysis results are described below.

(1) Component ratios of assessment ranks for different regions (Model I) (Fig. 3)

Rank-A links (exhibiting both disaster resistance and multiplicity) accounted for 59% of the total in Chubu and approximately 30% in Tohoku and Shikoku. Rank-B links (exhibiting disaster resistance only) accounted for approximately 30% of the total in Tohoku and Shikoku and 10% in Chubu and Kinki. Rank-C links (exhibiting multiplicity but not disaster resistance) accounted for 22% of the total in Kinki and 8% in Chubu. Rank-D links (exhibiting neither disaster resistance nor multiplicity) accounted for approximately 30% of the total in Tohoku and Shikoku and 22% in Chubu. The locations of the mentioned regions are shown in Figure 2 below.

Fig. 2 Locations of regions

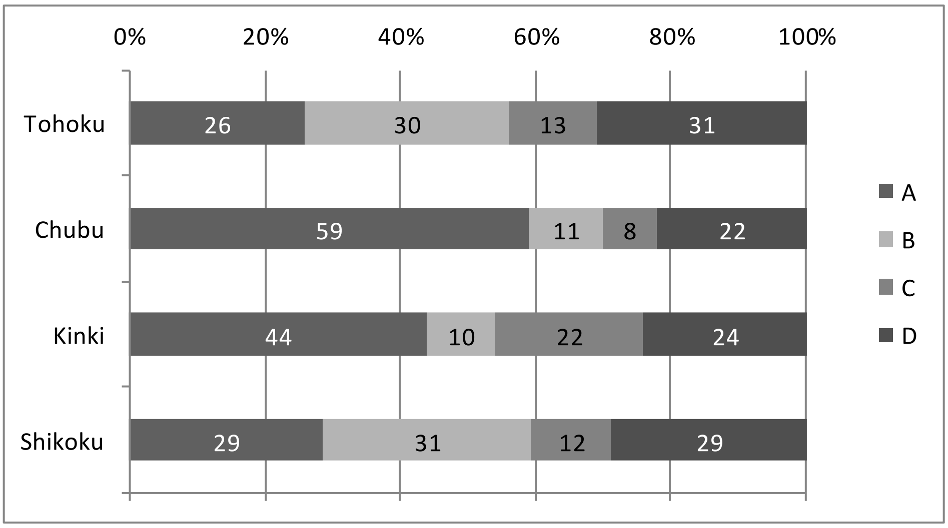


Fig. 3 Assessment rank ratios (Model I)

(2) Component ratios of assessment ranks for different regions (Model II) (Fig. 4)

Weakness levels were indicated by α (travel time in the event of a disaster/travel time in regular driving), and were divided into levels of i) no travel time change in the event of a disaster (α = 1), ii) the need for detours (α > 1), and iii) isolation (α = ∞). The percentage of cases involving isolation was as high as 43%, and was 14 to 23% in other regions with no significant difference.

