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TRAFFIC MANAGEMENT IN TERMS OF SPEED LIMIT IN HOKKAIDO AREA

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Abstract: Speed limit is one of the traffic problems in Hokkaido due to unreasonable speed limit for both summer and winter. Based on questionnaires, the opinions from more than half of examinees have shown that speed limit of the roads in Hokkaido is too low and should be different in summer and winter. Then, this study is introduced to adjust speed limit reasonably, depending on road characteristics and road conditions. In this study, Free Flow Speed (FFS) equation is applied to calculate the speed limit in summer. For speed limit in winter, FFS and Stopping Sight Distance (SSD) equations are used. Most of the drivers are satisfied with the results. Moreover, speed limit on a circular curve is adjusted by the minimum radius of circular curve equation. However, these results should be verified in terms of safety and traffic efficiency to obtain the optimal speed limit.

Key Words: speed limit, free flow speed, stopping sight distance, drivers' satisfaction

1. INTRODUCTION

Traffic Management is a wide area of controlling or organizing to make traffic more efficiency, which can be classified into many fields of studies. In this study, the speed limit study has been chosen. Speed limit is one of the major factors that affects the drivers and other road users (pedestrians, bikers) in terms of traffic safety, transport efficiency and comfortableness. The speed limit should be presented reasonably according to the road characteristics, road conditions and road safety. The lower or higher speed limit does not only make non-benefit to the driver, but also cause higher number of accidents.

According to the real situation in Hokkaido (Japan), most of drivers hardly follow the posted speed limit due to unrealistic speed limit. They usually drive faster than posted speed limit because road conditions can support drivers to produce higher speed. Moreover, it could be observed that roads in Hokkaido are in good condition but the posted speed limits are rather low compared with other countries (Table 1). This could be implied that the present posted speed limit has no meaning to the drivers.

Table 1. Speed Limit Comparison (km/h)

	Hokkaido	Other countries
Rural Highways	60	60-100
Urban Highways	40-50	50-80
Expressways	100	80-unlimited (Autobahn)

Remark: The speed limit of Sasson Expressway (Sapporo-Otaru) is 80 km/h.

Moreover, the road conditions in Hokkaido are obviously different between summer and winter season. The roads in winter season could be very slippery, even though some of them have coupled with heat transferred systems to melt snow and ice. Driving in winter could, therefore, be very dangerous for all road users, leading to higher number of accidents compared with other seasons. In addition, speed limit in Hokkaido during winter and summer season remains the same. One of the causes of accidents in winter is the slippery road (low coefficient of friction between tire and road surface) or the vehicle cannot stop on time, which results from the improper driving speed. Thus, to enhance safety awareness and to reduce the number of accident, speed limit should be assigned carefully, according to possible road condition during each season. If speed limit in winter is adjusted corresponding to the friction between tire and road surface and the drivers follow the posted speed limit, the number of accidents will decrease. Hence, speed limit in winter should be much lower than in summer due to the worse road conditions.

In this study, the speed limit model has been created to calculate and adjust the speed limit appropriately corresponding to the road characteristics, road conditions including drivers' satisfaction both in summer (dry condition) and winter (snow and icy condition). Most of studies have suggested that speed limit usually equals to the value of the 85th-percentile speed (Fitzpatrick K. *et al.,* 2003), which could be observed by application of spot speed measurement. However, if we determine the speed limit as the 85-th percentile speed, it will not be an answer for setting the speed limit because the 85th-percentile speed will be changed again after adjustment of speed limit due to relationship among them (Dixon K.K. *et al.,* 1999; ABD 2000). Adjustment according to the road condition will provide more benefit to the road users and easy to adjust.

For the roads in Japan or in Hokkaido, each road has its own design speed, the maximum safe speed that can be maintained over a specified section of highway (road) when conditions are so favorable that the design features of the highway govern (Fitzpatrick K. *et al.,* 2003). Refer to the Speed Limit Model, the design speed acts as the highest speed limit in each road. Therefore, many essential factors are required in speed limit calculation, i.e. road characteristics (lane width, lateral clearance number of lanes, interchange density, radius of curvature, and etc.). The procedures to adjust present speed limit are shown in Figure 1.

For the objectives of the study, there are two primary objectives as follows:

- To analyse the opinions of drivers regarding speed limit of roads in Hokkaido both in winter and summer.
- To calculate the speed limit in summer (dry condition) and winter (snow and icy condition) in Hokkaido according to road characteristics, road conditions and drivers' satisfaction.

