THE HIGHWAY MANAGEMENT SYSTEM FOR A HIGHWAY DISASTER PREVENTION PLANNING

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Abstract: This paper presents a prototype of a computer aided highway management system that supports an investment policy decision-making for highway disaster prevention planning. The data are collected from a previous inspection project for highway disaster prevention in Japan. In the project, the safety level for the types of disasters given with its improvement cost to increase the safety level at each inspection point on a highway network were measured. Using the data, I developed a calculation method to estimate total improvement cost for any route to achieve a cost efficient safety level. Furthermore, the achievement safety level at each link can be changed with an input parameter in the system. If a link is closed and has an alternate route, the achievement safety level at the link can be set lower than one that has no alternate route. Using this system, it is possible now to decrease the total investment cost when planning or upgrading any highway network.

Key Words: highway management system, highway disaster prevention planning

1. INTRODUCTION

In many Eastern Asia countries, natural disasters, such as a landslide and a flood of rocks and mud, often take place caused by monsoon rainfall. A highway network suffers damages and sometimes it is closed. Connectivity of a highway network is an important factor assuring mobility for an arrival at a destination. It is necessary to decide an investment policy for highway network planning which includes disasters that may take place.

In recent years, the importance of the infrastructure maintenance is on the increase. Many kinds of Highway Management Systems have been presented, pavement management system, bridge management system, maintenance system and so forth. These systems take important roles for decision-making of an investment policy. They have the advantages of data integration, coordination of projects or the like, which are very visible to the public.

This paper presents a prototype of a highway management system to support a decision-making of an investment policy for highway disaster prevention planning. This system will integrate into a Geographic Information System that includes a database of the inspection data on a highway network and a calculation system for an estimation of a highway improvement plan. An estimation method of a highway improvement plan for disaster prevention using the inspection data has been proposed already. This paper focuses on the development of an integrated calculation system to support a heuristic process for investment policy decision-making.

The data are collected from a previous inspection project for highway disaster prevention in Japan. In the project, the safety level for the types of disasters given and the improvement cost to increase the safety level at each inspection point on a highway network were measured. The safety level against a highway disaster is estimated as a score that intends to indicate a possibility of an occurrence of the highway disaster. Using the data, the author was able to develop a calculation method to estimate the total improvement cost at any route to achieve a cost efficient safety level for highway disaster prevention planning. Furthermore, the achievement safety level at each link can be changed with an input parameter in the system. If a link is closed and has an alternate route, the achievement safety level at the link can be set lower than one that has no alternate route. It is possible for us to consider decreasing the total investment cost on the highway network through an interactive process by use of this system. Results of a case study on the emergency highway network in Yamaguchi prefecture, Japan, are shown and discussed in this paper.

2. THE HIGHWAY MANAGEMENT FOR DISASTER PREVENTION

Figure 1 shows the system structure of a prototype of a highway management system developed in this study. This system includes a database, a calculation system and a visual interface.

The database consists of the inspection data for disaster prevention and the travel time data on a highway network. The inspection data are used to estimate the relationship between the achievement safety level and the improvement cost to satisfy the safety level. The highway network travel time data are used to calculate average travel time on a route between a pair of city nodes. The data structure will be described more in depth in chapter 3.

Using this database and the other input parameters, such as a type of disaster, pairs of city node numbers, achievement safety level in each link and alternate route travel time, we can calculate the route improvement cost under the conditions. We can also simulate and compare outcomes through this interactive process. The calculation process will be described in depth in chapter 4.

The visual interface takes important role in the calculation process. We can confirm which link (or route) is estimated on the display.

3. THE SOURCE DATA AND THE DATABASE

3.1 The Source Data

In an investment policy decision-making for disaster prevention on a highway network, the data that indicates the relationship between the safety level and the improvement cost at each

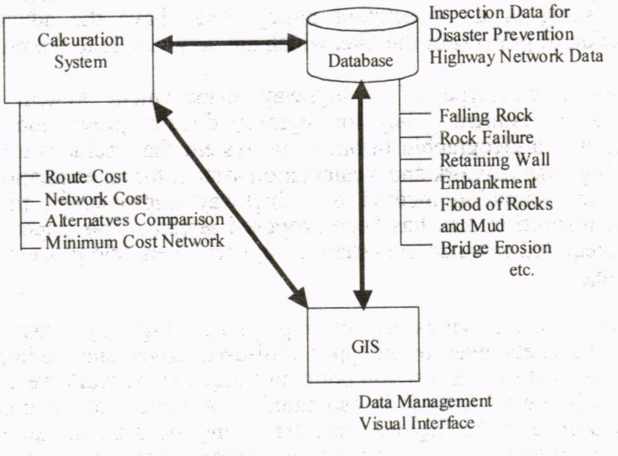

Figure1. System Structure

link becomes needed.