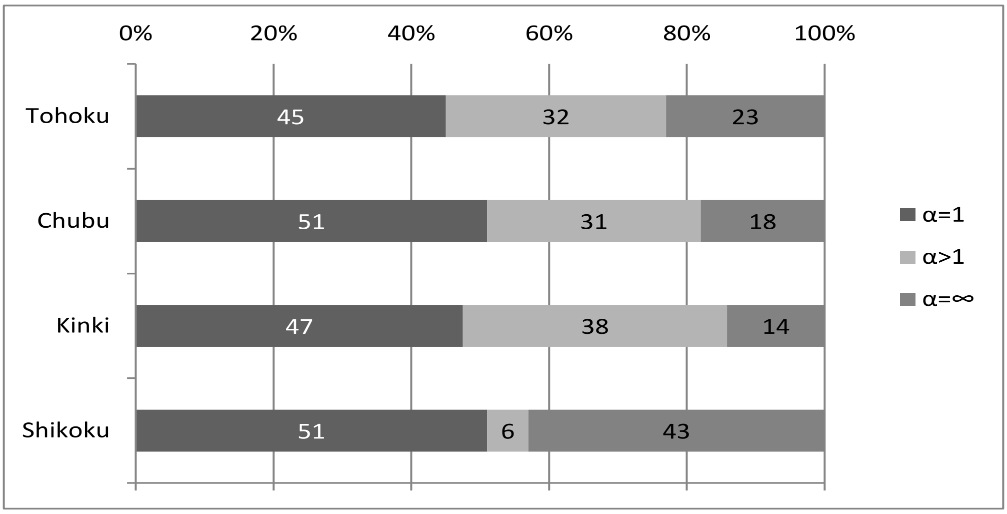
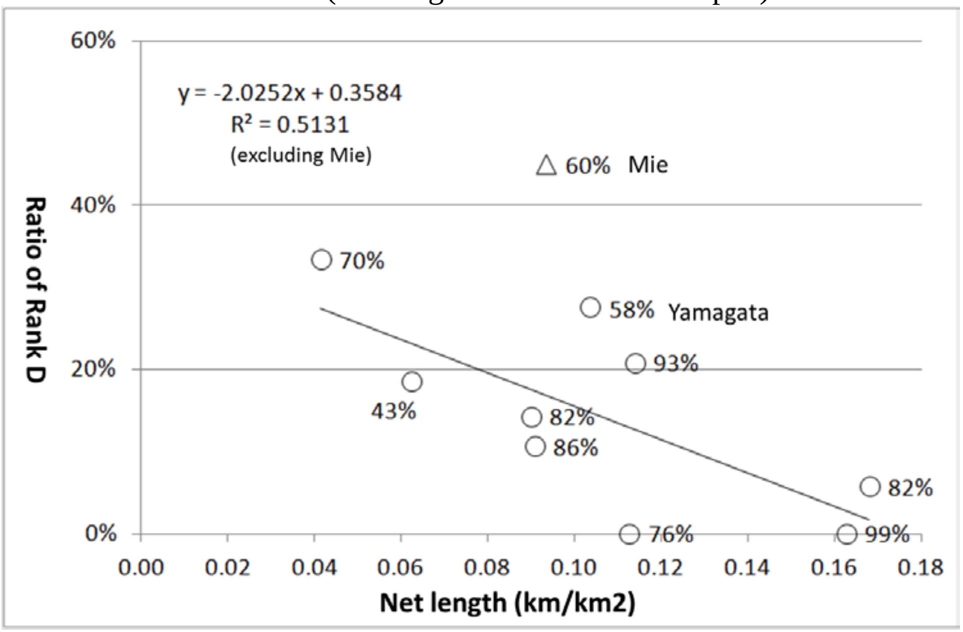
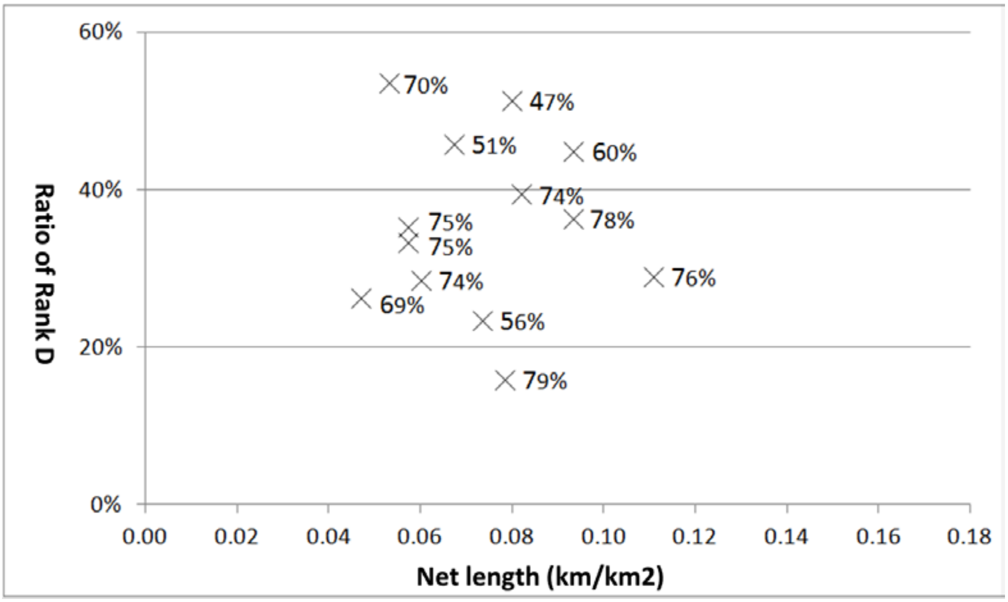


Fig. 4 Assessment rank ratios (Model II)

(3) Ratio of Rank-D roads (Model I) (Figs. 5 and 6)
In all prefectures with a habitable area ratio (habitable area/administrative area) higher than the national average (Group X) except for Mie, the ratio of Rank D tended to decrease for regions with greater net lengths (km) of national roads under the direct control of the national government or roads with a higher rank per km^2. While no correlation with the net value was seen for prefectures with a habitable area ratio lower than the national average (Group Y), the average ratio for Rank D was 35% (17% higher than that of Group X).