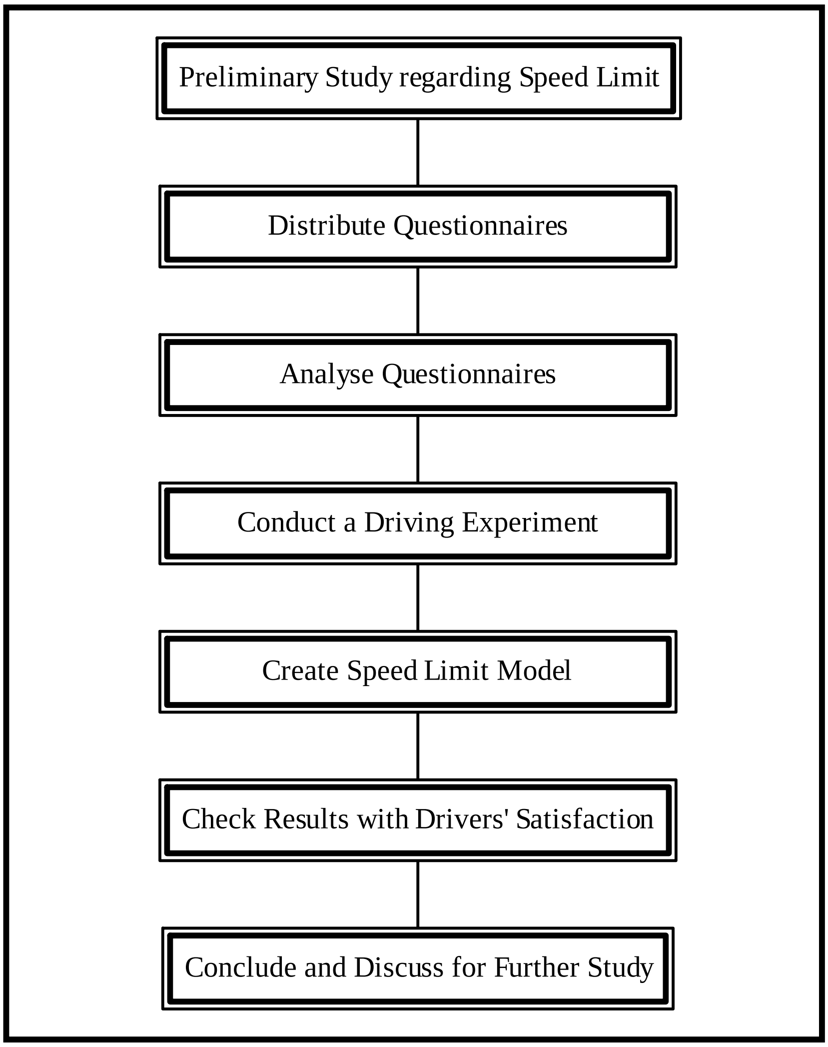

Figure 1. Procedures of the Study

This research has been divided into three parts; results from questionnaires, calculation procedures of speed limit and case study.

2. RESULTS FROM QUESTIONNAIRES

In this study, the questionnaires were distributed randomly to drivers who have ever driven in Hokkaido, regardless the nationality. The purposes of the survey by the questionnaires are shown as follows:

- To obtain the information from drivers regarding traveling in Hokkaido.
- To obtain the attitudes regarding speed limit on national roads (urban and rural) and expressways.
- To obtain drivers' opinions regarding the difference between speed limits in summer and winter.

The results from questionnaires are described below.

More than half of examinees agreed that speed limit in Hokkaido is too low (Table 2). Concern with safety awareness, some drivers thought that the current speed limit is suitable. Consider speed limit in summer and winter, more than 75% of the examinees suggested that the speed limit in summer and winter should be different (Table 3). Then, the speed limit in winter should be calculated according to the accumulated snow on the road and the lower coefficient of friction between tire and road surface.

Table 2. Speed limit in Hokkaido is too low or not (%)

Speed limit is too low?	Percentage
Yes	56.4
No	43.6
Total	100.0

Table 3. Speed limit in winter and summer should be different or not (%)

Speed Limit in winter should be different?	Percentage
Yes	76.7
No	23.3
Total	100.0

From table 4, 63.2% of examinees drove on the rural highways with the average speed around 61-80 km/h whilst the speed limit on the rural highways is 60 km/h. 72.1% of them drove on the urban highways with the speed around 41-60 km/h whilst the speed limit on the rural highways is 40-50 km/h. And on the expressways, 48.9% of them drove with the speed around 81-100 km/h and nearly half of them (43.6%) drove more than speed limit, 80 and 100 km/h as speed limit on expressway. From these results, it could be implied that speed limit in Hokkaido (Japan) is rather low or it means that the speed limit should be adjusted according to speed limit concept, for example the 85th-percentile speed. For the 85th-percentile speed concept, it means that there are only 15 percent of vehicles that are traveling over the 85th-percentile speed or speed limit, which increase the driver's satisfaction. However, in this study, the speed limit is adjusted corresponding to the road characteristics and road conditions.

