Application of Analytic Hierarchy Process on Preferable Speed Limit for Logistics Company: A Case Study on Hokkaido Roads

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Abstract

Recently, the National Police Agency of Japan has announced a plan to revise a speed limit regulation. Numbers of research have been done to determine an appropriate speed limit, but none of them have taken an analysis by Analytic Hierarchy Process (AHP) into account. AHP can help to reveal the road users' viewpoints. Therefore, this research proposes the application of AHP to determine the preferable speed limit on Hokkaido roads for logistics-based businesses. Herein, safety, driving comfort and travel time were used as AHP criteria. A verification of AHP with our previous speed limit studies was also accomplished. The results showed that safety was the most important criterion, followed by travel time and driving comfort, respectively. In conclusion, according to the road and traffic conditions, we implied that these preferable speed limits are appropriate for Hokkaido roads. So it could be a guideline to set the new limits for Hokkaido roads. Furthermore, AHP is proposed to be an effective tool to determine these appropriate speed limits.

Date of receipt of final manuscript: June 2007

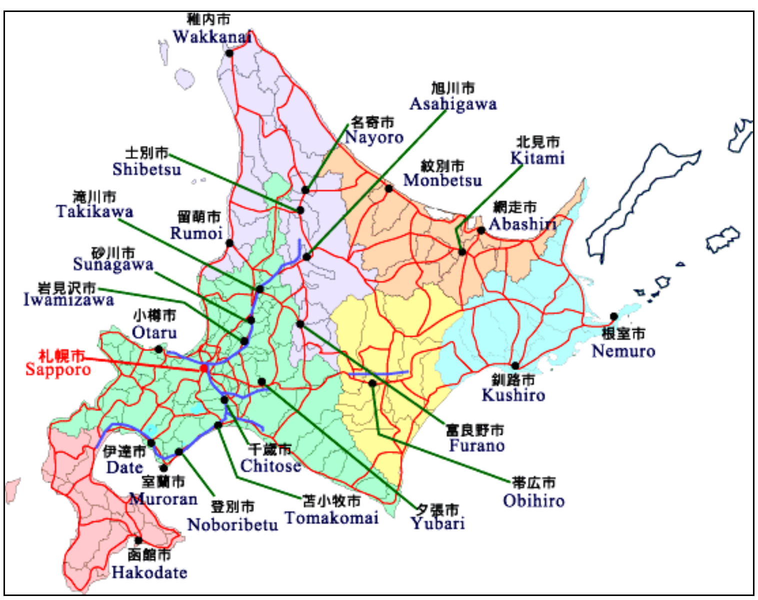
1.0 Introduction

The speed limit is the maximum speed applicable to a section of highway as established by law (Fitzpatrick et al, 2003), for the purpose of road safety. Japan's speed limit was first regulated on January 1919 due to the increasing number of traffic accidents. The first speed limit was about 25.7 km/h (Kitakyushu National Highways Office, 2006). Subsequently, the speed limits were increased to their present levels which has been in effect since 1963, i.e. 50 km/h for urban national highways, 60 km/h for rural national highways, 80 km/h for urban expressways, and 100 km/h for rural expressways.

It is apparent that present speed limits are inappropriate for contemporary road and traffic conditions and the National Police Agency of Japan has agreed to reconsider the speed limit regulations at the end of 2006. Research inputs include traffic accident analysis as well as questionnaire surveys to determine the attitudes of road users regarding the speed limit. The research is planned to be complete by the end of 2008. The present study paper reports on a pilot study of speed limits on Hokkaido roads.

In Hokkaido, the northern part of Japan, even though the road and traffic conditions are different from other parts of Japan, the same speed limit regulations are applied. Traffic volume is relatively low, especially on the rural national highways. Approximately 90% of the national highways in Hokkaido are two-lane highways and can be classified as rural national highways (Ministry of Land, Infrastructure and Transportation, 2005). Only a few areas in Hokkaido are classified as urban such as Sapporo, Otaru, Hakodate and Asahikawa as shown in Figure 1.

Figure 1
Map of Hokkaido



Source: Hokkaido Travel Data File, 2006

A spot speed study on May 2006, the results showed that many drivers exceeded the speed limits, especially on expressways which supports the general belief that drivers drive faster than the existing speed limits, especially on rural national highways and urban expressways. Therefore, it appears that the speed limits on Hokkaido roads may need to be reconsidered in the light of prevailing road and traffic conditions.

