Economic Evaluation of Advanced Cruise-Assist Highway Systems with Fuzzy Integral

Shinichi MUTO*, Akiyoshi TAKAGI **, Masashi OKUSHIMA ** and Takamasa AKIYAMA**

* Department of Environment Engineering, Osaka Institute of Technology,
5-16-1 Ohmiya Asahi-ku, Osaka 535-8585, JAPAN, muto@env.oit.ac.jp
** Department of Civil Engineering, Gifu University,
1-1, Yanagido, Gifu 501-1193, JAPAN

***Abstract* – The Advanced Cruse-Assist Highway Systems(AHS) are much expected to solve problems on traffic accidents. The AHS is expected not only the reducing effects of damage cost on traffic accidents but also the psychological effects like to improve comfortableness and reduce dangerous or anxious feeling. In this paper, we propose the method based on fuzzy integral to evaluate the psychological effects by introducing AHS. And we tried to construct the evaluation method by integrating fuzzy integral and conjoint analysis to execute the benefit evaluation of introducing AHS.**

***Keywords* - Advanced Cruise-Assist Highway Systems, Fuzzy Integral, Benefit Evaluation**

I. INTRODUCTION

The problems caused by traffic accidents have been serious in Japan. For these problems, the traffic safeties that make a good use of ITS technology are expected. The one of these is the Advanced Cruise-Assist Highway Systems (AHS)[1]. The AHS is the service which collects the information relating to the cause of the traffic accident such as road condition, traffic condition and so on with the sensor attached to both road infrastructure and vehicle, and it urges the attention and warning to the driver, furthermore, it may assist the operational work such as the brake or handle. When introducing the AHS, reduction of traffic accidents or its damage is expected. In addition, it is also expected that the AHS brings the psychological effects such as the improvement of comfortableness and the reductions of dangerous or anxious impression. However, because the much cost will be needed for the introducing of AHS, its effects have to be ascertained carefully based on cost benefit analysis, after measuring not only the effects of accidents damage reduction but also the psychological effects.

In this paper, we propose the method with fuzzy integral to evaluate the introduction of AHS focusing the psychological effects. The fuzzy integral is the method to evaluate by integrating some evaluation items in which the synergistic or offset influence among each item is able to be measured. In addition, we try to be in harmony this fuzzy integral method with the conjoint analysis that authors have researched in previous studies [2], and we will execute benefit evaluation of introduction of AHS.

II. PRVIOUS STUDIES ON EVALUATING PSYCHOLOGICAL EFFECTS

Fig. 1 is concept chart in which methods to evaluate psychological factors are arranged. The CVM (Contingent Value method) is a method of asking the valuation of psychological effects directly. However the CVM has a problem with low reliability, so the conjoint analysis has been used to make up for the fault of CVM. In the conjoint analysis, preferable circumstance is selected from the profiles presented to the subjects by the one-paired comparison, and the valuation of

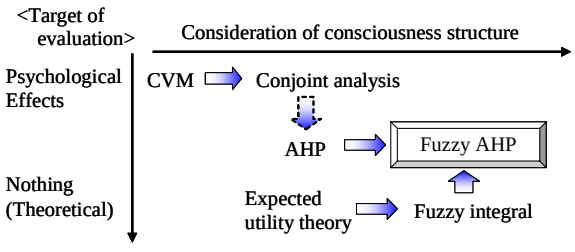

Figure 1. Concept chart of methods to evaluate psychological factors

psychological effects is obtained by dealing with results of one-paired comparison processes statistically. Though in the conjoint analysis there is a characteristic that is able to consider some evaluation items together, its analysis has a problem that arbitrary may be included when designing the questionnaire.

Recently the AHP (Analytic Hierarchy Process) is noticed. Though AHP is similar to conjoint analysis, the point to ask the valuation of each evaluation item is different. And the weight among items also is asked, at last the psychological effects is evaluated synthetically by calculating weighted sum like below,

$$z_j = \sum_{k=1}^{K} w_k \cdot h_j^k \qquad (1)$$

where z_j : synthetic valuation, j : the superscript that means the alternative plan, w_i : the important degree (= weight) of evaluation item, h_j^k : the valuation of evaluation item k .

The AHP is calculated by simple weighted sum. So, there is a problem that it is not able to appreciate the synergetic or offset influence with the AHP. Recently, the method that is in harmony fuzzy integral with AHP was proposed by Takahagi[3], the synergetic or offset influence also has been evaluated in the frame of AHP.

