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DISASTER IMPACT ANALYSIS OF LIMITED ACCESS THROUGH TRAFFIC NETWORK MODEL: THE CASE OF MT. USU ERUPTION

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Abstract: Employing a Traffic Network Model to quantify road users' cost on regional road network during a disaster period, this study analyzes the effect of limited roadway accessibility caused by the 2000 Eruption of Mt. Usu. This model features estimating "travel-time cost" due to restricted roadways and "opportunity cost" for trip cancellation at the same time. Especially, the model simulates a change in travel time and cost to road users who keep their planned trips, and identifies the proportion of road users, who cancel their trips and taking alternative actions, and their opportunity costs. With this analyzing features, the study compares the actual traffic volume based on traffic census data with the traffic volume estimated by the model developed here, showing the limited road network for the eruption period. This empirical analysis then shows the estimated total loss caused by this eruption.

Key Words: Traffic Network Model, Road Users' Cost, Trip Cancellation

1. INTRODUCTION

Located on the northernmost island of Japan, Hokkaido, Mt. Usu erupted in 2000, causing serious damages to not only the neighboring communities but also the socioeconomic activity through the entire Hokkaido area because of the disconnected main transportation routes linking to Japan's main island. As for the road network, the eruption cut off traffic on the national expressway and highway running through the Mt. Usu area, and it also led to access control along some other roadways. This restricted flow condition forced road users to make substantial detour, which resulted in a great loss due to increasing travel time. It might also make some road users to cancel their trips because of decreased travel reliability.

In this study, we attempt to calculate the impact of limited roadway accessibility caused by the 2000 Eruption of Mt. Usu by employing the "Traffic Network Model" designed and developed to quantify road users' cost subject to a regional road network during disaster (Uchida). A key distinguish feature of the model is to estimate travel-time costs brought about by limited roadways and opportunity costs caused by trip cancellation at the same time,

considering the situation of road users canceling their trips as a result of increasing travel times. Furthermore, in case of road users canceling their trips and taking alternative actions, they could not appropriate all the planned, expected travel times toward the alternatives; otherwise, it would bring about some losses. With showing these losses, the model makes it possible to not only identify the proportion of road users who cancel their trips and their opportunity costs but also simulate a change in travel times and costs of road users who keep their trips.

Showing the region's limited accessibility at the time of the 200 Eruption of Mt. Usu, this study compares the normal traffic volume based on traffic census data, which has been conducted all over the country in order to recognize the existing traffic conditions, with the assigned traffic volume estimated by the model developed here. The study also calculates the proportion of road users who cancel their trips and the loss in travel-time cost and opportunity cost due to trips cancelled, in addition to the loss in travel time for road users keeping their travel activities.

2. THE 2000 ERUPTION OF MT. USU

Mt. Usu is an active volcano located to the south of Lake Toya in the southwest of Hokkaido, and in late March 2000 Mr. Usu erupted for the first time in 23 years (Ministry of Land, Infrastructure and Transportation. 2001). The 2000 Eruption occurred significant ground deformation with an upheaval of several meters at the western side of the mountain. Besides, several centimeters of volcanic ash was accumulated on the roads (see Figure 2), and the mudflows caused extensive damage to land and civil works including roadways and bridges.

