Application of Analytic Hierarchy Process on Preferable Speed Limit for Logistics Company

Suthipun Thanesuen[1], Seiichi Kagaya[2], Ken-etsu Uchida[3]

[1] Doctoral Student, Graduate School of Engineering, Hokkaido University, North 13, West 8, Kita-ku, Sapporo, 060-8628 Japan (email: suthipun@eng.hokudai.ac.jp)
[2] Professor, School of Public Policy, Hokkaido University, North 13, West 8, Kita-ku, Sapporo, 060-8628 Japan (email: kagayas@eng.hokudai.ac.jp)
[3] Research Associate, Graduate School of Engineering, Hokkaido University, North 13, West 8, Kita-ku, Sapporo, 060-8628 Japan (email: uchida@eng.hokudai.ac.jp)

Introduction

The speed limit is the maximum speed applicable to a section of highway as established by law (1), with the purpose of road safety. In Japan, the speed limit is set according to the speed limit regulation which has been used for a long period, 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. 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 regulation is also applied. Moreover, the traffic volume is relatively low, especially on the rural national highways. Approximately 90% of national highways in Hokkaido are two-lane highways and can be classified as the rural national highways (2). In other words, only some areas in Hokkaido are classified as the urban area, for example Sapporo, Otaru, Hakodate, Asahikawa, etc., as shown in the figure 1.

Figure 1 - Map of Hokkaido

Generally, the 85th percentile speed, the speed at or below which 85 percent of motorized vehicles travel, is set as the speed limit. There are also other setting methods, e.g. setting speed limit according to road geometry or road characteristics, according to type and level of roadside development, etc. From the authors' point of view, the speed limit should be set appropriately to the speeds that drivers feel to be safe and proper. The 85th percentile speed could be one of the answers but the experiment called the spot speed study is needed. Therefore, this research introduces one of the methods to determine the speed at which drivers feel safe and proper. The logistics-based businesses or logistics companies were our targets because the punctual delivery is one of the most important indexes to indicate their delivery efficiencies. Moreover, it is an important index that customers would rely on to evaluate the logistics companies. Therefore, this kind of businesses may have their own preferable speed limits, which probably changed from the existing speed limits or unchanged.

This research is aimed at determining the preferable speed limit on Hokkaido roads for logistics-based businesses by the application of analytic hierarchy process (AHP) regarding safety, travel time, and driving comfort.

Fundamental Concept of Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a basic approach to decision making. It is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria. In this process, the decision maker carries out simple pairwise judgments, which are then used to develop overall priorities for ranking the alternatives (3). 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.

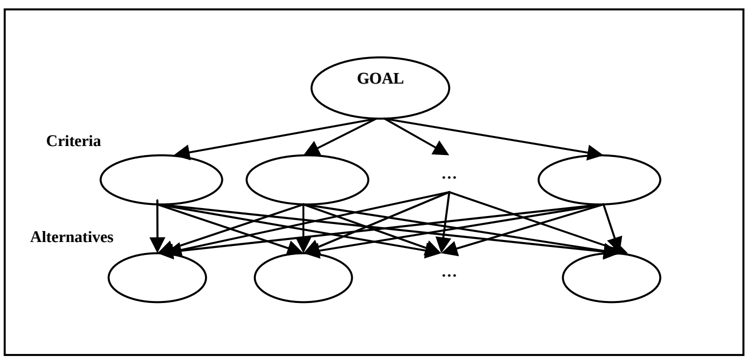

Figure 2 - AHP Structure

The procedures of AHP consist of five steps as follows:

1. Constructing a hierarchy model
2. Evaluating the criteria and alternatives by a pairwise judgment
3. Calculating the evaluation criteria weight
4. Calculating the synthesising priority values

5. Checking the consistency ratio

First step

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

Second step

The criteria and alternatives with respect to each criterion are evaluated by pairwise judgment. The pairwise judgment is the representation of a relationship between two elements that share a common parent (4). The numerical representation is a 9 point-scale, from 1 to 9 as shown in table 1. The number of pairwise judgment is $n(n-1)/2$, where n is the number of elements (criteria or alternatives). From the example in the figure 3, it implies that respondent feels that criterion A is moderate more important than criterion B.

Table 1 - Definitions of Numerical Representation (4)

Intensity of Importance	**Definitions***	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favour activity over another
5	Strong Importance	Experience and judgment strongly favour activity over another
7	Very Strong or demonstrated Importance	An activity is favoured very strongly over another; its dominance demonstrated in practise
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.

* The definitions here are for the intensity of importance but it can be applied to others like "desirable" in this research, e.g. moderate desirable, extreme desirable, etc.