Table 4. Average Driving Speed and Speed Limit (km/h)

Types of Road	Average Driving Speed		Speed Limit
	First Rank	Second Rank	
Rural Highways	61-80 (63.2%)	51-60 (21.0%)	60
Urban Highways	41-60 (72.1%)	> 60 (15.8%)	40-50
Expressways	81-100 (48.9%)	> 100 (43.6%)	100

Here, the average driving speed on urban highways, rural highways, and expressways analysed from the questionnaires are 45, 64, and 88 km/h, respectively, as shown in Figure 2. The suggested speed limits from the examinees are shown in Table 5 to Table 7. For rural highways, the present posted speed limit is 60 km/h. Most of the examinees suggested that the speed limit in summer should be 80 km/h. It is not significantly difference because the percentages of 80, 70 and 60 km/h speed limits are closed to each other. In winter, most of them suggested that the speed limit should be 50 km/h.

For urban highways, the present posted speed limit is in the range between 40 and 50 km/h depending on area. Most of the examinees agreed that the speed limit in summer should be 60 km/h. And in winter, most of them suggested that the speed limit should be 40 km/h or less.

For expressways, the present posted speed limit is 100 km/h, except 80 km/h speed limit for Sasson Expressways (Sapporo-Otaru). Most of the examinees suggested that the speed limit in summer should be 100 km/h. But the percentages between examinees who suggested 100 km/h speed limit and more than 100 km/h speed limit are not significantly different. This means that some drivers are satisfied with the present speed limit but some desire higher. And in winter, most of them suggested that the speed limit should be 80 km/h.

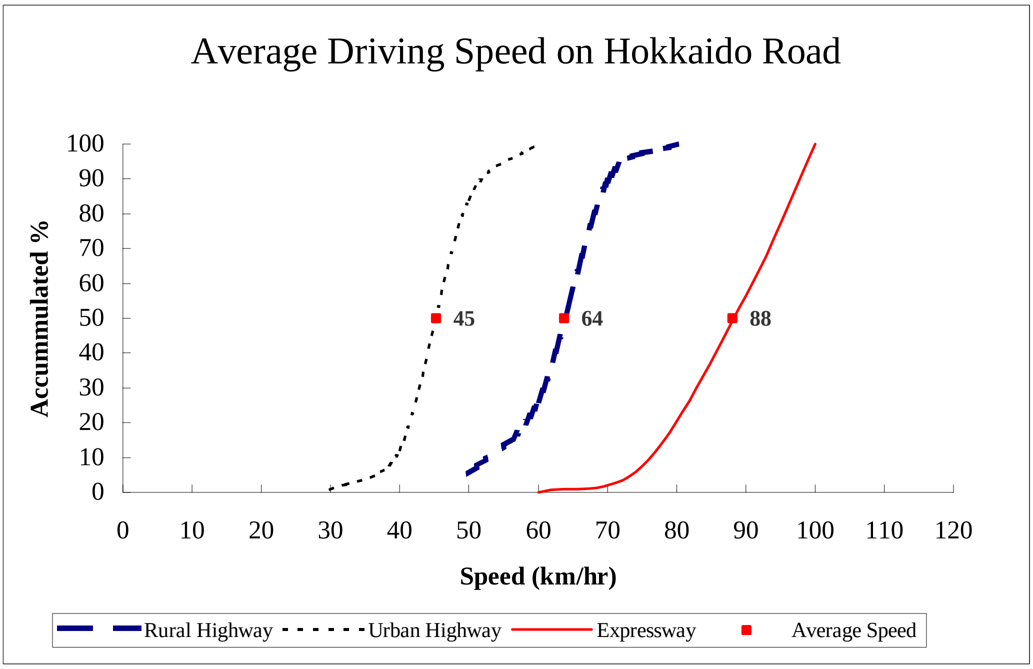

Figure 2. Average Driving Speed on Hokkaido Road

The *p*-values (Cramer's phi) of Table 5-7 are very low which imply that examinees thought that speed limit in winter and summer should be different. They could be used as the speed limit references according to drivers' satisfaction. Therefore, it can be concluded that the adjustment of posted speed limit should consider average driving speed and drivers' satisfaction as one of criteria. According to the surveyed data, the posted speed limit on rural highways should be considered as the first priority. There is no problem with drivers' satisfaction in terms of speed limit on urban area due to high traffic volume or traffic-congested problem.

Table 5. Speed Limit on Rural Highways for Summer and Winter (%)

Speed Limit on Rural Highways	Summer	Winter
<=40 km/h	1.0	20.8
50 km/h	7.3	40.6
60 km/h	27.1	32.3
70 km/h	30.2	6.3
80 km/h	32.3	0.0
> 80 km/h	2.1	0.0
Total	100.0	100.0

Remark: Chi-Square = 88.00 with 5-degrees of freedom and *p*-value is less than 0.001

Table 6. Speed Limit on Urban Highways for Summer and Winter (%)

Speed Limit on Urban Highways	Summer	Winter
<=40 km/h	5.2	57.3
50 km/h	27.1	31.3
60 km/h	49.0	11.4
70 km/h	13.5	0.0
80 km/h	5.2	0.0
Total	100.0	100.0

Remark: Chi-square = 82.30 with 4-degrees of freedom and *p*-value is less than 0.001