There are many methods for setting speed limits. The most common method is to set the limit on the basis of an engineering study (Transportation Research Board, 1998). In the U.S.A., a state and local government survey (Fitzpatrick et al, 1997) found that the 85th percentile speed is the most widely used factor to determine the level at which to set the limit. It is the speed at or below 85 percent of motorized vehicles travel. However, the authors noted that this method may not be appropriate for all road classes and is not sustainable in the long run as drivers adapt their speeds to an increase in the posted speed limit.

Other common methods to determine an appropriate speed limit include setting the speed limit according to the road characteristics (Thanesuen, et al 2005); according to type and level of roadside development; to minimize the total societal costs of transport (Elvik, 2002). In addition, decision support tools (DST) can be applied to determine an appropriate speed limit, such as a Multi-Criteria Decision Analysis (MCDA). The DST can facilitate communication among decision makers and stakeholders in reaching a justifiable decision through a systematic, transparent and documented process (Promentilla et al, 2006). This tool can be useful in recognising road users' views on many factors involved in determining the speed limit, such as travel time, safety, which influence drivers' preferences. Other physical characteristics can also be incorporated such as warning signs, traffic lights, more police patrolling, more divided highways, etc. One way to incorporate drivers' preferences over a number of factors would be through the use of an Analytic Hierarchy Process (AHP).

AHP(Saaty et al, 2001) is one of the MCDA which has been applied for solving complex decision-making problems in various studies, for example waste management (Brent et al, 2006), transportation (Sangjin, 2006), and heating systems (Dytczak al, 2006). We are not aware of any application of AHP to the determination of an appropriate speed limit. As there are some potential difficulties in defining quantitative comparisons between each speed limit, AHP appears to be a promising approach.

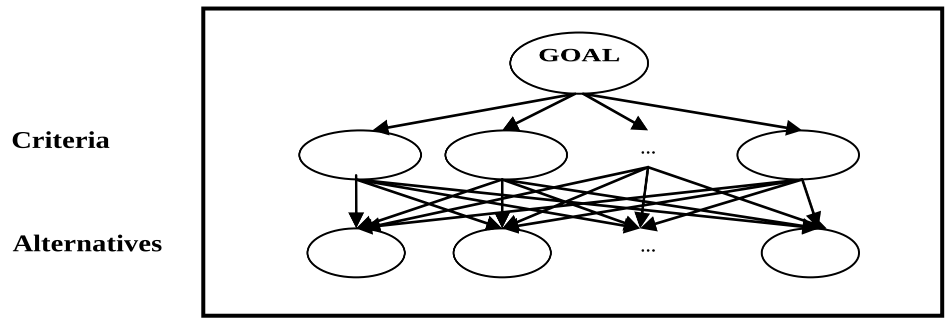
The logistics-based businesses or logistics companies were used as focus groups for the study since punctual delivery is an important factor in their operating efficiency. Moreover, it is an important index that their customers use to evaluate such companies. Therefore, these businesses are likely to well-developed views about the appropriateness of existing speed limits. Thus this paper presents a pilot study of optimal speed limit regulation from the view of a particular group of road users in a particular area of Japan. Moreover, as there is no distinct winter speed limit on Hokkaido road as yet, the study can be used as an approach to the setting of seasonal speed limits.

In summary, the objectives of the research are (1) to determine the preferable speed limits in summer and winter on Hokkaido roads from viewpoint of logistics-based businesses using an Analytic Hierarchy Process (AHP) involving safety, travel time, and driving comfort; and (2) to confirm that AHP can be applied as an effective tool to determine an appropriate speed limits.

2.0 Fundamental Concept of Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is designed to cope with both the rational and the intuitive inputs to select the best solution from a number of alternatives evaluated with respect to several criteria. In this process, the decision maker carries out simple pair-wise judgments, which are then used to develop overall priorities for ranking the alternatives (Saaty et al, 2001). The simplest form used to structure a decision problem is a hierarchy consisting of three levels: the overall goal at the top level, followed by the criteria in the middle, and the alternatives at the bottom, as shown in Figure 2.

Figure 2
AHP Structure



The AHP procedure consists of five steps as follows:

1. Constructing a hierarchy model.
2. Evaluating the criteria and alternatives by pair-wise judgments.
3. Calculating the evaluation criteria weights.
4. Calculating the synthesised priority values.
5. Checking the consistency ratio.