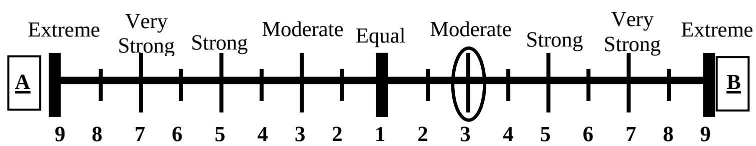

Figure 3 - Example of How to Evaluate the Criteria

After evaluating the pairwise judgment, the values are accumulated into the matrix as shown in equation 1.

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

where a_{ji}: pairwise judgment rating for element i and element j = w_i/w_j

w_i: weight of element i

a_{ji}: $1/a_{ij}$

Third step

This consists of the computation of a vector of priorities from the given matrix. In mathematical terms, the principal eigenvector is computed, and when normalized becomes the vector of priorities. However, Saaty (1980) suggested the estimation method of that vector by introducing the geometric average which is easier and not 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 results, thus the final results now add up to unity (5). The results here are criteria weights. From Saaty (1980), there are four methods to estimate the eigenvector; however, he suggested that this method only gives a very good approximation. Afterwards, the same methods are also applied to determine the weight of each alternative regarding the criteria.

Fourth step

The synthesising priority values are calculated by applying the equation 2.

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

where *E(i)*: points of the alternative i
w_j: priority of criterion j
f(i,j): priority of the alternative i over the criterion j

Equation 2 means that the point of alternative *i* is equal to the summations of the multiplication of each criteria weight with the weight (priority) of alternative *i* with respect to that criterion. Then, the alternatives are ranked.

Fifth step

From the eigenvalue problem in equation 3, as *w* matrix is already computed, λ_{max} (called the maximum or principal eigenvalue) can later be computed.

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

Then, the consistency index (C.I.) is calculated, as shown in equation 4.

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

where *n*: number of elements

Finally, the consistency ratio (C.R.) is verified, which is the ratio of C.I. to the average random index (Table 2) for the same order matrix. A consistency ratio of 0.10 or less is considered acceptable.

Table 2 - 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

AHP has been applied in many studies but as yet not towards determining preferable speed limit.

Application of AHP

Initially, the hierarchy was created. The goal in the hierarchy was the same as the 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. If the drivers feel that the speed limit is proper or comfortable to drive, this will absolutely lead to a decrease in the accident rate.

As we had 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 3.

Table 3 - Lists of Alternatives (unit: km/h)

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

These alternatives were prepared for both summer and winter due to the limitations of questionnaire study. The questionnaire should not too difficult and the amount should be in the acceptance level of the respondents, otherwise there is no response. If we had applied the different alternatives for summer and winter, the number of questions and pages would be increased which would make the respondents ignore them or answer them wrongly or carelessly. Thus, four alternatives were used for urban and rural highways, while expressways had three criteria. Therefore, the hierarchy for this research was shown in the figure 4 below.

Examples of questions in the questionnaire were:

- Criteria

  On urban highways in summer, between criteria "safety" and "travel time", which one is ***more important*** for determining the speed limit? And how much more?

- Alternative

  On urban highways in summer, between speed limits "40 km/h" and "45 km/h", which one is ***more desirable*** in terms of "safety" for determining the speed limit? And how much more?

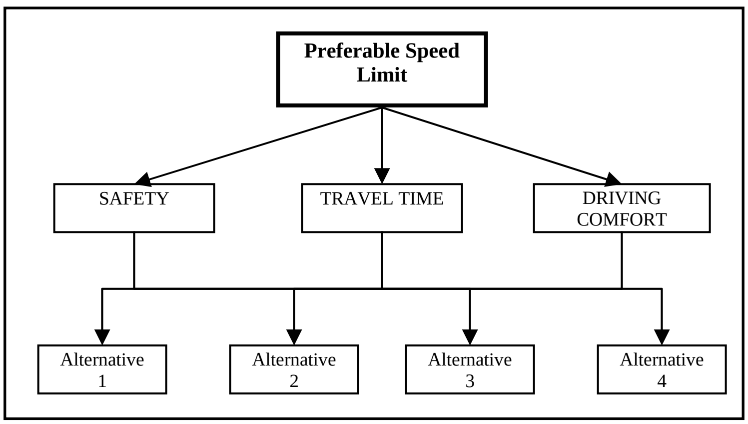

Figure 4 - Hierarchy of this research

Herein, 197 questionnaires were distributed to logistics companies in Hokkaido via means of posting. The purpose of questionnaire survey was to observe the preferable speed limit for both summer and winter on Hokkaido roads. Up until the deadline, only 26 questionnaires were returned or 13.2%. The rate was very low which was probably caused by the difficulty of questionnaires.