Table 7. Speed Limit on Expressways for Summer and Winter (%)

Speed Limit on Expressways	Summer	Winter
<=60 km/h	0.0	18.9
70 km/h	0.0	18.9
80 km/h	14.7	36.8
90 km/h	9.5	7.5
100 km/h	37.9	17.9
110 km/h	8.4	0.0
120 km/h	22.1	0.0
>120 km/h	7.4	0.0
Total	100.0	100.0

Remark: Chi-square = 88.06 with 7-degrees of freedom and *p*-value is less than 0.001

3. Calculation Procedures of Speed Limit

3.1 Reason for Speed Limit Adjustment

According to the experiment, the drivers always drive 10-20 km/h higher than posted speed limit on roads in Hokkaido. Drivers' behavior could be recognized that posted speed limits are lower than their satisfaction. Consequently, the speed limit in summer and winter should be adjusted to make it more reliable. Usually, the speed limit is estimated as the 85th-percentile speed, which is recognized by the traffic engineers as the optimum level at which to set speed limits. However, the experiments have been conducted with high cost of equipments.

3.2 Calculation Procedures

As mentioned above, most of studies use the 85th-percentile speed as the speed limit, which have to conduct the experiments, e.g. spot speed measurement (Nicholas and Lester, 2002). In this method, the spot speed data are obtained and plotted as a cumulative distribution curve to obtain the 85th-percentile speed.

In this study, the types of road are classified into three types, which are highways (two-lane and multilane), urban highways and expressways. In terms of speed limits on the roads, they are classified into two types, i.e. long straight road and circular curve. Then, the road conditions are considered, i.e. dry (summer) and snow/icy (winter) road conditions.

In summer (dry condition), the Free-Flow Speed (FFS) equation is introduced (HCM 2000) to calculate the speed limit according to the changes in road characteristics. Free-Flow Speed (FFS) definition is the speed of traffic at low volume and low density. It is the speed at which drivers feel comfortable traveling under the physical, environmental and traffic-control conditions on an uncongested section of multilane highway.

According to the AASHTO Green Book (1994), design speed is defined as the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. The assumed design speed should be logical one with respect to the topography, the adjacent land use, and the functional classification of highway (Fitzpatrick K. *et al.,* 2003). Although a new definition for design speed has been developed (a selected speed used to determine the various geometric design features of the roadway, AASHTO Green Book, 2001), the regulation of design speed in Japan has not been changed. Then, the value of design speed will be substituted to Base Free Flow Speed (BFFS) in this study, except for the multilane highway that follows Highway Capacity Manual 2000.

Here, the speed limit will be calculated automatically after input the road characteristics. The required road characteristics are as follows:

- Design speed or Base Free Flow Speed (BFFS)
- Number of lanes
- Lane width
- Lateral clearance
- Median
- Access-point density
- Interchange density (Freeway)
- Coefficient of friction between tire and road surface
- Road location

For the speed limit on a circular curve, the additional data are radius of curvature and superelevation.

Therefore, this section is separated into three parts up to the calculation processes, which are Free Flow Speed (FFS), Stopping Sight Distance (SSD), and speed limit on circular curve.

3.2.1 Free Flow Speed (FFS)

The Free Flow Speed equations of each type of roads are defined below (HCM 2000).

- For Two-Lane Highways,

$$FFS = BFFS - f_{LS} - f_A \tag{1}$$

where *BFFS*: Base Free Flow Speed (Design speed)
f_{LS} : adjustment for lane width and shoulder width (See Table 8)
f_A : adjustment for access points (If the access point per km is more than or equal to 24, f_A will be 16 km/h. If not, f_A will be 2/3 km/h per one access point)

Table 8. Adjustment (f_{LS}) for Lane Width and Shoulder Width (km/h)

Lane Width (m)	Reduction in FFS (km/h)			
	Shoulder Width (m)			
	≥ 0.0 < 0.6	≥ 0.6 < 1.2	≥ 1.2 < 1.8	≥ 1.8
2.7 < 3.0	10.3	7.7	5.6	3.5
≥ 3.0 < 3.3	8.5	5.9	3.8	1.7
≥ 3.3 < 3.6	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0.0

Source: Highway Capacity Manual 2000 (Metric Units)

- For Multilane Highways,

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \quad (2)$$

where *BFFS*: Base Free Flow Speed (100 km/h, according to HCM 2000)
f_{LW} : adjustment for lane width (See Table 9)
f_{LC} : adjustment for lateral clearance (See Table 10)
f_M : adjustment for median type (See Table 11)
f_A : adjustment for access points (If the access point per km is more than or equal to 24, f_A will be 16 km/h. If not, f_A will be 2/3 km/h per one access point)

Table 9. Adjustment (f_{LW}) for Lane Width (km/h)

Lane Width (m)	Reduction in FFS (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Source: Highway Capacity Manual 2000 (Metric Units)

Table 10. Adjustment (f_{LC}) for Lateral Clearance (km/h)