Japanese Ministry of Land, Infrastructure and Transport carried out a total inspection project for highway disaster prevention countrywide in 1996. The projects aim was to collect data that indicated a possibility where an occurrence would likely happen on a highway network. The project included 10 types of highway disasters, that are 'falling rock', 'rock failure', 'retaining wall', 'embankment', 'flood of rocks and mud', 'bridge erosion', 'landslide', 'snowslide', 'snowstorm' and the other. Inspection points were chosen and also score and improvement cost at each point was estimated based on prespecified criterion that was decided by specialist in each specific field of disaster. The highest score was rated by the type of disaster. For example, 'Rock failure' was 126, 'retaining wall' was 195, 'bridge erosion ' was 150 and the other disasters were 100.

Estimated 'score' that indicates a possibility of an occurrence of disaster and the improvement cost that is necessary to reinforce it are used in this paper. The data are collected at each inspection point. The calculation system presenting here intends to estimate an investment policy plan from the viewpoint of route or network connectivity.

3.2 The Database

The database is made from the original source data. The original data are summarized in a table based on each inspection point number. Therefore the original data needs to be restructured for each link for its network calculation. Figure 2 shows an example of inspection points at a link on a highway network. Table 1 summarizes estimated score and improvement cost at each inspection point on the link.

The achievement safety level at each link is called 'FC_{max}' in this paper. 'FC_{max}' is defined that there is no inspection point of which estimated score is beyond 'FC_{max}' within the link. The improvement cost to achieve 'FC_{max}' for a link is called 'link improvement cost'. It is defined that the summation of improvement cost for each inspection point of which estimated score is beyond 'FC_{max}' within the link.

Table 2 shows calculation results of 'link improvement cost' from the data shown in Figure 2 and Table 1. For example, in the case of FC_{max}=60, 'link improvement cost' is calculated 1800, because improvements are necessary at the inspection points C and D to achieve FC_{max}=60. After the improvements, there is no inspection point of which estimated score is beyond FC_{max} within the link. Table 3 shows an example of the 'link improvement cost' data calculated in each type of disaster in the same manner. An order of improvement cost is not recorded in this manuscript.

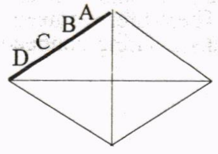

Figure 2. Inspection Points at a Link on a Highway Network

Table1. Estimated Score and Improvement Cost at Each Inspection Point

Inspection Point	Estimated Score	Improvement cost (yen)
A	15	100
B	40	500
C	70	800
D	90	1000

Table 2. Link Improvement Cost to Achieve the Safety Level 'FC_{max}'

FCmax	10	20	30	40	50	60	70	80	90	100
Link Improvement Cost (yen)	2400	2300	2300	1800	1800	1800	1000	1000	0	0

Table 3. Example of the Data of Link Improvement Cost (_yen)

FCmax	Disaster1	Disaster2	Disaster3	Disaster4	Disaster5	Disaster6
10	125.6	0	17.7	48.3	0	0
20	125.6	0	0.1	48.3	0	0
30	125.6	0	0.1	48.3	0	0
40	125.6	0	0.1	48.3	0	0
50	125.3	0	0.1	10.5	0	0
60	107.7	0	0	10.5	0	0
70	78.2	0	0	10.5	0	0
80	0	0	0	0	0	0
90	0	0	0	0	0	0
100	0	0	0	0	0	0

Disaster1:Falling rock Disaster2:Rock failure Disaster3:Retaining wall
Disaster4:Embankment Disaster5:Flood rocks and mud Disaster6:Bridge erosion

4. THE CALCULATION SYSTEM AND CALCULATION RESULTS

4.1 Distribution of Estimated Score and Improvement Cost for Each Link

Spatial distributions of estimated score and link improvement cost on the emergency highway network in Yamaguchi prefecture, Japan, are shown. The emergency highway network is designated by the prefectural government to assure connectivity between cities for disaster prevention.

Figure 3 shows distributions of maximum estimated score within each link. We can confirm that the possibilities of highway disasters are widely located on the highway network and the distributions of estimated scores depend on the type of disaster.

Figure 4 shows distributions of improvement cost for each link in the case of the achievement safety level of the link (FC_{max}) equal to 10. After the improvement, there is no inspection point of which estimated score is beyond FC_{max}=10 within a link. If a link includes many inspection points and their estimated scores are comparatively high, the link improvement cost increases. In Figure 4, the graphs of 'falling rock' and 'rock failure' are reduced to a scale of one-tenth of the others.