In this paper, we accept the model proposed by Takahagi. But in the AHP, evaluation is done by score method mainly. So here we calculate the benefit evaluation by using the conjoint analysis further.

III. EVALUATION OF INTRODUCING AHS BY FUZZY AHP

A. *Framework of Fuzzy AHP*

The fuzzy AHP is based on the traditional AHP. In the AHP, at first the valuation of each evaluation item h_j^k and the weight among them w_k are calculated from the questionnaire results. And the synthetic valuation is led by weighted sum of equation (1). In the fuzzy AHP, the calculation used weighted sum in traditional AHP takes place the fuzzy integral. Though there are some kinds of fuzzy integral, here we accept the Choquet integral as below,

$$z_j^{FI} = (\mathrm{c}) \int_0^{\infty} h_j^k \, d\mu \,. \qquad (2)$$

where z_j^{FI} : synthetic valuation by using Choquet integral, μ : fuzzy measure.

Fuzzy measure is the one having fuzziness that is defined here to possess monotonicity, but not to posses additivity always. At first, we will show in below equation about additivity,

$$\mu(A \cup B) = \mu(A) + \mu(B) \,. \qquad (3)$$

On the other hand, fuzzy integral may not be always required the formation of equation (3) and $\mu(A \cup B)$ is defined by another frame. As the one of them, there is λ -fuzzy measure. λ -fuzzy measure is expressed as below,

$$\mu_\lambda(A \cup B) = \mu(A) + \mu(B) + \lambda \, \mu(A)\mu(B) \,. \qquad (4)$$

The λ -fuzzy measure has the characteristics as below,

If $\lambda > 0$ then $\mu_\lambda(A \cup B) > \mu_\lambda(A) + \mu_\lambda(B)$ [synergistic], (5a)

If $\lambda = 0$ then $\mu_\lambda(A \cup B) = \mu_\lambda(A) + \mu_\lambda(B)$ [additive], (5b)

If $\lambda < 0$ then $\mu_\lambda(A \cup B) < \mu_\lambda(A) + \mu_\lambda(B)$ [offset]. (5c)

In this paper, we calculate the synthetic valuation by using the fuzzy integral that defined as the λ -fuzzy measure.

B. *Outline of Evaluation*

Japanese Ministry of Land, Infrastructure and Transport is working on some AHS services for utilization. But here, we assumed to choose the following four AHS services and evaluate them with fuzzy AHP.

1) Support for prevention of collisions with forward obstacles
2) Support for prevention of line departure
3) Support for prevention of crossing collisions
4) Support for prevention of collisions with pedestrians crossing streets

As for the evaluation items, we assumed to pick up following five items.

(a) The mitigation of the dangerous feeling to traffic accidents: It is expected by introducing AHS that the dangerous feeling to the driver's own life or body mitigates.

(b) The relief of the strain feeling when driving: It is expected by AHS to be liberated from the strain feeling felt while people pay attention to the some road traffic situations in driving.

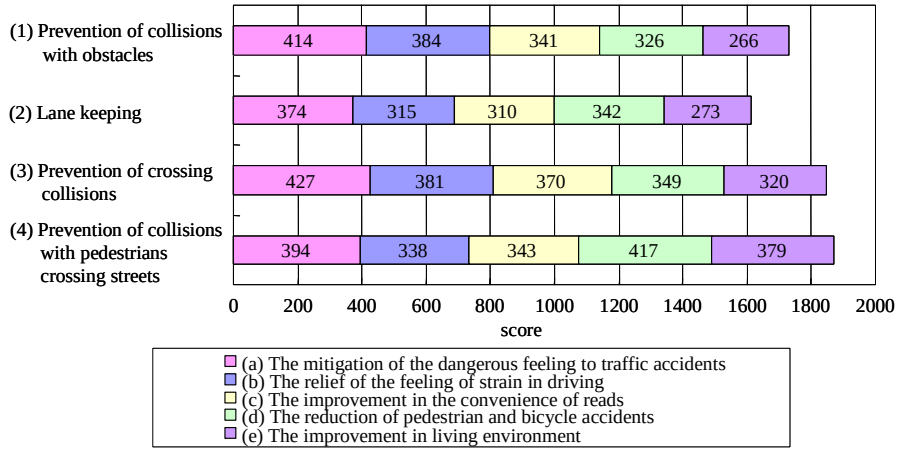

Figure 3. Scored evaluation of each evaluation item of the psychological effect

Table 1. One-paired comparison matrix and proper vector with the AHP

	(a)	(b)	(c)	(d)	(e)	Proper vector
(a)Mitigation of dangerous feeling	1.000	0.495	1.818	0.586	1.612	0.424
(b)Relief of strain feeling	2.018	1.000	0.470	2.378	0.402	0.424
(c)Improve of road convenience	0.550	2.126	1.000	3.014	0.436	0.483
(d)Reduction of pedestrian accidents	1.705	0.420	0.332	1.000	1.452	0.360
(e)Improvement in living environment	0.620	2.486	2.292	0.689	1.000	0.527