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)	Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)
3.6	0.0	3.6	0.0
3.0	0.6	3.0	0.6
2.4	1.5	2.4	1.5
1.8	2.1	1.8	2.1
1.2	3.0	1.2	2.7
0.6	5.8	0.6	4.5
0.0	8.7	0.0	6.3

Remark: a. Total lateral clearance is the sum of the lateral clearances of the median (if greater than 1.8 m, use 1.8 m) and shoulder (if greater than 1.8 m, use 1.8 m). Therefore, for purpose of analysis, total lateral clearance cannot exceed 3.6 m.
Source: Highway Capacity Manual 2000 (Metric Units)

Table 11. Adjustment (f_M) for Median Type

Median Type	Reduction in FSS (km/h)
Undivided highways	2.6
Divided highways (Including TWLTLs)	0.0

Remark: TWLTLs means two-way left-turn lanes (US) but for Japan (and other right-hand driving countries), means two-way right-turn lanes.
Source: Highway Capacity Manual 2000 (Metric Units)

- For Freeway (Expressways),

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \tag{3}$$

where $BFFS$: Base Free Flow Speed (Design speed)
f_{LW} : adjustment for lane width (See Table 9)
f_{LC} : adjustment for left-shoulder lateral clearance (See Table 12)
f_N : adjustment for number of lanes (See Table 13)
f_{ID} : adjustment for interchange density (See Table 14)

Table 12. Adjustment (f_{LC}) for Left-Shoulder Lateral Clearance (km/h)

Left-Shoulder Lateral Clearance (m)	Reduction in FFS (km/h)			
	Lanes in One Direction			
	2	3	4	≥ 5
≥ 1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.7	0.3	0.2
1.2	1.9	1.3	0.7	0.4
0.9	2.9	1.9	1.0	0.6
0.6	3.9	2.6	1.3	0.8
0.3	4.8	3.2	1.6	1.1
0.0	5.8	3.9	1.9	1.3

Source: Highway Capacity Manual 2000 (Metric Units)

Table 13. Adjustment (f_N) for Number of Lanes (km/h)

Number of Lanes (One Direction)	Reduction in FFS (km/h)
≥ 5	0.0
4	2.4
3	4.8
2	7.3

Remark: For all rural freeway segments, f_N is 0.0.
Source: Highway Capacity Manual 2000 (Metric Units)

Table 14. Adjustment (f_{ID}) for Interchange Density (km/h)

Interchange Density per km	Reduction in FFS (km/h)
≤ 0.3	0.0
0.4	1.1
0.5	2.1
0.6	3.9
0.7	5.0
0.8	6.0
0.9	8.1
1.0	9.2
1.1	10.2
1.2	12.1

Source: Highway Capacity Manual 2000 (Metric Units)

3.2.2 Stopping Sight Distance (SSD)

Calculating the speed limit in winter (snow condition), the road condition is worse due to narrower of lane width and lower friction between tire and road surface. Thus the Free Flow Speed equation and Stopping Sight Distance (SSD) equation (Iida 1992; Nicholas and Lester, 2002) are introduced to calculate the speed limit in winter. Here, the snow factors, affecting from the snow and icy, are introduced. The first step for the calculation speed limit in winter is the speed due to the accumulated snow by using FFS equation. After that the speed due to the lower friction is calculated by using SSD equation.

From the equation (4), the first term indicate the distance from perception-reaction and the second term represents braking distance.

$$SSD = \frac{vt}{3.6} + \frac{v^2}{2g(f \pm G)(3.6)^2} \tag{4}$$

Then, the value of perception-reaction time (t = 2.5 seconds as recommended by AASHTO) and the gravitational force (g = 9.8m/s^2) are substituted as shown in equation (5).

$$SSD = 0.694v + \frac{v^2}{254.016(f \pm G)} \tag{5}$$

In this study, the stopping sight distance in winter and summer with dry condition are assumed to be equal. After applied the equation (6) to solve the polynomial function, the speed in winter with regard to the friction between tire and road surface is shown in equation (7). The coefficient of friction between tire and road surface of each road condition are shown in Table 15. However, in reality, these coefficients could not be obtained easily. In the other words, it might be impossible to obtain these values due to the road surface condition change continuously, i.e. the road surface condition of the first 10 meters is not the same as the next 10 meters. Hence, it can be concluded that there is no fixed value for coefficient of friction between tire and road surface in real winter due to the continuous changes in the road surface condition. In the calculation procedure, the values in Table 15 are applied, which have been experimented long time ago in Hokkaido. It is safe to use these values because nowadays there are many tire manufacturers that invent new types of winter tires which will make higher coefficient of friction between tire and road surface. To increase more safety, the coefficient for icy condition is employed in this study.