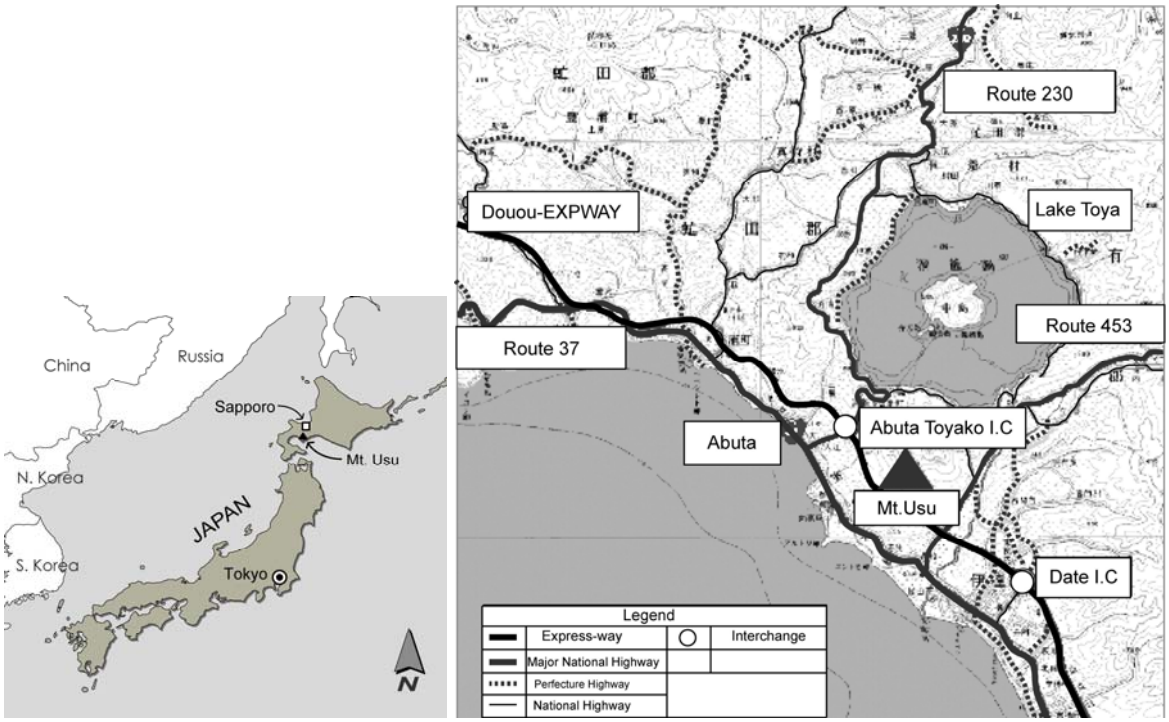

Figure 1. Locational Map of Mt. Usu & Area's Road Network

The damage to civil works amounted to approximately 4.4 billion yen with 59 damaged roadways and bridges (Fire Defense Agency. 2001). Especially, running at the southern foot of Mt. Usu, Douou Expressway and the interurban railway system of JR Muroran Line, which play a vital role as the physical distribution function with linking between Hokkaido and the main land of Japan, seriously damaged from the Eruption. Furthermore, in addition to disrupted traffic on Douou Expressway and Route 230 (National Highway) in the Mt. Use area, it had been taken action to restrict traffic on the widespread road network including Route 37 and 453, and prefecture highways.

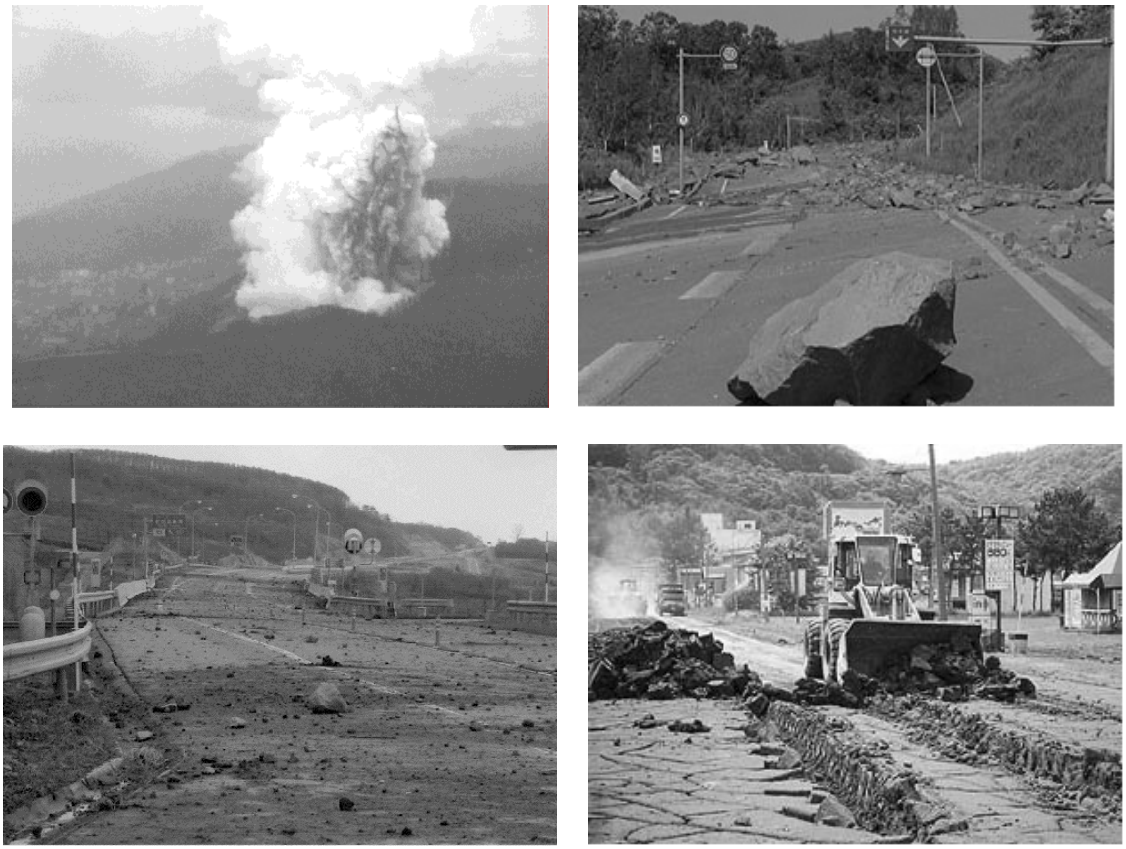

Figure 2. Thick Smoke from Mt. Usu (upper left), Cinders on Roads (upper right), Damaged Roadway (lower left), Removing-Work for Volcanic Ash (lower right)

3. TRAFFIC NETWORK MODEL

Various studies have been conducted on the calculation procedures of economic impacts caused by disrupted traffic on roadways. The most common approach is to calculate the amount of loss with converting increment of road user cost (travel-time cost) measured by extending the fixed demand model to trip distribution into monetary (Ministry of land, Infrastructure and Transportation. 1998., Tamura. 2001). This approach calculates the impacts based on an assumption that all the people take not different travel activities with whether having disrupted traffic on roadways or not. However, for the real situation, there might be travelers who cancel their trips because of its detour level. The traffic network model employed in this study is designed to consider these trip cancellations because of travelers' increased travel times cased by restricting traffic on road network.