(c) The improvement in the road convenience: The burdens of beginner or elderly people in driving are expected to be mitigated by AHS.

(d) The reduction of grave accidents relating with pedestrian and bicycle: The traffic accidents relating with pedestrian and bicycle are afraid to become graver. The reduction of such grave accidents by introducing AHS is also thought to decrease mental burden of the assailant.

(e) The improvement of living environment: The reduction of accidents is expected to lead to the improvement of the living environment in community.

C. Evaluation of Introducing AHS

Next the questionnaire survey was executed, and the valuations of each evaluation item and weights among them were calculated. As for the evaluation of valuation, we measured from scores obtained by five stage score evaluation which is executed for four AHS services and five items respectively. The results of score evaluation are shown in Fig.3. From this result, it is understood that the forth AHS that is prevention of collisions with pedestrians crossing streets is best evaluation. The weights among each item are calculated from the one-paired comparison questionnaire. From its questionnaire results, we make the one-paired comparison matrix and lead proper vector, and we introduced the weights among each evaluation items. The one-paired comparison matrix and proper vector are shown in table 1.

The proper vector in table 1 means to the weights. From these results, it is understood that the weight for the item of (e) that is 'improvement of living environment' is highest. Next we executed the synthetic evaluation based on the traditional AHP that means to evaluate by simple weighted sum method. Those results are shown in table 2. The results of synthetic valuation and order of the AHS evaluated are shown at right column in table 2. And the Fig. 3 is the graph shown those results. In Fig. 3, the results of simple weighted sum are also shown together. From these results, it is understood that the evaluation by using the AHP tends to enlarge the difference of evaluation of each AHS.

Next we execute the synthetic valuation by Choquet integral. When applying the Choquet integral, the fuzzy measure has to be determined. We accept the ϕ transformation following below which is proposed by Tsukamoto[4] to obtain fuzzy measure.

$$\phi_s(u) = \frac{s^u - 1}{s - 1} \quad \forall\, s \in [0, \infty]. \tag{6}$$

Where s: parameter which determine interaction, u: sum of weight for each item.

Table 2. Synthetic valuation by weights sum

	(a)Mitigation of dangerous feeling (0.4237)	(b)Relief of strain feeling (0.4241)	(c)Improve of road convenience (0.4830)	(d)Reduction of pedestrian accident (0.3601)	(e)Improvement in living environment (0.5269)		
Prevention of collisions with forward obstacles	0.257 (0.10902)	0.271 (0.11485)	0.250 (0.12076)	0.227 (0.08187)	0.215 (0.11321)	0.5397	<3>
Prevention of lane departure	0.232 (0.09848)	0.222 (0.09421)	0.227 (0.10978)	0.238 (0.08588)	0.221 (0.11619)	0.5046	<4>
Prevention of crossing collisions	0.265 (0.11244)	0.269 (0.11395)	0.271 (0.13103)	0.243 (0.08764)	0.258 (0.13619)	0.5813	<2>
Prevention of collisions with pedestrians	0.245 (0.10375)	0.238 (0.10109)	0.251 (0.12147)	0.291 (0.10472)	0.306 (0.16130)	0.5923	<1>