The link improvement cost and estimated score differ with each link on the emergency highway network as shown in Figure 3 and Figure 4. If the all links on the network are improved, the total improvement cost becomes expensive. Therefore, we need to decide the cost efficient investment plan in which the improvement links assuring connectivity between cites are selected.

4.2 Route Improvement Cost

Route improvement cost is calculated as a summation of each link improvement cost that is included in the route. Table 4 shows an example of calculation results of the route improvement costs in the case of 'rock failure' between Hagi and Yamaguchi city. FC_{max} is changed from 10 to 100 in 10 intervals. The calculation results of some routes between the pair of cities are summarized. According to FC_{max} becomes small, that means the achievement safety level for disaster prevention on the route becomes high, route improvement cost increases. We can understand the relationship between the achievement safety level of disaster prevention and its route improvement cost. Also we can compare the improvement route plans under a budget constraint.

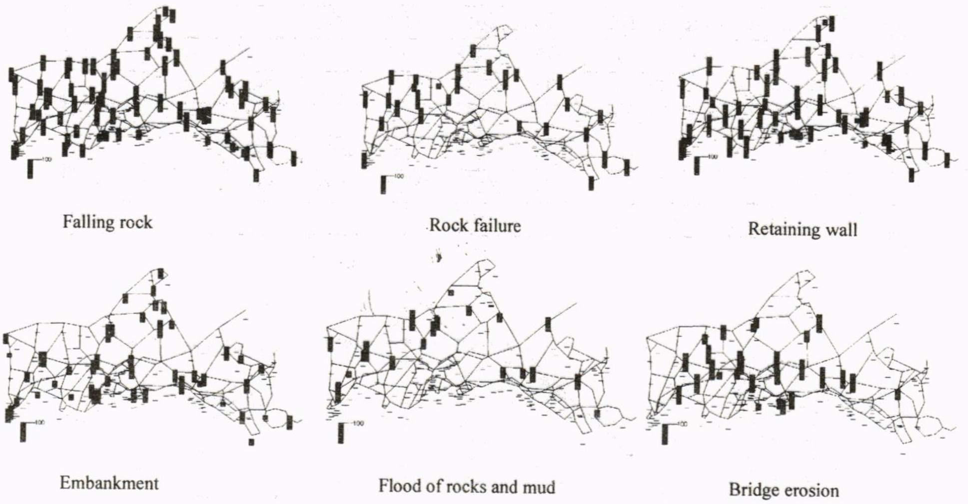

Figure 3. Distribution of Maximum Estimated Score within a Link on the Emergency Highway Network

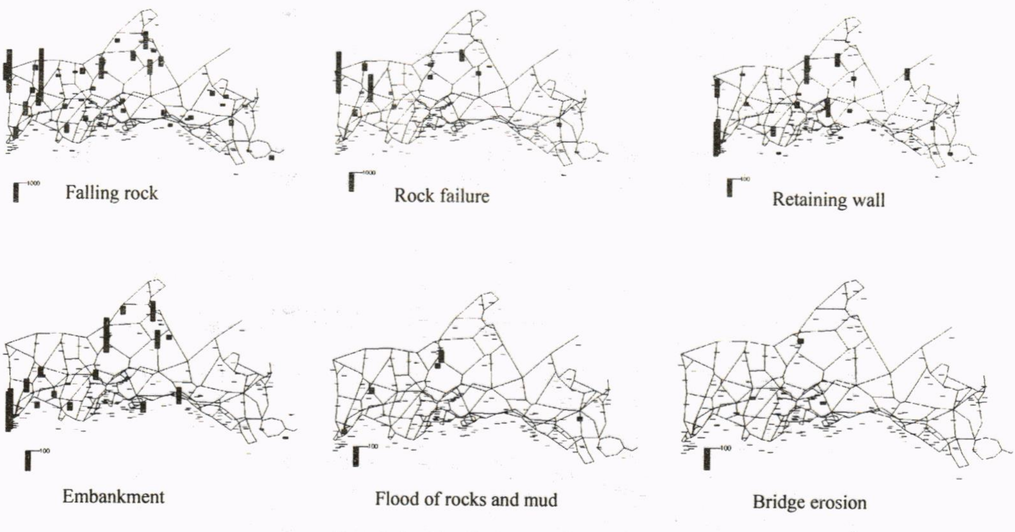

Figure 4. Distribution of Link Improvement Cost (_yen) on the Emergency Highway Network (FC_{max}=10)

Figure 5 shows the relationship between FC_{max} and route improvement cost in the case of 'rock failure'. The calculation results are about the shortest routes between 6 pairs of cities, Yamaguchi-Hagi, Yamaguchi-Houfu, Shimonoseki-Nagato, Ube-Houfu, Onoda-Mine and Mine-Nagato. The route improvement cost that becomes needed to satisfy the achievement safety level is calculated in each shortest route. If the achievement safety level is given, we can understand the route improvement cost satisfying the level. Also if a budget constraint is given, we can understand the highest achievement safety level of the route satisfying the constraint.