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{6}$$

$$v_w = \frac{-0.694 + \sqrt{0.694^2 + 4\left(\frac{1}{254.016(f_w \pm G)}\right)\left(0.694v_c^2 + \frac{v_c^2}{254.016(f_d \pm G)}\right)}}{2\left(\frac{1}{254.016(f_w \pm G)}\right)} \tag{7}$$

where v_w : Speed in winter with regard to friction between tire and road surface (km/h)
v_c : Speed from the reduction in capacity (km/h)
f_s : Coefficient of friction between tire and road surface in winter condition
f_d : Coefficient of friction between tire and road surface in dry condition
G : % Gradient

Table 15. Coefficient of Friction Between Tire and Road Surface

Road Condition	Coefficient of Friction
Normal (Dry)	0.7
Snow	0.3
Icy	0.2

Source: Uchida, K., Kagaya, S. and Satoh, K. (2002) Study of Overtaking on Slippery Two-Lane Road. **Proceedings 11th PIARC International Winter Road Congress,** Sapporo, Japan, 28-31, January 2002.

For the winter's road characteristics in Japan, the lane width of multilane road will be reduced 0.25 meter each lane but the two-lane road's lane width is remained the same. And the left-shoulder lateral clearance will be reduced to 0.5 meter (Japan Road Association 2004).

3.2.3 Speed Limit on Circular Curve

For the circular curve, the speed limit is derived from the equation of minimum radius of a circular curve (Iida 1992) as in equation (8). Then the effects from road capacity and road friction (winter case) are introduced. This calculation is included before calculation process of the speed limit of the long straight road.

$$R = \frac{V^2}{127(f_0 + i)} \tag{8}$$

where R : radius of circular curve (meter)
V : design speed (km/h)
f_o : coefficient of side friction
i : rate of superelevation

Refer to Japanese minimum radius of a circular curve regulation, a relationship between design speed and coefficient of side friction is inversely proportional (Iida 1992; Bonneson 1999). By applying least squares method, the above relationship can be determined as shown in equation (9) and shown as graph in Figure 3.

$$f_o = 0.172 - 0.000784V + 0.00000166V^2 \tag{9}$$

Then, substitution of equation (9) into equation (8) produces equation (10).

$$V = \frac{0.1R - \sqrt{(0.0082 - 0.107i)R^2 + (87.376 + 508i)R}}{0.00042R - 2} \tag{10}$$

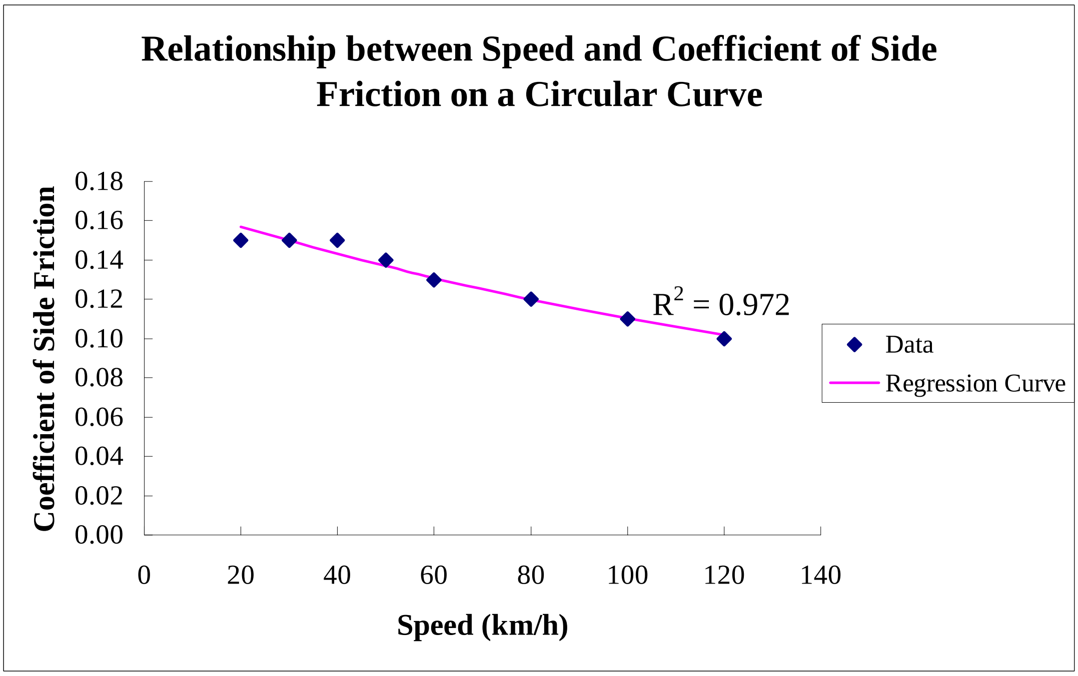

Figure 3. Relationship between Speed and Coefficient of Side Friction on a Circular Curve

From equation (10), radius of circular curve and value of rate of superelevation are obtained from the field measurement. Here, rate of superelevation (i) is neglected, to get the lower design speed (*V*), which is the safest condition for adjusting the speed limit at a circular curve. It is obviously noticed that high rate of superelevation can raise design speed higher when the radius of curvature curve is fixed (Krammes 2000).