3.1. PREREQUISITE FOR MODELIZATION

The Traffic Network Model employed for this study is designed and developed based on the following assumptions.

(a) Travel activity is taken because benefits received from trips, for instance going work or shopping, are higher than travel time costs.

(b) Some road users might cancel their travel activities because of increasing travel time with restricted traffic flow condition caused by disaster. Canceling travel activities leads to losing travel benefits, but at the same time road users could receive other benefits by spending travel-time costs used for going to destinations before disaster for other purposes. However, we assume that these road users could still have some kind of loss, for instance not using their travel time effectively, in case of canceling their planned travel activities.

(c) Deciding of whether road users cancel their trips or not is determined only with the relations between net benefits (travel benefit - travel-time cost) and total travel times, not considering running costs.

(d) Even though alternative travel activity, for instance changing destination, would be taken because of canceling intended travel activity, the alternative is not considered.

(e) After disaster, the damaged roadways might not be recovered, but assuming that traffic is recovered at the normal level. This shows that all road users recognize which roadways are restricted with enough information.

3.2. FORMULARIZATION OF TRAVEL ACTIVITY

In order to formularize travel activities, we first consider road users who would cancel travel activities after disaster. These road users would cancel their travel activity with comparing their travel benefits received by taking travel activities with after-disaster travel time costs. Second consideration is road users who take same travel activities before and after disaster. These road users would take same travel activities with recognizing that their benefits received by taking travel activities are still higher than after-disaster travel-time costs even though travel-time costs for reaching their destinations might be increased.

Considering traffic activities mentioned above, before-disaster travel benefit between origin-destination pair (r, s) is symbolized as B_{rs}^{p} (1) and the equation (2) represents after-disaster travel benefit symbolizing as B_{rs}^{a}. The relation between B_{rs}^{p} and B_{rs}^{a} is shown in (3).

$$B_{rs}^{p}=b_{rs}f_{rs}^{p} - tC_{rs}^{p}f_{rs}^{p}>0 \quad \forall rs \tag{1}$$

$$B_{rs}^{a}=b_{rs}f_{rs}^{a} - tC_{rs}^{a}f_{rs}^{a}+t\gamma C_{rs}^{p}e_{rs}^{a}>0 \quad \forall rs \tag{2}$$

$$B_{rs}^{p} - B_{rs}^{a} \geq 0 \quad \forall rs \tag{3}$$

b_{rs}: Travel benefit received by going from origin r to destination s (yen)
t: Time-value (yen/minute)
C_{rs}^{p}: Before-disaster travel time between r and s (minute)
C_{rs}^{a}: After-disaster travel time between r and s (minute)

f_{rs}^{p}: Before-disaster traffic volume between r and s (vehicle/day)
f_{rs}^{a}: After-disaster traffic volume between r and s (vehicle/day)
e_{rs}^{a}: Traffic volume cancelled their activities between r and s after disaster (vehicle/day)
γ: Cost for travel-time in case of canceling their activities ($0 \le \gamma \le 1.0$)

γ in the equation (2) is a parameter showing the loss in travel-time as mentioned in the assumption (b), and it indicates to reduce travel-time cost in case of canceling travel activities.

The Traffic Network Model employed in this study finds before-disaster travel-time (C_{rs}^{p}) between r and s by employing the BPR function (Japan Society of Civil Engineers. 2003), and the equation is as follow:

$$t_a(x_a) = t_a(0)\left\{1 + \alpha\left(\frac{x_a}{C_a}\right)^{\beta}\right\} \qquad (4),$$

where a is the link between origin r and destination s, $t_a(x_a)$ is the travel time for traffic volume on the link a, $t_a(0)$ is the travel-time for zero-flow on the link a, C_a is the traffic capacity of the link a, x_a is the traffic volume of the link a and α, β are parameters.

Besides, before-disaster traffic volume between origin and destination equals to the sum of after-disaster traffic volume and traffic volume canceling travel activities after disaster. Thus the following relation can be formed.

$$f_{rs}^{p} = f_{rs}^{a} + e_{rs}^{a} \quad \forall rs \qquad (5)$$

Supposing that after-disaster travel activity would be to minimize the square sum of difference between before-disaster and after-disaster benefits, we set the following objective function.

$$\min Z(\mathbf{f}^{a}) = \sum_{rs} (B_{rs}^{p} - B_{rs}^{a})^2 \qquad (6)$$

Furthermore, considering the total travel time between r and s before disaster and after disaster with applying the assumption (c), we define that the equation (7) is formed between each origin-destination pair (r, s). This shows that constraints are ease because road users' motivation going to their destinations is enhanced as the loss in time-value in case of trip cancellation is greater while the value of γ is closed to 0.