Table 4. Route Improvement Cost between Hagi and Yamaguchi(_yen) ('Rock failure')

Route number	Route Improvement Cost (FCmax=10,20,30,40,50,60,70,80,90,100)									
	10	20	30	40	50	60	70	80	90	100
1	396.4	396.4	396.4	396.4	396.4	301.4	206.4	84.4	60.0	0.0
2	189.2	189.2	189.2	189.2	189.2	94.2	74.2	72.2	60.0	0.0
3	985.9	985.9	972.4	972.4	968.4	571.4	406.4	378.3	133.2	90.5
4	767.5	767.5	754.0	754.0	750.0	353.0	188.0	188.0	0.0	0.0
5	14.5	14.5	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

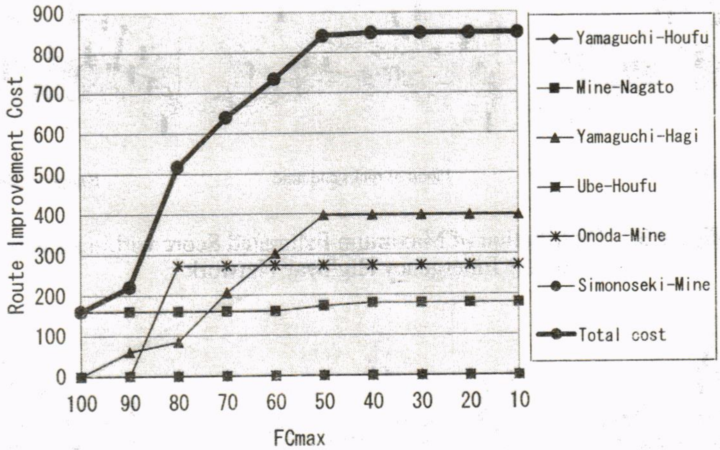

Figure 5. Relationship between FC_{max} and Route Improvement Cost (_yen) ('Rock failure', The shortest travel time route)

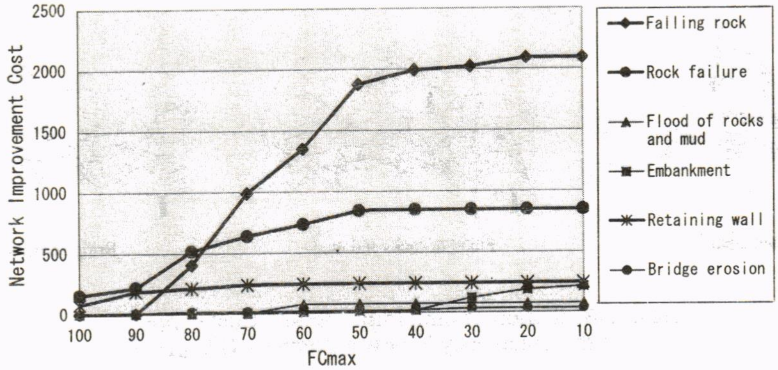

Figure 6. Relationship between FC_{max} and Network Improvement Cost (_yen) (The shortest travel time routes between 6 pairs of cities)

Figure 6 shows the relationship between FC_{max} and network improvement cost for each type of disaster. They are the summation of the improvement costs of the shortest routes between 6 pairs of cities as shown in Figure 5. When the improvement routes are given, the achievement safety level and its network improvement cost are clarified under a budget constraint.

4.3 Route Improvement Cost considering the Existence of an Alternate Route

In a investment policy decision-making for highway disaster prevention planning, the priority of an improvement for each link needs to be considered from the viewpoint of assuring connectivity between cities. It is an important factor when making a decision on an improvement policy that a link, which is closed caused by highway disaster, has an alternate route or not.

We can consider that the achievement safety level of a link and the improvement cost differ depends on the existence of an alternate route. If a link has no alternate route, we need to improve the link to assure connectivity. The achievement safety level of a link, which has no alternate route, should be higher than the safety level of a link, which has an alternate route.

