COMPARATIVE METHODS FOR SETTING SPEED LIMIT ON HOKKAIDO ROADS

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1. Introduction

As the speed limit are the controversial issue for road safety and also travel time, many researches were dealt with speed limit to find out which speed limits are suitable for road safety, the road condition and also travel time. The speed limit is usually needed to increase road safety and control the aggressive drivers. However, if the speed limit is not reasonable or does not set corresponding to road condition, it has no meaning and no one will follow.

In Hokkaido, method to set speed limit follows the same regulation from long time ago, regardless the better road quality, road characteristics, the number of traffic volume, amount of emitted pollution, amount of energy consumed, and also safety. Moreover, the posted speed limit is significantly unreasonable as one can recognize that by driving through the roads in Hokkaido, which have good condition with low traffic volume but have low posted speed limit, especially on rural roads (60 km/h).

In this study, two methods are introduced to set the speed limit reasonably which are setting according to the road characteristics and the user life cycle cost (user LCC). First method, the speed limit depends on the road characteristics and Free Flow Speed (FFS) equation is applied to this method[1)].

Second method, speed limit was determined according to user life cycle cost (user LCC). User life cycle costs, defined in this study, were composed of value of time (VOT), vehicle operating cost (VOC), environmental cost (noise and pollutions) and accidental cost. The minimum cost leaded to sustainable speed limit for each type of road[2)].

Four types of road are concerned in this study, i.e. urban highways, rural highways, urban expressways and rural expressways. The details of each method will be described in the next section.

2. First method: speed limit in terms of road characteristics

In this method, Free Flow Speed equation was employed in this study to determine speed limit on dry condition road which is the speed that drivers can travel without facing any dangerous situation. Free-Flow Speed (FFS) definition is the mean speed of traffic under low flow conditions[3)]. 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.

FSS was calculated by estimation method, which was equal to Base Free Flow Speed (BFFS) minus adjusting factors. In calculation, BFFS term was assumed to be equal to design speed, 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.

Here, the speed limit was calculated automatically after input the road characteristics. The required road characteristics were design speed or Base Free Flow Speed (BFFS), number of lanes, lane width, lateral clearance, median, access-point density, interchange density (Expressway), coefficient of friction between tire and road surface, and road location.

*Keywords: speed limit, road characteristic, optimal user life cycle cost

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The free flow speed equation was shown in equation 1. The adjustment factor was depended on type of road which follows HCM 2000. For example, for two-lane highways, the adjustment factors are the adjustment for lane width and shoulder width and the adjustment for access points.

$$FFS = BFFS - f_{Adj.} \tag{1}$$

where $BFFS$: Base Free Flow Speed (Design speed)
$f_{Adj.}$: Adjustment factor

The results in table 1 showed that current speed limits on rural highways and urban expressways are too low according to road characteristics but present posted speed limits on other roads matched with road characteristics.

Table 1: Results from the first method

	Speed Limit				Current Speed Limit
	Two-lane Highways		Multilane Highways		
	Calculated	Proposed	Calculated	Proposed	
Urban Highways	-	-	45.5	*40*	40-50
Rural Highways	70.8	*70*	85.5	*80*	60
Urban Expressways	-	-	96.0	*90*	80
Rural Expressways	-	-	109.8	*100*	100

Moreover, in this study, the questionnaires were used to survey people's opinions about speed limit. It informed that 56.4% of examinee considered that speed limits on Hokkaido roads were too low. And more than half (63.2%) usually drive over speed limit on rural highways. Furthermore, the results of the speed limit on rural highways and expressways seemed to satisfy the responses from questionnaires or the drivers' satisfaction.

In this method, only road characteristics were concerned, regardless of safety, traffic efficiency and emitted pollution. Therefore, the second method introduced these factors.

3. Second method: speed limit in terms of optimal user life cycle cost

In this method, one part of life cycle cost (LCC) was applied to determine speed limit, i.e. user life cycle cost (user LCC). The definition of user LCC here was components of LCC that have direct effect to users (drivers, pedestrians, and other stakeholders). In this method, user LCC was composed of five components, i.e. cost from travel time (Value Of Time: VOT), Vehicle Operating Cost (VOC), cost from emitted pollutions (NOx, CO_2 and noise pollution), congestion cost, and accidental cost. The results here or so called as the sustainable speed limit meant speed limit that produced the minimum user LCC. As the user LCC was composed of five components, the sustainable speed limit does not mean that it will produce lowest pollution or lowest cost from travel time or lowest accidental cost. It is just the combination of environment protection, energy, and safety.

In the calculation, the average daily traffic volume on Hokkaido roads was determined first. Costs were proportional to traffic volume, or in other words, high traffic volume leaded to high cost. Then, the relationships between each components and traveling speed were described below.

- Cost from travel time[4)]
  Generally, driving with faster speed requires lesser travel time. And as cost is proportional to travel time, then, cost is lowest when driving with the highest speed or cost from travel time is inversely proportional to traveling speed.
- Vehicle operating cost (VOC)[4)]
  It could be observed that driving with very high or very low speed has high VOC, VOC of bus is higher than car, and VOC in urban area is higher than that in rural area. From the calculation, the minimum vehicle operating costs were situated between 45-60 km/h, i.e. 45 km/h for urban roads, 50 km/h for rural roads and 60 km/h for expressways.
- Cost from emitted pollutions[5)]
  Emitted pollutions dealt with present study were NOx, CO_2 and noise pollution. The relationships between cost and traveling speed for NOx and CO_2 were almost the same, which produced high cost at low or high speed and had the

minimum cost at 60 and 70 km/h for NOx and CO_2, respectively. But for noise pollution, cost was the same for speed less than 60 km/h and increased afterwards.