After the design speed is obtained, FFS equation will be employed to calculate the speed limit at the circular curve in summer. However, FFS equation alone is not enough to derived speed limit in winter, SSD equation, considering lower friction coefficient between tire and road surface, is added up.

Calculation procedures of speed limit can be concluded as shown in figure 4. Three equations and road characteristics are involved. As the speed limit from this study depends on the road characteristics (lane width, shoulder width, coefficient of friction, etc.), the posted speed limit can be increased if the road is modified, e.g. expansion of lane width, application of heat-transferred system on roads, etc.

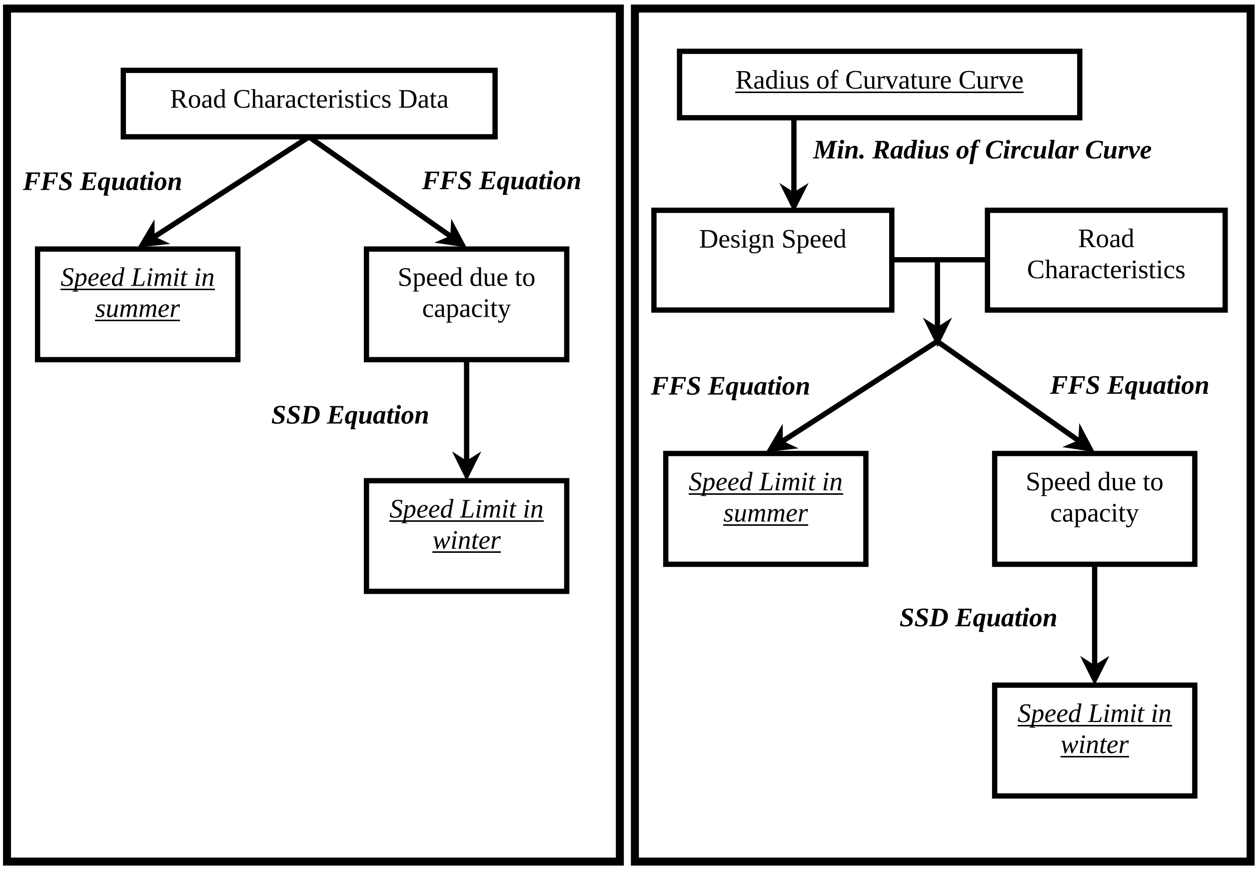

Figure 4. Calculation Procedures of Speed Limit

4. CASE STUDY

Some of the national routes in Hokkaido are introduced by case study, which are:

- National route (urban and rural)
  - No. 5 Hakodate-Sapporo
  - No. 12 Sapporo-Asahikawa
  - No. 40 Asahikawa-Wakkanai
- Expressways (Rural and Urban (Sapporo-Otaru: Sasson Expressway) Expressways)

The results of speed limit from the speed limit model are shown in Table 16-18.