Using the calculation system developed in this paper, the route improvement cost can be calculated considering the existence of an alternate route at each link. The achievement safety level is able to set as an input parameter in both cases that a link on the route has an alternate route or not.

The notations of input parameters are as follows.

- m : The restriction of an alternate route travel time. The ratio of a primary route travel time to an alternate route travel time.
- L_n : The link number on the primary route
- T_{Ln} : The route travel time of the alternate route when the L_n^th^ link on a primary route is disconnected.
- FC_{max} : Achievement safety level for disaster prevention of the primary route
- FC_{max1} : Achievement safety level for disaster prevention of the link which has an alternate route.
- FC_{max2} : Achievement safety level for disaster prevention of the link which has no alternate route.
- C_{route} ; Improvement cost on the primary route considering the existence of an alternate route in each link. (If a link on the primary route has an alternate route, achievement safety level of the link is FC_{max1}. If a link on the primary route has no alternate route, achievement safety level of the link is FC_{max2}.)

Table 5 shows the calculation process and results of route improvement cost between Mine city and Nagato city. In this case, FC_{max1} is 60 and FC_{max2} is 10. The primary route, that is the shortest route in this case study, consists of 3 links. If m=2.0, an alternate route is considered for the calculation at the 3rd link only. However, if m=3.0, alternate routes are considered at all 3 links. As a result, the calculated value of the route improvement cost is 179.5 in the case of m=2.0 and it becomes 160.0 in the case of m=3.0.We can confirm that route improvement cost can be decreased when the existence of an alternate is considered.

Table 6 shows the calculation results of the improvement cost of the primary route between two pairs of city nodes. In this case, FC_{max1} is 60 and FC_{max2} is 30. The value of m is changed as an input parameter. Improvement costs of the primary route are same between Yamaguchi city and Hagi city, because there is an alternate route for each link on the primary route in all cases of m=1.5, 2.0, 2.5 and 3.0. Between Mine city and Nagato City, route improvement cost are different depends on m values as shown in Table 5.

Table 7 shows the calculation results in the case of m=3.0. FC_{max1} and FC_{max2} are changed as input parameters. The route improvement costs are calculated based on each combination of FC_{max} values. In the case between Yamaguchi city and Hagi city, when FC_{max2} decreases from 80 to 10, the route improvement cost doesn't increase. However, when FC_{max1} decreases from 80 to 10, the cost increases from 84.4 to 396.4. We can confirm that the route improvement cost depends on the consideration of the existence of an alternate route. Also we can choose the cost efficient plan through this heuristic process.

Table 5. Calculation Process of Route Improvement Cost considering the Existence of an Alternate Route between Mine and Nagato city (_yen)
[Rock failure, FC_{max1}=60, FC_{max2}=10]

L_n	T_{Ln} (min.)		Link Cost (_yen)	
	m=2.0	m=3.0	FC_{max1}=60	FC_{max2}=10
1	—	64	0.0[c]	12.0[a]
2	—	60	0.0[d]	7.5[b]
3	46	46	160.0[e]	160.0
	m=2.0 → C_{route} =a+b+e=179.5 m=3.0 → C_{route} =c+d+e=160.0			

[Primary route travel time=29(min.)]

Table 6. Route Improvement Cost considering the Existence of an Alternate Route (_yen)
[Rock failure, FC_{max1}=60, FC_{max2}=30]

	m			
	1.5	2.0	2.5	3.0
Yamaguchi-Hagi	301.4	301.4	301.4	301.4
Mine-Nagato	179.5	179.5	160.0	160.0

Table 7. Route Improvement Cost considering the Link Achievement Safety Level (_yen)
[Rock failure, m=3.0]

	FC_{max1}, FC_{max2}			
	10, 10	80, 80	80, 10	60, 30
Yamaguchi-Hagi	396.4	84.4	84.4	301.4
Mine-Nagato	179.5	160.0	160.0	160.0

5. CONCLUSIONS

The prototype of a highway management system for highway disaster prevention planning has been developed. The advantages of this system are as follows. The database is made from the inspection project countrywide in 1996. Therefore we can expand our analysis all covering Japan. Achievement safety level for disaster prevention and its cost can be simulated in each link considering the existence of an alternate route. It is possible for us to decrease total investment cost on a highway network. We can also investigate the relationship between achievement safety level and its cost under a budget constraint through the heuristic process. The developments of a calculation system to lead an optimum solution under a budget constraint and integrate to highway management system, such as highway maintenance system, traffic control system and so forth, are the subjects for a future study.

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