$$C_{rs}^{a} f_{rs}^{a} + \gamma\, C_{rs}^{p} e_{rs}^{a} \le C_{rs}^{p} f_{rs}^{p} \qquad (7)$$

The relation among the equation (1), (2) and (5) can be shown in the equation (8), and the equation (6) can be formed in the equation (9).

$$\begin{aligned} B_{rs}^{p} - B_{rs}^{a} &= b_{rs} f_{rs}^{p} - tC_{rs}^{p} f_{rs}^{p} - (b_{rs} f_{rs}^{a} - tC_{rs}^{a} f_{rs}^{a} + t\,\gamma\, C_{rs}^{p} e_{rs}^{a}) \\ &= b_{rs}(f_{rs}^{p} - f_{rs}^{a}) + t(C_{rs}^{a} f_{rs}^{a} + \gamma\, C_{rs}^{p} e_{rs}^{a} - C_{rs}^{p} f_{rs}^{p}) - 2\,\gamma\, tC_{rs}^{p} e_{rs}^{a} \end{aligned} \qquad (8)$$

$$\min Z'(\mathbf{f}^a) = \sum_{rs} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^p - f_{rs}^a)^2 \tag{9}$$

Furthermore, optimization as new constraints recognizing the equation (9) as the objective function and adding all the value between r and s (11) is as follows:

$$\min Z'(\mathbf{f}^a) = \sum_{rs} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^p - f_{rs}^a)^2 \tag{10}$$

$$\sum_{rs} (C_{rs}^a f_{rs}^a + \gamma C_{rs}^p e_{rs}^a - C_{rs}^p f_{rs}^p) \le 0 \tag{11}$$

$$x_a = \sum_{rs} \sum_k f_{rs}^{ak} \delta_{rs}^{a,k} \qquad \forall a \tag{12}$$

$$\sum_k f_{rs}^{ak} = f_{rs}^a \qquad \forall rs \tag{13}$$

$$f_{rs}^a + e_{rs}^a = f_{rs}^p \qquad \forall rs \tag{14}$$

$$e_{rs}^a \ge 0 \qquad \forall rs \tag{15}$$

$$f_{rs}^{ak} \ge 0 \qquad \forall k, rs \tag{16},$$

where $\mathbf{f}^a$ is the variable for the origin-destination traffic volume vector taking travel activity after disaster, f_{rs}^{ak} is the variable for traffic volume on the kth route between the origin-destination pair (r, s) and δ_{rs}^{ak} is the variable for the link a, and these are defined as 1 if included in the kth route between the origin-destination pair (r, s) and 0 if not included in.

Symbolizing λ^* as the Lagrange multiplier's optimal value based on constrain (11), the above problem is shown as follows:

$$\min L(\mathbf{f}^a, \mathbf{e}^a) = \sum_{rs} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^p - f_{rs}^a)^2 + \lambda^* \sum_{rs} (C_{rs}^a f_{rs}^a + \gamma\, C_{rs}^p e_{rs}^a - C_{rs}^p f_{rs}^p) \tag{17}$$

where $\mathbf{e}^a$ is the origin-destination traffic volume vector canceling travel activities after disaster. (17) can be rewritten as:

$$\begin{aligned} \min L'(\mathbf{f}^a, \mathbf{x}) &= \sum_{a \in A} t_a x_a + \sum_{rs} \left\{ -\gamma\, C_{rs}^p f_{rs}^a + \frac{1}{\lambda^*} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^{a\,2} - 2 f_{rs}^p f_{rs}^a) \right\} \\ &= \sum_a \int_0^{x_a} \left\{ t_a(w) + w \frac{dt_a(w)}{dw} \right\} dw - \sum_{rs} \int_0^{f_{rs}^a} \left\{ \gamma\, C_{rs}^p + \frac{2}{\lambda^*} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^p - v) \right\} dv \end{aligned} \tag{18}$$

where $\left\{ t_a(w) + w \frac{dt_a(w)}{dw} \right\}$ is the equation corresponding to the link-cost function, and $\left\{ \gamma\, C_{rs}^p + \frac{2}{\lambda^*} (b_{rs} - 2\gamma t C_{rs}^p)^2 (f_{rs}^p - v) \right\}$ is one corresponding to the inverse demand function.

3.3. FORMULARIZING BENEFITS RECEIVED BY TRAFFIC ACTIVITY

In this Traffic Network Model, it is necessary to find travel benefit (b_{rs}) received by taking travel activities beforehand, and here shows its formulation.

Based on the equation (18), passing through (f_{rs}^{p}, C_{rs}^{p}) when γ=1, the inverse demand curve between each origin-destination intersects with the supply curve at this point before disaster. Maximizing the consumer's surplus, this results in achieving the traffic equilibrium.

This model finds b_{rs} based on the condition that the value multiplied the consumer's surplus by time-value equals to the value deducted travel cost from travel benefit, as shown Figure 3 and the equation (19). It thus determines the value of b_{rs} by finding $\lambda^{*}_{\gamma=1}$ with solving the problem setting γ=1 in the equation (18).