- Congestion cost

  Here, the two main components of delay costs for road users are time costs, and vehicle operating costs represented in terms of fuel, tires, etc. The BPR function (equation 2) was applied to obtain the congestion cost from delay. The first term in equation 2 or travel time at free-flow speed was already determined in the cost from travel time. The second term was presented here as the delays due to the congestion, as shown in equation 3.

$$t = t_0\left(1+\alpha\left(\frac{Q}{C}\right)^{\beta}\right) \tag{2}$$

where		
	t_0:	travel time at free-flow speed
	Q:	Daily traffic flow (PCUs per day)
	C:	Daily capacity
	α, β:	0.15 and 2.95

$$Delay = t_0\alpha\left(\frac{Q}{C}\right)^{\beta} \tag{3}$$

  As the delay increased, the vehicle operating cost (VOC) also increased due to fuel consumption. We considered that the congestion had an effect to the fuel consumption only. Barnes et al. [1] found that the fuel consumption costs varied with type of vehicle, traffic and road condition. The fuel consumption costs (for baseline cost, rural area) were 32.7% and 49.3% of VOC for car and truck respectively. For the city driving (urban), the fuel consumption costs were 45.8% and 64.5 of VOC for car and truck, respectively.

- Accidental cost

  In the calculation, we assumed crash speed as free flow speed (FFS) since FFS is the mean speed of traffic under low flow conditions (up to two-way flows of 200pc/h). The reasons why crash speed was assumed to be equal to free flow speed are as a) most of fatal accidents can be occurred when the traffic flow is very low which makes driver driving at high speed, e.g. FFS; b) due to limitation of data, other than FFS could not be calculated.

  In the calculation, the required data of each accident were locations of accidents, number of lanes, average hourly traffic volume, heavy vehicle ratio (0.22 for rural area), and peak hour factor (PHF = 0.88 for low traffic volume or V/C ratio less than 0.7744). Then, FFS could be obtained from measurement (depending on flow rate and average speed) as shown in equation 4 and from estimation (according to road characteristics, for two-lane highways only).

$$FFS_m = ATS + 0.0125v_p + f_{np} \tag{4}$$

where		
FFS_m	: free flow speed from measurement (for two-lane highways only)
ATS	: average travel speed for both directions of travel combined (km/h)
v_p	: passenger-car equivalent flow rate for peak 15-min period (pc/h)
f_n	: adjustment for percentage of no-passing zone (assumed to be zero)

  The relationships between accidental cost and traveling speed were expressed by the power function, which were directly proportional to each other. Accidental cost in urban area was higher than other areas at the same traveling speed due to people-crowded area and high traffic volume. There were three assumptions in the calculation here. First, FFS was assumed as a crash speed. Second, only fatal accidents were considered. And finally, percentage of no passing zone on two-lane highways was assumed to be zero.

Finally, the total costs of each traveling speed were finalized, which had a unit in yen per kilometer per day, as shown in figure 1.

4. Comparison and selection of speed limit

In this study, criteria to select speed limit here was the most important purpose for setting speed limit, i.e. safety. According to the accidental cost in user LCC, the faster we drive, the higher accidental cost (number of accidents) occurs. Therefore, the selected speed limit is the minimum value obtained by comparing the results of both methods. The results were shown in table 2.

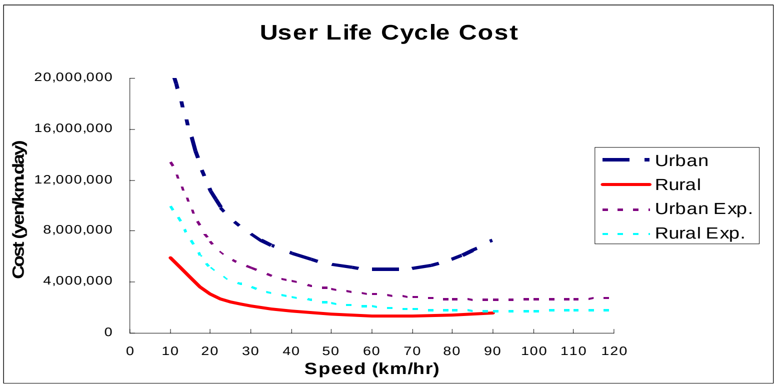

Figure 1: User LCC versus travelling speed

Table 2: Sustainable speed limit

Type of Road	Speed Limit (km/h)		Current Speed Limit	Selected Speed limit (Safety aspect)	Average Speed	The 85th percentile speed
	Road characteristics	User LCC				
Urban Highways	40	60	40-50	**40**	N/A	N/A
Rural Highways	70	70	60	**70**	60	65
Urban Expressways	90	90	80	**90**	89	98
Rural Expressways	100	90	100	**90**	108	118

From spot speed measurement which had been conducted on May and June 2006, compared with the average speed and the 85th percentile speed, the speed limit on Hokkaido roads could be higher. Additionally, we noticed that drivers drove regardless the speed limit. They concerned only the traffic condition, road condition, and the surrounding. One reason that we can concluded here is that the speed limits on Hokkaido roads are unrealistic.

5. Conclusion

In this study, two methods for setting speed limit are introduced, i.e. setting in terms of road characteristics and user life cycle cost. In the selection of speed limit, the criterion that is applied to select speed limit is safety which means the minimum speed limit between both methods because the higher speed limit will make higher accidental rate than the lower one. However, if the travel time is involved for selecting the speed limit, the trade-off analysis should be raised up.

Even though speed limit has been adjusted suitably, most of drivers still drive with speed according to their judgments (road conditions, their visibilities and so on). Nevertheless, adjusting speed limit suitably, based on whichever road characteristics or sustainable in terms of user life cycle cost, it may help driving comfort of drivers, which may reduce one cause of accidents. Drivers may not be nervous while driving with suitable speed limit.

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