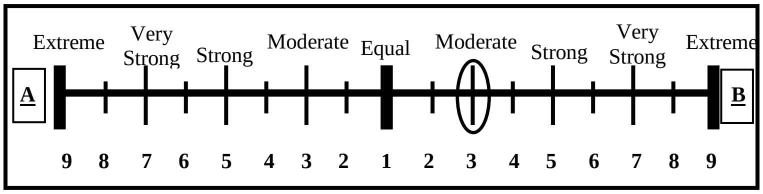
2.1 Constructing the hierarchy model

The goal, criteria, and alternatives of the study are verified and then the hierarchy is determined. It is important to note that all criteria should be independent of each other.

2.2 Evaluating the criteria and alternatives

The criteria and alternatives with respect to each criterion are evaluated by pair-wise judgment. The pair-wise judgment is the representation of a relationship between two elements that share a common parent (Saaty, 1990). The numerical representation is a point-scale, from 1 to 9 in which a score of “1” represents the view that the items are of equal importance and “9” that one of them is extremely important with respect to the other. (See Figure 3). Thus the example in Figure 3 implies that the respondent feels that criterion B is moderately more important than criterion A. The number of pair-wise judgment is n(n-1)/2, where n is the number of elements (criteria or alternatives).

Figure 3
Example of Pair-wise comparison tool



After evaluating the pair-wise judgment, the values are accumulated into a matrix, A, where:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{2n} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

in which a_{ij} = pair-wise judgment rating for element i and element j and
$a_{ji} = 1/a_{ij}$

For example, A and B are compared, as shown in Figure 3. The result shows that criterion B is moderately more important than criterion A thus a_{AB} is equal to 1/3 or 0.33 and a_{BA} is equal to 3/1 or 3.

2.3 Calculating the Evaluation criteria weights

The third step consists of the computation of a vector of priorities from the matrix, A. In mathematical terms, the principal eigenvector is computed, and when normalized becomes the vector of priorities, w. However, Saaty (1980) suggested an estimation method for the vector by using the geometric average which is simpler and less time-consuming. The geometric average is calculated by multiplying the numbers in each row and taking the *n*th root. Then, the results are normalized by dividing by the sum of the results, thus the final results now add up to unity. The results here are criteria weights. The same method is used to determine the weight of each alternative regarding the criteria.

2.4 Calculating the synthesised priority values

The synthesised priority values are calculated as follows:

$$E(i) = \sum_{j=1}^{n} w_j . f(i, j) \quad (2)$$

where $E(i)$ = points for alternative i
w_j = priority of criterion j
$f(i,j)$ = priority of alternative i on criterion j

Thus the point of alternative *i* is equal to the summation of each criterion weighted by the priority of alternative *i* with respect to that criterion.

2.5 Checking the consistency ratio

Since the *w* matrix has already been computed, λ_{max} (the maximum or principal eigenvalue) can later be determined as:

$$A.w = \lambda_{max}.w \quad (3)$$

Hence the consistency index (C.I.) is calculated, as :

$$C.I. = (\lambda_{max} - n)/(n-1) \quad (4)$$

where n = the number of elements.

Finally, the consistency ratio (C.R.) is verified, which is the ratio of C.I. to the average random index (Table 1) for the same order matrix. A consistency ratio of 0.10 or less is considered acceptable (Saaty and Vargas, 2001).

Table 1
Random Index (R.I.)

n	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.0 Application of AHP

Initially, the hierarchy was created. The goal in the hierarchy was the same as the first objective of this research. Then, the criteria and alternatives for determining the preferable speed limit was required. The most important criterion was safety which is the main purpose of speed limit in the first place. Moreover, as the logistics companies are the businesses that rely on time and concern with punctual deliveries, therefore, the second criterion regarding the speed limit setting was the travel time. The last criterion was the driving comfort. This criterion helped to determine an appropriate speed limit which drivers feel comfortable to drive.

As there were three criteria to determine preferable speed limit, the next step was to propose the alternatives on each type of Hokkaido roads, as shown in Table 2.