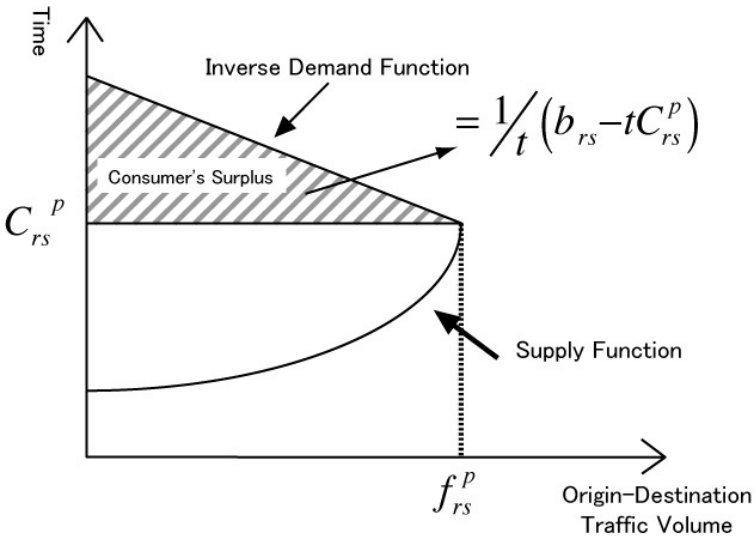

Figure 3. Relation between b_{rs} and Consumer's Surplus

$$b_{rs} - tC_{rs}^{p} = \frac{t}{\lambda^{*}_{\gamma=1}}(b_{rs} - 2tC_{rs}^{p})^{2} f_{rs}^{p\,2} \qquad (19)$$

Finding b_{rs} under the condition that travel benefit exceeds travel-time cost from the above equation, we can define:

$$b_{rs} = 2tC_{rs}^{p} + \frac{\lambda^{*}_{\gamma=1}}{2tf_{rs}^{p\,2}}\left(1 + \sqrt{\frac{4}{\lambda^{*}_{\gamma=1}} t^{2} C_{rs}^{p} f_{rs}^{p\,2} + 1}\right) \qquad (20)$$

4. IMPACT CALCULATION FOR MT. USU'S LIMITED ROADWAY ACCESSIBILITY

4.1. SETTING UP PREREQUISITE

After the eruption of Mt. Usu, the restricted traffic condition has been changed as shown in Table 1. Based on the model's assumption (e), the 3rd condition which results in continuing the same level of restricted traffic flow conditions for some time periods and restricting all the traffic crossing the stricken area including Route 37 is applied into the model (see Table 1 & Figure 4).

Table 1. Restricted Traffic Flow Conditions Caused by the 2000 Eruption of Mt. Usu

Restricted Pattern		Restricted Traffic Flow Condition
1	3/30 - 4/1	Closed Roadway: Douou-Expressway (Oshamanbetsu IC ~ Muroran IC), National Highway (3 routes), Prefecture Highway (11 routes)
2	4/2 - 4/12	Closed Roadway: Douou-Expressway (Toyoura IC ~ Date IC), National Highway (3 routes), Prefecture Highway (5 routes)
3	4/13 - 5/23	Closed Roadway: Douou-Expressway (Toyoura IC ~ Date IC), Route 37, Route 230 in Abuta, Prefecture Highway (1 route)
4	5/24 - 7/12	Closed Roadway: Douou-Expressway (Toyoura IC ~ Date IC), Route 230 in Abuta, Prefecture Highway (1 route)
5	7/13 - 11/24	Closed Roadway: Douou-Expressway (Abuta-Toyako Temporary IC ~ Date IC), Route 230 in Abuta * In order to make up for the function of the closed highway (Route 230) has been passable to traffic on and after Nov. 25th