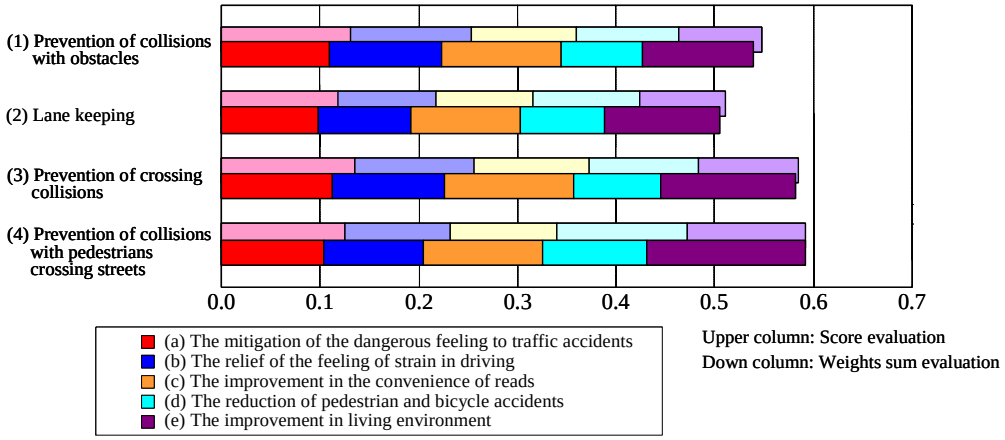

Figure 4. Comparison of the item evaluation with the score and weights sum method

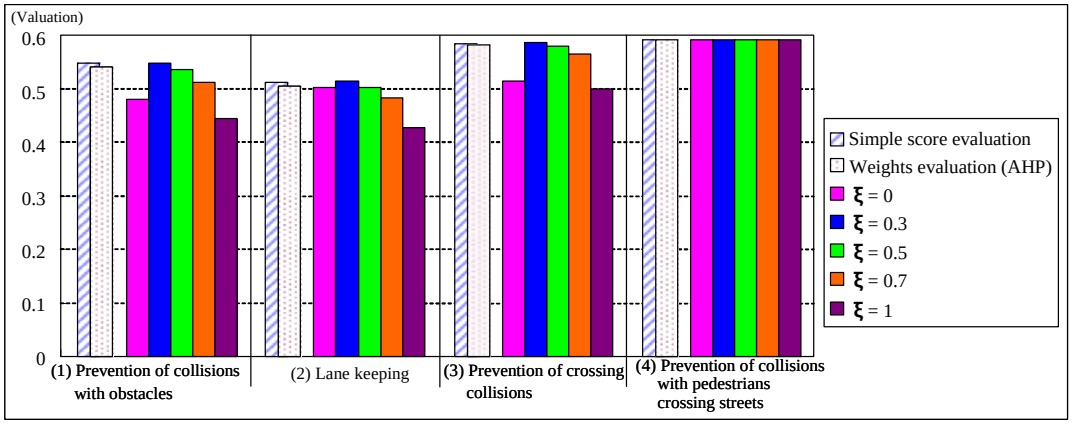

Figure 7. Synthetic valuation results of Choque integral (2)

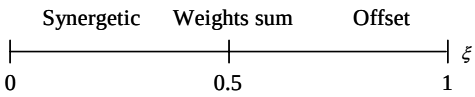

Figure 5. Relation between parameter ξ and interaction among each item

And parameter s is transformed to parameter ξ.

$$\xi(s) = \frac{1}{1+\sqrt{s}}. \qquad (7)$$

The relation of this parameter ξ and interaction of each item is shown in Fig. 5.

In this paper, we give the parameter ξ, calculate the parameter s from equation (7) and obtain ϕ_s from equation (6). And from this ϕ_s, the fuzzy measure is led

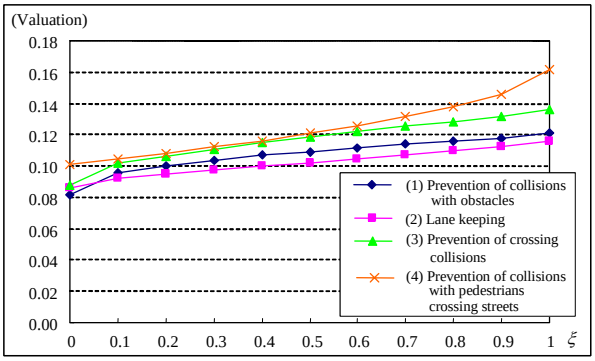

Figure 6. Synthetic valuation results of Choquet integral (1)