Table 2
Alternative speed limits systems (km/h)

Roads	**Alternatives**			
	1	**2**	**3**	**4**
Urban Highways	40	45	50	60
Rural Highways	50	60	70	80
Urban Expressways	80	90	100	-
Rural Expressways				

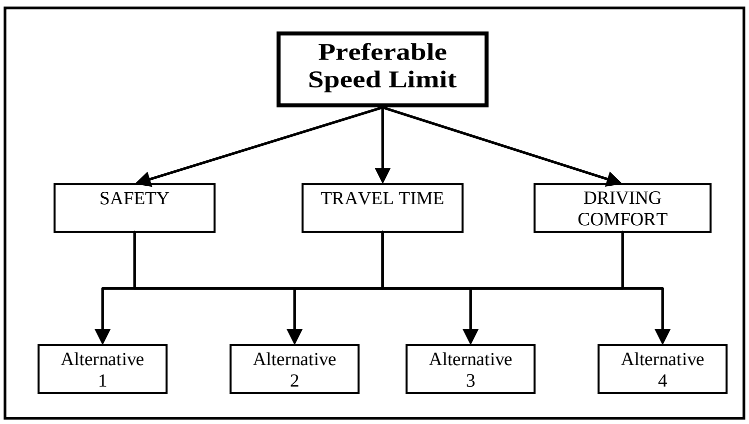
These alternatives were prepared for both summer and winter limits to avoid undue complication in the questionnaire. Hence four alternatives were presented for urban and rural highways, and three alternatives for both expressways. The resulting hierarchy is shown in Figure 4.

Examples of questions in the questionnaire are:

> Criteria: "On urban highways in summer/winter, between safety and travel time, which is more important for determining the speed limit? And how much more?"
>
> Alternative: "On urban highways in summer/winter, between speed limits 40 km/h and 45 km/h, which is more desirable in terms of safety for determining the speed limit? And how much more?"

The respondents (the representatives of logistics companies) gave the answer regarding these questions on the chart illustrated in Figure 3.

Figure 4
Hierarchy of this research



Between December 2005 to January 2006, 197 questionnaires were distributed to logistics companies in Hokkaido by mail. By the deadline, only 26 questionnaires had been returned or 13.2%. The rate was relatively low which was probably caused by the complexity or unfamiliarity of the questionnaire.

4.0 Results

Before proceeding with the calculations, the consistency ratio was calculated for each individual response and confirmed to be within the acceptable range (less than 0.1). Having established the reliability of the responses, the three criteria were compared with each other and the resulting weights derived as reported in Table 3.

Table 3
Criteria Weights

		Weight		
		Safety	**Travel Time**	**Driving Comfort**
Urban Highways	Summer	0.591	0.245	0.164
	Winter	0.526	0.270	0.204
Rural Highways	Summer	0.534	0.323	0.144
	Winter	0.561	0.282	0.158
Urban Expressways	Summer	0.500	0.360	0.140
	Winter	0.512	0.325	0.164
Rural Expressways	Summer	0.499	0.321	0.180
	Winter	0.614	0.227	0.159

Next the weights for the alternatives with respect to each criterion were obtained, and the synthesised priority values were calculated by applying Equation (2). These values and the preferable speed limits obtained are reported in Table 4.

Table 4
Synthesised Priority

All speeds in km/h		**Synthesised Priority of Alternatives**				**Speed Limit**	
						Preferred	**Present**
Urban Highways	**Limit**	40	45	50	60		
	Summer	0.140	0.233	**0.363**	0.265	***50***	***50***
	Winter	**0.336**	0.255	0.223	0.186	***40***	**-**
Rural Highways	**Limit**	50	60	70	80		
	Summer	0.273	0.278	**0.292**	0.156	***70***	***60***
	Winter	**0.311**	0.274	0.216	0.199	***50***	**-**
Urban Expressways	**Limit**	80	90	100	-		
	Summer	0.291	0.343	**0.381**		***100***	***80***
	Winter	**0.418**	0.318	0.265		***80***	**-**
Rural Expressways	**Limit**	80	90	100	-		
	Summer	0.302	0.337	**0.361**		***100***	***100***
	Winter	0.323	**0.370**	0.307		***90***	**-**

In summer, the preferable speed limits on rural highways and urban expressways are 10 and 20 km/h higher than the existing ones, respectively. The others are the same as the existing speed limits. In winter, Hokkaido roads are usually covered with snow or ice thus one might expect preferred speed limits to be lower than in the summer. Table 4 confirms that the preferred winter speed limits are indeed 10-20 km/h lower than those in summer.

5.0 Discussion

The most important criteria for determining the preferable speed limit was safety, followed by travel time and driving comfort for both summer and winter. The weights for the safety criterion in winter were higher than those in summer, which was expected due to the road slipperiness in winter, apart from the urban highways. However, the differences were not large.