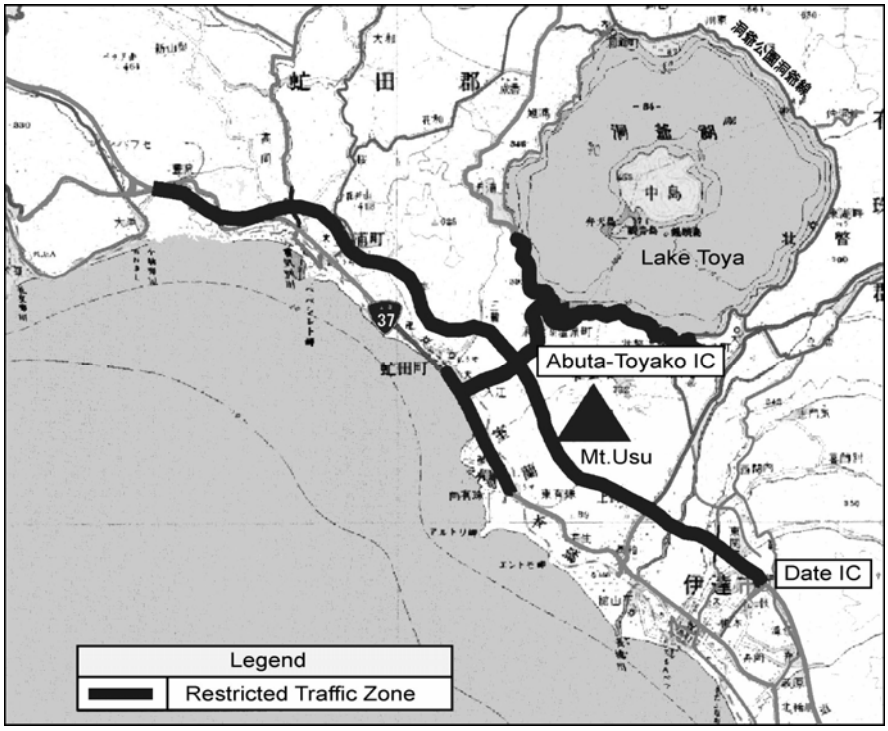

Figure 4. Restricted Traffic Flow Condition in Pattern 3

The BPR parameters (α, β) are set at (0.14, 2.95) which are estimated subject the Hokkaido's prefecture-wide road network based on the 1999 traffic census data (Hokkaido Development Bureau). The study also applies the simple time-value even though the Manual for Benefit-Cost Analysis sets the time-value for every vehicle type (Ministry of Construction), and it is set at 73.79 Japanese yen per minute. This time-value is calculated with the weighted average to the origin-destination (OD) traffic volume, which is based on the 1999 traffic census data, for each vehicle type in Hokkaido. Moreover, the parameter γ showing the cost in case of

canceling trips is calculated with changing γ at intervals of 0.1 between 0.0 and 0.4, expecting that trip cancellation would lead to a huge loss, especially by taking the alternative actions.

4.2. APPLIED RESULTS

4.2.1. VALIDITY OF ESTIMATED TRAFFIC VOLUME

In order to verify the validity of the model, here compares between the actual traffic volume and estimated traffic volume under usual "unrestricted" traffic flow condition and restricted traffic flow condition caused by the eruption: the actual traffic volume is based on the 1999 traffic census data and traffic volume at the time of the eruption refers to a change in traffic volume for the 3rd restricted setting mentioned before.

As for the model's reproducibility under the unrestricted condition (before the eruption), we find that there is the point with the estimated traffic volume of 1.6 times higher than the actual one (see Table 2 & Figure 5). Nevertheless, on the whole, the model has succeeded to reproduce the traffic flow condition with a correlation coefficient of 0.86, as shown in Table 2. On the other hand, as for the reproducibility after the eruption, we do not find the noticeable change in the estimated traffic volume with varying the γ value, and even though the result shows that the correlation coefficients tend to be high as the γ value is closed to 0, these are around 0.6. Otherwise, the study could not have a creditable enough result to validate the model reproducibility. Beside, we find that some points showing the actual traffic volume increased after the eruption while the estimated one decreased, and the contrary pattern can be seen at some other points.

Table 2. Comparison of Actual Traffic Volume & Estimated Traffic Volume before and after the 2000 Eruption of Mt. Usu

POINT#	ACTUAL TRAFFIC VOLUME 【VEHICLE/DAY】		ESTIMATED TRAFFIC VOLUME 【VEHICLE/DAY】					
	BEFORE	AFTER	BEFORE	AFTER				
				γ=0.0	γ=0.1	γ=0.2	γ=0.3	γ=0.4
①	3,900	5,400	6,400	7,000	7,000	6,900	6,900	6,900
②	6,600	6,100	6,600	10,100	10,100	10,100	10,100	10,000
③	11,300	11,700	11,000	11,600	11,500	11,500	11,300	11,200
④	6,900	7,300	4,900	5,200	5,300	5,300	5,400	5,300
⑤	3,200	4,700	2,900	5,400	5,400	5,300	5,200	5,100
⑥	6,700	3,900	7,400	7,300	7,400	7,500	7,600	7,500
Correlation Coefficient			0.86	0.65	0.64	0.64	0.62	0.62
RMS Error			0.21	0.31	0.31	0.31	0.32	0.31

* The actual after-disaster traffic volume is calculated with adding the fluctuation value after the disaster into the traffic-census value before the disaster.