belonging to below equation,

$$\mu_\lambda^{K'} = \phi_s\left(\sum_{k'=1}^{K'} w_j^{k'}\right). \qquad (8)$$

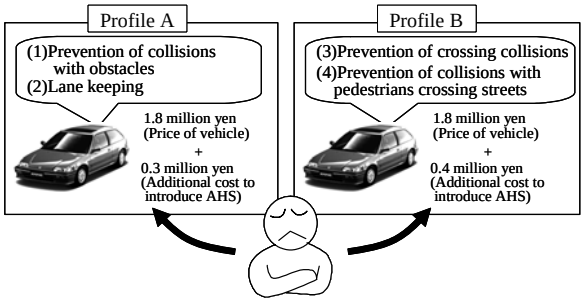

Figure 8 Profile of traditional conjoint analysis

Though it is necessity to be given the parameter ξ by proper method, here we set ξ properly and execute the synthetic valuation. The results are shown in Fig.6. From the results of Fig.6, it is understood that the fourth AHS that is prevention of collisions with pedestrians crossing streets is best evaluation in any case. Especially, in the range of $\xi > 0.5$, its evaluating valuation rises rapidly. Its range is the one of offset evaluation. The reason is thought that evaluations of the item (e) 'improvement of living environmental' and (d) 'reduction of grave accidents relating with pedestrian and bicycle' of the forth AHS is especially high. In the range of offset evaluation, the synthetic valuation rises high when the evaluation of only one item is high. So it is considered that the results in Fig.6 are obtained for the fourth AHS. On the other hand, in the neighborhood of zero, the evaluating valuations of the First and Third AHS fall rapidly. This reason is thought that the difference among the evaluations of each item in these AHS is leveled.

Next we express the comparison with the result of simple weighted sum to Choquet integral. In Fig.7, the graph in which the results of both evaluations are compared is shown. From this results, though $\xi = 0$ is exceptional, it is understood that the difference of evaluation is more grater as the value of ξ increasing.

IV. APPLICATION OF FUZZY AHP TO BENEFIT EVALUATION OF AHS

A. *The Model of Conjoint Analysis*

In this section, we try to be in harmony the Fuzzy AHP shown above section with the conjoint analysis that has been researched by authors and calculate the benefit evaluation of AHS.

In the conjoint analysis, at first the profiles shown as Fig. 7 is made and it is questioned "Which profile do you select?" Next the theoretical model of traditional conjoint analysis is formulated by Logit model as below,

Table 3 Estimated results of parameters

	Estimate results	
α_1	3.293 (7.895)	
α_2	0.283 (0.396)	hit ratio
α_3	3.518 (5.032)	58.0%
α_4	5.367 (8.789)	likelihood ratio
β	-0.016 (-4.334)	0.0957

( ) t value

$$P_A = \frac{\exp(\theta V_A)}{\exp(\theta V_A) + \exp(\theta V_B)} \tag{9a}$$

$$V_i = \sum_j \alpha_j x_j + \beta y_i \tag{9b}$$

where P_A : probability of choosing the profile j $(j = A, B)$, V_j : utility level of choosing profile j, y_i : burden charge of choosing profile i, x_j : dummy variable indicating with or without AHS, θ : Logit parameter(=1), α, β : parameters.

And from the questionnaire results, the parameters α, β of Logit model are estimated.

The willingness to pay (WTP_j) of introducing the AHS is yielded as marginal WTP like below,

$$WTP_j = \frac{dy_i}{dx_j} = -\frac{\alpha_j}{\beta}. \tag{10}$$

Here, we try to introduce the synthetic valuation given by the fuzzy AHP shown at previous section for the traditional conjoint analysis. Concretely, x_j of utility function in (10) is replaced by $z(x_j)$ as below,

$$P_A = \frac{\exp(\theta V_A)}{\exp(\theta V_A) + \exp(\theta V_B)} \tag{11a}$$

$$V_i = \sum_j \alpha_j \cdot z(x_j) + \beta y_i \tag{11b}$$

where $z(x_j)$: synthetic valuation given by the fuzzy AHP.

The WTP in (11) is obtained as below,

$$WTP_j = \frac{dy_i}{dx_j} = -\left(\frac{\partial V_i}{\partial z}\frac{\partial z}{\partial x_j}\right) \Big/ \frac{\partial V_i}{\partial y_i} = -\frac{\alpha_j}{\beta} \cdot z_j(x_j) \tag{12}$$

B. *Benefit evaluation of AHS by fuzzy AHP*

The results of parameters estimated for the model of previous section at $\xi = 0.3$ case are shown in table 3. And the willingness to pay (WTP_j) measured by