Results

Before proceeding to the calculation, each individual data had been checked and verified with the consistency ratio (less than 0.1 is acceptable). Hence, the results can be much more reliable. From the calculation step, our three criteria were compared with each other and resulted as a weight in the table 4. It was shown that safety was the most important criteria for determining the preferable speed limit followed by travel time and driving comfort for both summer and winter. The weights of 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.

Table 4 - Weight of Criteria

		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

Furthermore, safety on urban highways in summer had the highest weight since there are high numbers of traffic volume on urban highways in summer. This is a result of a high risk of accident and most of respondents are in the urban area. If an accident occurs, the delay will be increased which also reduces their delivery efficiency. In winter, the highest weight of safety was attributed to the rural highways. On rural expressways, the difference between weights of safety criterion in summer and winter was 0.115 or 11.5%. It meant that safety in winter was much more important than that in summer. This may be because the logistics companies concern that their drivers always drive at high speed even in winter. If the accident occurs in winter, the loss will be higher than that in 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. For the driving comfort criterion, the weights in winter were higher than the weights in summer, except for the rural expressways.

After the weight of criteria and alternatives regarding each criterion were obtained, the next step was the calculation of synthesis priority. The synthesis priority and the preferable speed limits were shown in table 5.

Table 5 - Synthesis Priority

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

In summer, the preferable speed limit on urban highways and rural expressways were the same as the existing speed limits while the preferable speed limit on rural highways and urban expressways were 10 and 20 km/h higher than the existing ones, respectively. From this, it means that the logistics companies judged that the existing speed limits on urban highways and rural expressways were appropriate. On the other hand, they thought that the speed limits on rural highways and urban expressways should be higher which are matched to the current traffic conditions on rural highways and urban expressways.

In winter, Hokkaido roads are usually covered with snow or ice thus it is natural that speed limit in winter should be lower than speed limit in summer. Therefore, due to the road conditions in winter and comparing with the preferable speed limits in summer, the preferable speed limits in winter were suitable. In Hokkaido, nowadays, there is no regulation to set the speed limit in winter yet. However, some parts of Hokkaido roads, mainly on the expressways, use the variable message sign (VMS) to inform drivers of the present speed limit which is set by police according to the weather condition and other criteria. If the weather in winter is really bad, the police will close the roads and inform via television and radio.

Conclusion

This research used questionnaire survey to determine the preferable speed limit from the view-point of logistics companies which always deal with transportation and need to deliver goods on time. The method that was used in this study is the analytical hierarchy process (AHP), developed by Thomas L. Saaty. It is one of the decision making method which helps the decision maker to know which alternative is the best or should be treated first. It could be implied that the preferable speed limits for both summer and winter are suitable, especially on rural highways as we mentioned before that drivers generally drive 10 km/h higher than the existing summer speed limit.

However, in this research, there were some difficulties that may result in inaccuracies as follows:

- Pairwise comparisons are quite difficult for people who have no background about AHP. Therefore, some data had been excluded from the calculation due to low consistency ratio.

- The questionnaire surveys to logistics companies had a low return rate due to the difficulty of questionnaire. As a result, the number of data used in the analysis was relatively small.

As shown before, there are some limitations of analysis by AHP as we found some inconsistent data and a low return rate of questionnaires. However, these results are more reliable because each data has been check with the consistency ratio before analysis. Therefore, in a further study, the questionnaire will be simplified and sent to the other targets, i.e. pedestrians and drivers, to obtain the preferable speed limits. These results will then be compared with the calculated speed limits from the previous study (6). Then, the advisory speed limits for Hokkaido roads will be finalized. Finally, the advisory speed limits will be proposed to the government in the future.

References:

1. Fitzpatrick, K., Carlson, P., Brewer, M.A., Wooldridge, M.D., and Miaou, S., “Design Speed Operating Speed, and Posted Speed Practices.” *NCHRP Report 504*. Transportation Research Board, Washington, D.C. (2003)
2. Annual Statistics Road (Japanese), Ministry of Land, Infrastructure, and Transportation, Japan (2005)
3. Saaty, T.L. and Vargus, L.G., “Models, Methods, Concepts & Applications of the Analytic Hierarchy Process.” Kluwer Academic Publishers (2001)
4. Saaty, T.L., “How To Make A Decision: The Analytic Hierarchy Process”, European Journal of Operational Research (1990)
5. Saaty, T.L., “The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation”, McGraw-Hill, Inc. (1980)
6. Thanesuen, S., Kagaya, S., and Uchida, K., “Traffic Management in terms of Speed Limit in Hokkaido Area”, Journal of the Eastern Asia Society for Transportation Studies, Volume 6, pp. 2247-2262 (2005)