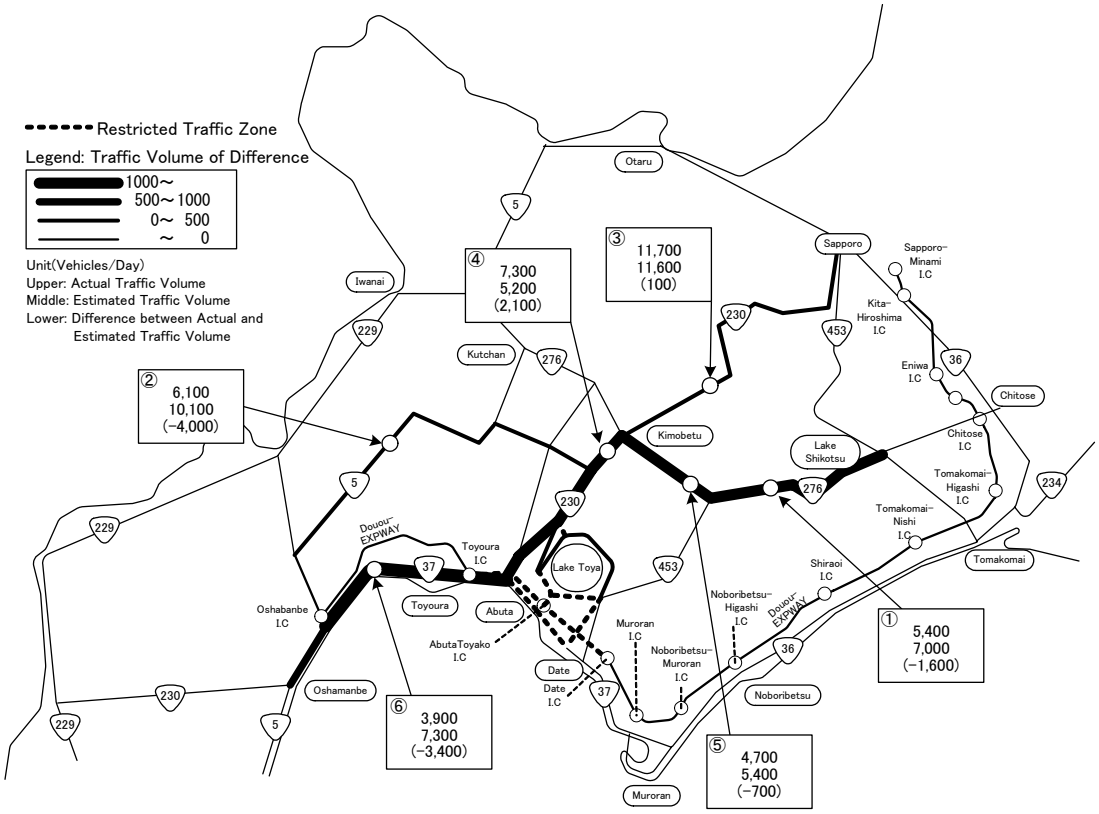

Figure 5. Change in Traffic Volume for Restricted Pattern 3

4.2.2. TRAFFIC VOLUME CANCELING TRIPS

Supposing that all of travel time is considered to be time loss ($\gamma = 0$) when road users cancel their travel activities, the calculated volume is 4,900 vehicles per day (see Figure 6). This might be due to the increasing of time costs in case of canceling trips and the enhancing of motivation going to destinations while the value of γ is closed to 0. Therefore, as shown in Figure 6, it is believed that the relations between the γ value and the traffic volume canceling trips would be appropriately represented in the actual road network.

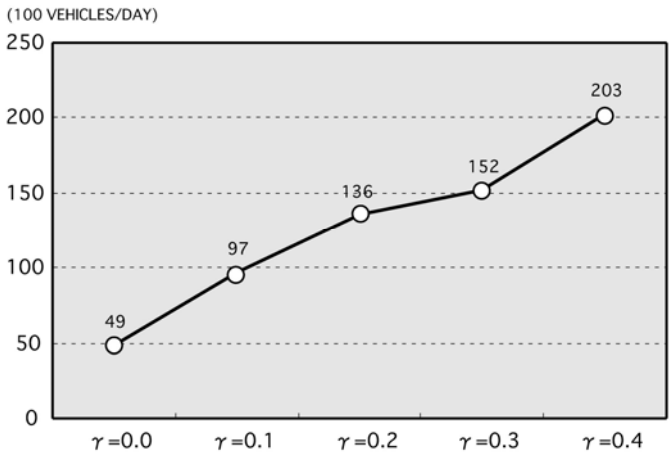

Figure 6. Traffic Volume Canceling Trips with Different γ Value

4.2.3. AMOUNT OF LOSS

Travel patterns after the eruption are divided into two groups; one is the travel pattern in which road users cancel their trips (trip cancellation) and the other is the pattern continuing their trips (continued trip). It results in a loss to both travel patterns.

As shown in Figure 7, the loss in trip cancellation results in which the higher the γ value is, the higher its amount is. This means the loss in time-value for trip cancellation shows the lower value with increasing the γ value; otherwise, the loss per vehicle for trip cancellation is the lower. On the other hand, because of decreased motivation for continuing travel after the eruption with increasing the γ value, road users who cancel their trips (volume of trips cancelled) are increased. Comparing the two groups of travel activity (keeping trip and canceling it), the increase in road users canceling their trips has a profound effect on the entire road network; thus, it follows that the amount of the loss is the higher whenever the γ value is the higher.

On one hand, the continued trips result in which the lower the γ value is, the higher the amount of the loss is (see Figure 7). It shows that an increase in the volume of road users canceling their trips is expected while increasing the γ value with the reason mentioned before, and instead this situation leads to easing traffic congestion. Otherwise, road users continuing their travel activities are able to receive benefits by reducing travel time as a result of easing traffic congestion. Consequently, it might decrease the amount of the loss for the continued travel activities with decreasing their travel-time costs.