* The values in the figure indicate the ratios for arterial high-standard highways.
Fig. 5 Ratio of Rank D and net length (Group X)



* The values in the figure indicate ratios for arterial high-standard highways.

Fig. 6 Ratio of Rank D and net length (Group Y)

(4) Discussion

Based on the above results, the following discussion was made concerning methods for the evaluation of disaster mitigation functionality in road projects.

a) Assessment rank ratios for individual regions

Many links in areas where tsunami damage was expected in the event of a large earthquake (e.g., Tokai, Tonankai) were ranked D, indicating that networks lacking disaster resistance and multiplicity are seen in such regions. Conversely, many links were ranked A in urban areas of Chubu and Kinki, which host the Daiichi Tokai Expressway and other arterial high-standard highways and networks characterized by disaster resistance and multiplicity. The results obtained from Models I and II also showed that Shikoku had a high number of roads vulnerable to disasters and areas at high risk of isolation.

b) Ratio of Rank-D roads

In Group X, a negative correlation was found between the net length (km) of national roads under the direct control of the national government and the ratio of Rank-D roads. This was probably because the formation of homogenous links reduces the number of areas expected to become isolated in the event of a disaster in prefectures with extensive flat terrain, and it was possible to determine the disaster resistance and multiplicity of road networks from the results of model-based calculation. However, the ratio of Rank-D roads was high in Mie and Yamagata due to the existence of advance traffic regulations and the presence of expected tsunami inundation areas. In Group Y, the ratio of Rank-D roads was higher than that of Group X, although no correlation was found between the net length of roads mentioned above and Rank D. This was probably because networks lacking disaster resistance and multiplicity are found in prefectures with extensive mountainous terrain.

7. CONCLUSION

The draft outlined by Japan ’s Ministry of Land, Infrastructure, Transport and Tourism in the summer of 2011 is provisional, and improvements, both in theory and practice should still be brought forth.

The findings of this study can be summarized as follows:

- Based on a review of past studies on methods for assessing the disaster mitigation functionality of traffic networks and examination of their advantages and disadvantages, requirements for practical assessment techniques were summarized and a new method was proposed.
- The proposed method was applied to road project assessment in the area stricken by the Great East Japan Earthquake, and the results were used in assessment for the adoption of the project for the construction of the Sanriku- Coastal Road and other new initiatives to contribute to restoration/recovery in the affected region. In this connection, approximately 1 trillion yen in roads over a 10-year period
- The proposed method was applied to the Tohoku, Chubu, Kinki and Shikoku regions for consideration of possible responses to the Tokai and Tonankai earthquakes expected to hit Japan in the future. This approach supported assessment for the disaster mitigation functionality of road networks.

Two key points for restoration from a major earthquake were identified. One was the importance of ongoing efforts to shift the population and various facilities to areas at lower risk of disasters from a mid-to-long-term viewpoint, and the other was the importance of establishing a vision for the status of regional industries 20 years from now. The shift of residential areas characterized by significant personal assets is expected to accelerate if national and local government bodies propose skeletal roads that will affect future regional structures.

Japan now has two new indices that differ from the cost/benefit analysis (B/C) assessment index used around the world. As discussed by the Panel on Infrastructure Development, it is important to decide how to combine these indices in road project assessment. The authors intend to conduct detailed examination to form indices unique to disaster-prone Japan, and will consider the use of these indices in order to eliminate the construction of unnecessary roads.

REFERENCES

Taylor, M. A. P., Sekhar, S. V. C. and D'Este, G. M.(2006) Application of accessibility-based methods for vulnerability analysis of strategic road networks, *Network & Spatial Economics*, Vol. 6, 267 – 291.

D'Este, G. M. and Taylor, M. A. P.(2001) Modeling network vulnerability at the level of the national strategic transport network, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 4, No. 2, 1 – 14.

D'Este, G. M. and Taylor, M. A. P.(2003) Network vulnerability: an approach to reliability analysis at the level of national strategic transport networks, *Bell, M. G. H. & Iida, Y. eds., The Network Reliability of Transport, Pergamon, Oxford, U.K.*, 23 – 44.

Berdica, K.(2002) An introduction to road vulnerability: what has been done, is done and should be done, *Transport Policy*, vol. 9, 117 – 127.

Jenelius, E., Petersen, T. and Mattsson, L-G.(2006) Importance and exposure in road network vulnerability analysis, *Transportation Research*, vol. 40A, 537 – 560.

The American Association of State Highway and Transportation Officials' Security Task Force (2002) A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection,http://security.transportation.org/sites/security/docs/guide VA_FinalReport.pdf