The adjusted speed limits in summer are higher than present posted speed limit for rural highways (10 km/h for Two-Lane Highways, 20 km/h for Multilane Highways) and urban expressways (Sasson) (10 km/h). The results of the speed limit on rural highways and expressways in summer seem to satisfy the responses from questionnaires or the drivers' satisfaction. But the speed limit on urban highways in summer is still low to serve with the drivers' satisfaction. While in the winter, the speed limits on rural highways (two-lane and multilane) are satisfied with the drivers' satisfaction but expressways' speed limit is lower than the satisfaction. Therefore, it can be explained that only road characteristics are related to the calculation processes, excluding the environment (or surrounding) and traffic flow that mainly affect to the drivers. Additionally, the questionnaire survey was just representatives of drivers in Hokkaido.

Table 16. Speed Limit on Rural Highways (km/h)

Route No.	Condition	Rural Highways							
		Two-Lane Highway				Multilane Highway			
		Ground		Mountainous		Ground		Mountainous	
		Calculated	*Proposed*	Calculated	*Proposed*	Calculated	*Proposed*	Calculated	*Proposed*
5, 12, 40	Summer	70.8	*70*	50.8	*50*	85.5	*80*	65.5	*60*
5, 12, 40	Winter	45.9	*40*	36.5-30.7	*30*	57.5	*50*	29.3-24.9	*30*

Remark: The average road width and road condition of each route are almost the same.
In the case study, the slopes of the mountainous area are between –6 to 6%.
Proposed means proposed speed limit based on calculated speed limit.

Table 17. Speed Limit on Urban Highways and Expressways in Summer (km/h)

	Location	Speed Limit			
		Summer		Winter	
		Calculated	*Proposed*	Calculated	*Proposed*
Urban Highways	Route 5, 12, 40	45.5	*40*	27.6	*30*
Sasson Expressways	Sapporo-Otaru	96.0	*90*	63.2	*60*
Rural Expressways	Rural area	109.8	*100*	66.0	*60*

Table 18. Speed Limit at the Circular Curve (km/h) Sensitivity Test

Radius (m)	Speed Limit			
	Summer		Winter	
	Calculated	*Proposed*	Calculated	*Proposed*
1000-900	110.05	*SL*	65.46	*60*
899-800	102.17	*SL*	61.00	*60*
799-700	94.12	*SL*	56.42	*50*
699-600	85.80	*SL*	51.65	*50*
599-500	77.04	*SL*	46.57	*40*
499-400	67.61	*60*	41.04	*40*
399-300	57.09	*50*	34.74	*30*
299-200	44.70	*40*	27.10	*20*
199-100	28.36	*30*	16.38	*20*
99-50	16.45	*20*	7.61	*10*

Remark: *SL* means using the same speed limit as the long straight road.
The results in the table are for rural highways only regardless the road's slope.

The example of the posted speed limit sign for both summer and winter is shown in Figure 5. Driver can easily recognize that the higher posted speed limit is for summer (dry condition) and the lower one is for winter (snow/icy condition). However, this method maybe confused with visitors so the easiest and most economic way is to close the winter speed limit in summer and vice versa. Anyway, color-pattern perception of drivers would be tested by experiment to get the appropriate pattern for two levels of speed limit. This kind of sign system is definitely economical. However, in some countries, there are many researches on speed limits for various road conditions; Dynamic Message Signs (DMS) and Variable Speed Limit (VSL) signs are installed in order to show a real time speed limit. These systems are very effective, but they are costly in terms of the installation and maintenance cost.

Figure 5. Example of Posted Speed Limit Sign on Urban highways

5. CONCLUSIONS AND FURTHER STUDY

Speed limits in Hokkaido are not reasonable according to the responses from questionnaires and the comparison among other countries' speed limit. Then, this study is raised up to be an effective tool to adjust speed limit. Here, the speed limit in summer and winter are adjusted reasonable corresponding to the road characteristics (lane width, lateral clearance, number of lanes, coefficient of friction between tire and road surface, and etc.). The Free Flow Speed (FFS) equation is introduced to the process of calculation of the speed limit in summer and winter. Also, the stopping sight distance (SSD) equation is applied to the calculation of the speed limit in winter, which is the speed that affects from the change in friction between tire and road surface.

In comparison with the suggested speed limit from questionnaires, speed limits obtained from this study satisfy with the drivers' satisfaction, except the speed limit on urban highways in summer and expressways in winter, which are lower than the satisfied level.

For the speed limit at the circular curve, the equation of minimum radius of a circular curve is introduced to determine the design speed for each radius range. After the design speed on the circular curve is resulted, FFS equation is used to compute the speed limit in summer while FFS including SSD equation are used to compute the speed limit in winter. If the speed limit at the circular curve is over than the one on the long straight road, the speed limit on the long straight road should be used instead.

Even though the speed limits from calculation are reasonable and satisfy the drivers' satisfaction, these speed limits cannot be used in the real world yet. The speed limits have to be judged once more in terms of safety and traffic efficiency to optimize the speed limit. Therefore, the further study to achieve more reliable speed limit model will clarify that these speed limit levels improve traffic efficiency and safety level on the roads.

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