With the loss for both the trip cancellation and continued trip included, the total loss with $\gamma=0$ runs up 90 million Japanese yen per day; the opportunity cost for trip cancellation is 32 million yen per day and the travel-time cost for continued trip is 58 million yen per day (see Figure 7). It makes clear that the cost for continued trip has a profound effect on the total cost, and the total is reduced as the γ value is going up, which results in the negative value with $\gamma=0.3$.

Further considering the relation between γ and the total loss, we find that the loss brought about by canceling trips exceeds the benefit by easing traffic congestion under the situation in which the total loss shows positive ($\gamma< 0.3$). This shows the situation that all the road users attempt to go on traveling even after the eruption although some road users consequently cancel their trips because of increasing travel time. On one hand, even though it brings about the loss by canceling trips, the benefit by easing traffic congestion exceeds it under the situation in which the total loss shows negative ($\gamma\geq 0.3$). This means it is desirable that more road users cancel their trips. Therefore, in this applied case study, we believe that the study get appropriate result with the γ value of below 0.3.

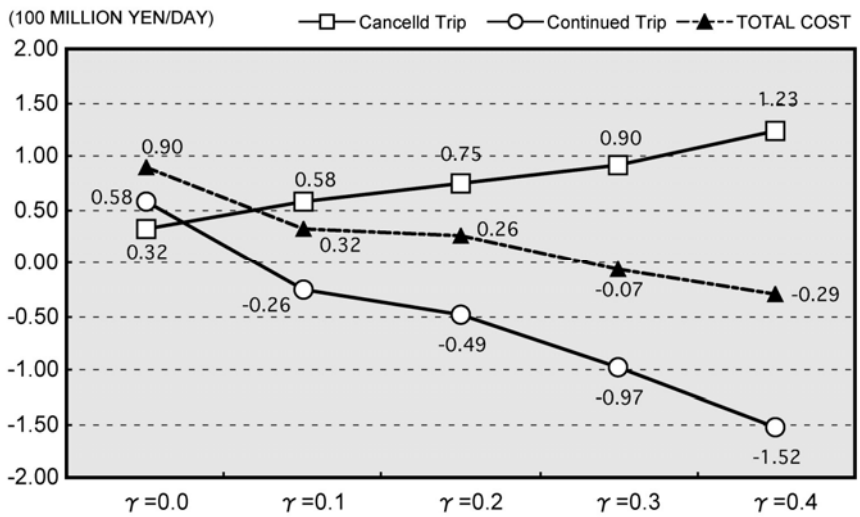

Figure 7. Change in Costs with Different γ Value

5. CONCLUSION

Throughout the course of this paper, we have attempted to demonstrate how the Traffic Network Model designed to quantify road users' cost on regional road network at the time of disaster is applied to the actual restricted traffic condition for the disaster time. Specifically, the study calculates traffic volume, travel-time cost and opportunity cost in case of trip cancellation with changing the γ value of the parameter on the loss in travel-time, in addition to comparing the traffic volume estimated by this model with the actual traffic volume.

As a result of applying this model, it is not an entirely satisfactory result to verify appropriate estimates of the traffic volume after the eruption. On one hand, we can extract conclusions that, even comparing with the actual trip, it shows significant association between the cancelled traffic volume and γ, and between the amount of loss and γ. Therefore, this model can be practicable to not only a situation with the limited road network caused by disaster, as applied in this study, but also any limited road networks, for instance detour or restricted flow conditions under rebuilding-bridge work for a fixed period of time, if providing enough information on restricted and unrestricted roadways.

Furthermore, in order to expand the range of the practicable situations with improving the model's validity and practicability, it is necessary for furthering empirical investigation, as well as considering the BPR parameters and time-value parameters. Besides, the travel-time cost related parameter value of γ needs considering the way to set a appropriate value, and it awaits future studies.

REFERENCES

Fire Defense Agency. (2001) **Corresponding Situation on Activities at Mt. Usu,** Vol. 115. June 2001.

Hokkaido Development Bureau. **1999 Traffic Census**. Hokkaido Development Bureau, Construction Department, Road Planning Section.

Japan Society of Civil Engineers. (2003) Toward Applying Users' Equal Distribution Approach, **Theory for Estimating Road Traffic Demand and Its Application, Vol. 1.** Japan Society of Civil Engineers, The Infrastructure Planning Committee.

Ministry of Construction (present Ministry of Land, Infrastructure and Transportation). **Manual for Benefit-Cost Analysis**. Road Bureau, Ministry of Construction.

Ministry of Land, Infrastructure and Transportation. (1998) **Guideline for Evaluation of Road Investment**. Road Bureau, Ministry of Land, Infrastructure and Transportation.

Ministry of Land, Infrastructure and Transportation. (2001) **Report on the 2000 Eruption of Mt. Use**. Hokkaido Development Bureau, Ministry of Land, Infrastructure and Transportation.

Uchida, Kenetsu et al. A Study on Traffic Network Model Considering Abandon of Traveling Behavior in the Case of Disaster. **Journal of the Japan Society of Civil Engineers**. Will be published in January 2005.

Tamura, Toru. (2001) Effects of Limited Accessibility by Mt. Usu's Eruption to Local Communities. **Road Traffic Economy. No.96**, 49-54.