In summer, safety on urban highways had the highest weight which is to be expected from the high traffic volume on urban highways during the summer. In turn this increases the risk of accidents which increases delays and hence reduces delivery efficiency. Most of respondents were in urban areas.

In winter, safety on the rural expressways had the highest weight which gave rise to the large difference between summer and winter, i.e. 0.614 as opposed to 0.499. The emphasis on safety in winter may be capturing concern by the logistics companies for the tendency to drive at high speed due to good road condition even in winter. Accidents in these circumstances are likely to cause greater delays than in the summer.

For the travel time criterion, the weights in summer were higher than the weights in winter, except for the urban highways due to traffic congestion in winter. With the exception of urban highways, they gave weights in excess of 32%. Clearly logistics firms attached considerable importance to travel time for its impact on delivery efficiency.

For the driving comfort criterion, the weights in winter were higher than the weights in summer, except for the rural expressways. Companies appear to recognise that driving in winter is difficult than driving in summer and implicitly to acknowledge that speed limits should reflect this.

Of particular interest are the differences between the preferable speed limits and the existing ones. It is observed that the logistics companies believed that the existing speed limits in summer on urban highways and rural expressways were appropriate. On the other hand, they thought that summer speed limits on rural highways and urban expressways should be higher to correspond to current traffic conditions.

For speed limits in winter, due to the road conditions in winter and compared with the preferable speed limits in summer, the preferable speed limits in winter were the same or lower than the existing ones. Currently in Japan, there is no permanent separate speed limit for winter. However, some sections of Hokkaido roads, mainly on the expressways, use Variable Message Sign (VMS) or Variable Speed Limit (VSL) indicators to inform drivers of a temporary speed limit which is set by police according to weather conditions and other criteria. If weather conditions in winter are particularly dangerous for driving, the police will close the roads and inform people via television and radio.

To examine the effectiveness of AHP for the determination of appropriate speed limits, the results from AHP were compared with the results from two previous speed limit studies of the same area. The first method set speed limits according to road characteristics (Thanesuen et al, 2005) while the second method used cost analysis and the effects of road and traffic conditions (Thanesuen et al, 2007a and 2007b)). The results are shown in Table 5.

Table 5
Speed Limit Comparison

Road Types		Speed Limit (km/h)			
		Current	AHP	Road Characteristics	Cost Analysis
Urban Highways	Summer	50	50	46	70
	Winter		40	28	47
Rural Highways	Summer	60	70	71	76
	Winter		50	46	56
Urban Expressways	Summer	80	100	96	97
	Winter		80	63	61
Rural Expressways	Summer	100	100	110	106
	Winter		90	66	85

Since crash severity and the risk of accidents are generally positively related to speed the limits in the last two columns of Table 5 would be rounded downwards in practice. We note that all methods support very similar speed limits in summer, except for the speed limit on urban highways suggested by the cost analysis method. There is general agreement across the methods that the speed limits on rural highways and urban expressways should be raised which accords with the spot speed study which showed problems with speed limit violation which may be due to inappropriate speed limits. Therefore, we can infer that AHP appears to be an effective tool to determine an appropriate speed limit in summer.

For winter, Table 5 shows that the speed limits from AHP and cost analysis are higher than those derived from road characteristics except in the case of urban expressways. It has been suggested elsewhere (Thanesuen et al, 2007b) that the speed limit on urban expressways from cost analysis is too low. As a result, we can infer that AHP appears to be an effective tool to determine an appropriate speed limit in winter.

6.0 Conclusion

This research used a questionnaire survey to determine the preferred speed limits from the viewpoints of logistics companies in Hokkaido. The paper applied a particular form of Multi-Criteria Decision (MCDA) Analysis known as Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty. In general AHP generates similar results to other established methods of speed limit analysis using road characteristics or cost analysis. These results are also consistent with observed driver behaviour.

The present study requires expansion in a number of ways. There was a relatively low rate of return from the questionnaires and some of the returned data was excluded due to poor consistency ratio scores. These shortcomings could be addressed by using a more extensive sampling frame; making the questionnaire more readily understood, and utilising follow-up messages to non-respondents to encourage response and cope with misunderstandings.

As the Japanese National Police Agency has recently planned to revise speed limit regulation, this study serves as a useful model for incorporating the opinions of a wide variety of road users into the limit setting process, including police, government, traffic engineers, and commercial and private road users.

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