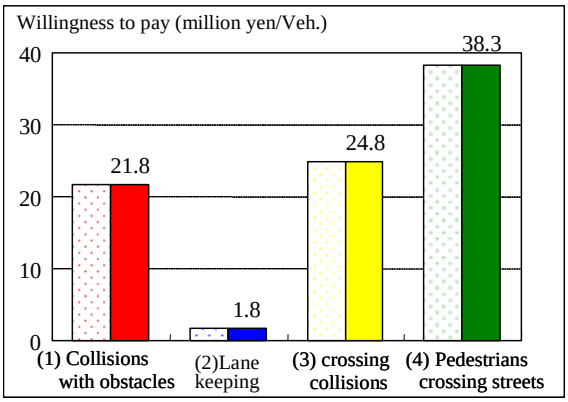

Figure 9 Willingness to pay by using fuzzy integral

parameters of table 3 are expressed in Fig. 9. The compared results with traditional conjoint analysis also were shown in Fig. 9, but it was not found the difference of those results. The reason was thought that the difference of psychological effects for each AHS which we try to grasp by fuzzy AHP was absorbed to the parameters in (11), so the influence to the results of WTP did not appear.

Next we try to evaluate more detail influence of introducing AHS. We assume to introduce the each AHS, but for which the measure on the evaluation item of improvement of living environment is added. And the results of evaluation benefit are shown in Fig.10. Like this, the evaluation that is focusing on each effect item is able to be executed by using fuzzy AHP(show Fig. 11). In Fig. 10, it is understood that AHS (1) has changed places into the order of AHS (3). This reason is considered that the weights of improvement of living environment in AHS (1) are greater than the one of AHS (3).

V. CONCLUDING REMARKS

We proposed the method based on fuzzy integral to evaluate introduction of AHS focusing on psychological effects. It means that it is the evaluation which is considered the synergetic or offset effects among each evaluation item. And we tried to construct the evaluation method by integrating fuzzy integral and conjoint analysis to execute the benefit evaluation of introducing AHS.

In future, we need to execute integrated evaluation in which damage cost decreasing benefits is also included. And the evaluation in which characteristics in region is considered is also necessity.

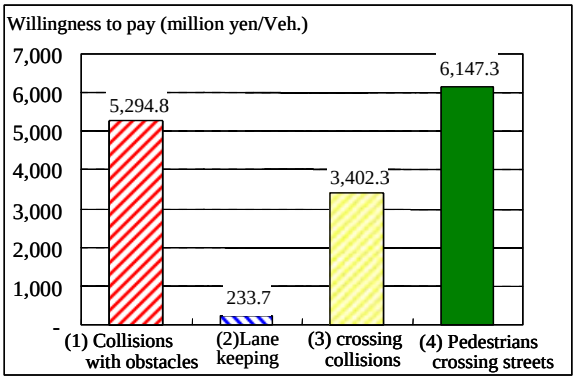

Figure 10 Evaluation results focusing 'improvement of living environment'

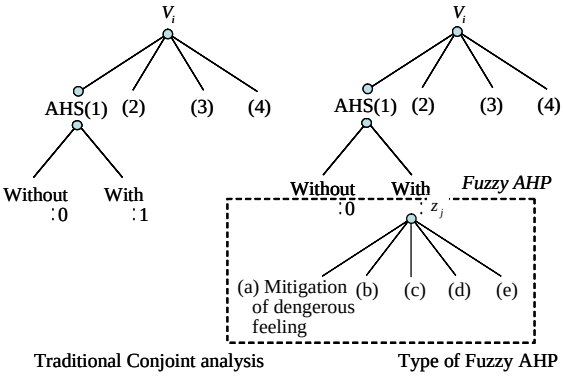

Figure 11 Difference between traditional model and fuzzy AHP

ACKNOWLEDGHMENT

This research is a part of the research projects in the subcommittee for traffic accident analysis corresponding to the intelligent transport systems, in Japan Society of Civil Engineers.

REFERENCE

[1] Advanced Cruise-Assist Highway System Research Association Homepage(2004): http://www.ahsra.or.jp/

[2] Takagi, A., Muto, S. and Akiyama, T. (2005) : Economic Evaluation of Advanced Cruise-Assist Highway Systems focusing on Psychological Effects, Selected Proceedings of the 10th WCTR, CD-ROM, No. 1443.

[3] Takahagi, E. (1997): AHP with Fuzzy measure-Fuzzy integral model, Bulletin of the Research Institute of Commerce, No.116, The Research Institute of Commerce Senshu University (in Japanese).

[4] Tsukamoto, Y. and Takahagi, E. (1994): Fuzzy theory and economics, chapter 4, pp.139-187, in Japan fuzzy conference, Fuzzy theory and cultural and social science, Nikkan Kougyou Shinbun-sya (in Japanese).