ECONOMIC EVALUATION OF ADVANCED CRUISE-ASSIST HIGHWAY SYSTEMS FOCUSING ON PSYCHOLOGICAL EFFECTS

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Abstract

One of the most advanced systems in the Intelligent Transport Systems (ITS) is the Advanced Cruise-Assist Highway Systems (AHS) that improves the safety of road traffic by assisting the operational work of drivers. Although the various effects are expected from the AHS, the realization of the AHS needs many kinds of roadside infrastructures and a great cost. Therefore, we have coolly to judge whether the AHS brings the effect corresponded to the cost of the infrastructure development.

This paper tried to economically evaluate the AHS focusing on the psychological effects with the conjoint analysis that is one of the non-market evaluation methods, after showing the judgment structure in case the subject of questionnaire states a preference. As the result, we were able to estimate the willingness to pay reflecting the psychological effect, because the sequence of the willingness to pay had consistency in the relative sequence of the scored evaluation of psychological effects. Furthermore, we evaluated the plural kinds of AHS services considering the synergistic or offsetting effect between them by applying the nonlinear functions such as the CES type function and the fuzzy integral type functions to the utility function in the conjoint analysis.

Keywords: economic evaluation, Advanced Cruise-Assist Highway Systems, psychological effect, conjoint analysis, fuzzy integral, Sugeno integral, Choquet integral
Topic area: C2 Safety Analysis and Policy

1. Introduction

The active utilization of the Intelligent Transport Systems (ITS) is examined in a traffic safety measures as the progress of information technology. One of the most advanced systems in the ITS, is the Advanced Cruise-Assist Highway Systems (AHS) that improves the safety of road traffic by assisting the operational work of drivers. The AHS 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 and vehicle, and it urges the attention and warning to the driver with providing some information, furthermore, it may assist the operation such as braking and handling.

If the information needed for the instantaneous judgment is provided on real time by the AHS, then the traffic accidents decrease and the damage reduces,. In addition, it is hoped that the AHS brings the psychological effects such as the improvement of comfortableness and the reductions of dangerous and anxious impression. Although the various effects are expected from the AHS, the realization of the AHS needs many kinds of roadside infrastructures and a great cost. We have coolly to judge whether the AHS brings the effect corresponded to the cost of the infrastructure development. However, the AHS is just going on experiment now and has not been introduced in the general road yet. This economically means that the market of AHS service does not exist. Therefore, it is difficult to evaluate the AHS.

This paper tries to economically evaluate introducing the AHS focusing on the psychological effects with the conjoint analysis that is one of the non-market evaluation methods. The conjoint analysis is one of the stated preference methods that would be able to evaluate the psychological effects. There are the problems relating to bias and reliability at the stated preference method. Regarding this point, we evaluate the AHS with the conjoint analysis, after showing the judgment structure in case the subject of questionnaire states a preference. Furthermore, we evaluate the plural kinds of AHS services considering the synergistic or offsetting effect between them by applying not only a linear function but also nonlinear functions such as the CES type function and the fuzzy integral (Sugeno integral and Choquet integral) type function to the utility function in the conjoint analysis.

2. Outline of the AHS for improving the traffic safety in Japan

The AHS that the Ministry of Land, Infrastructure and Transport aims at utilization for improving the traffic safety in Japan are systematized in the principal user services those are shown in Figure 1 (Japanese Ministry of Land, Infrastructure and Transport, 2004).

Figure 2 shows the traffic accidents encountered on roads all over Japan, classified into causative types (Japanese Ministry of Land, Infrastructure and Transport, 2004). In this study, we try to evaluate the following services that are capable of preventing the traffic accidents by main causes selected from Figure 1. However, the lane keeping targets only a straight lane.

(1) Prevention of collisions with obstacles
(2) Lane keeping (straight lane)
(3) Prevention of crossing collisions
(4) Prevention of collisions with pedestrians crossing streets

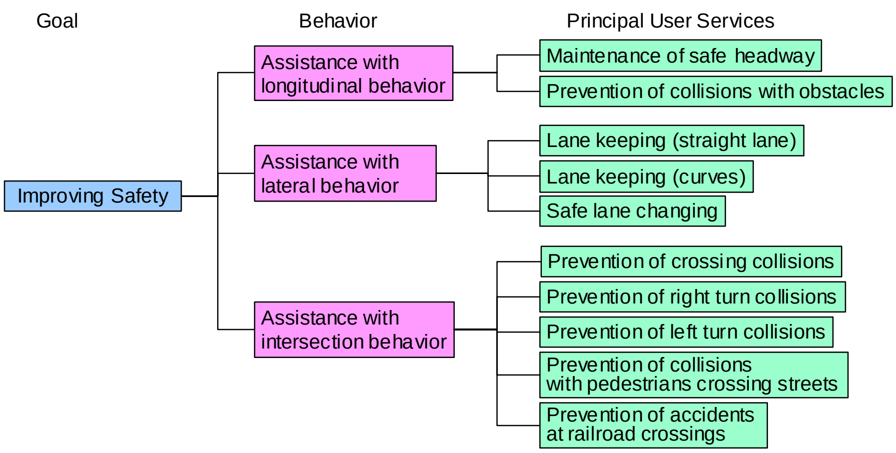

Figure 1 AHS services for improving traffic safety in Japan

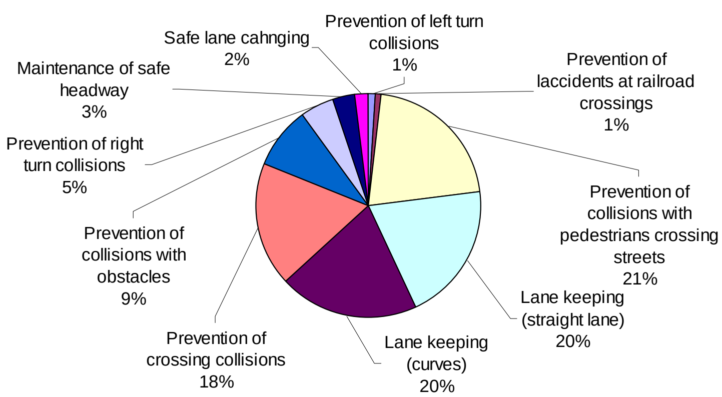

Figure 2 Number of fatalities in accidents covered by each principal user service

3. Evaluation of the psychological effect by the AHS service

3.1 The psychological effect brought by the AHS service

We investigate what kind of psychological effect is effective to the four kinds of the AHS services shown in the preceding chapter by the questionnaire. We aim at the five kinds of the psychological effects below.

(a) The mitigation of the dangerous feeling to traffic accidents

The reduction of the traffic accident brought by the AHS service mitigates the dangerous feeling to the driver's own life and own body.

(b) The relief of the feeling of strain in driving

The AHS service relieves the feeling of strain of driving while always paying attention to the road traffic situation.

(c) The improvement in the convenience of roads

The burden in driving is mitigated by the AHS service considering an operation inexperienced person and elderly people.

(d) The reduction of pedestrian and bicycle accidents

An assailant undertakes a big burden, because the traffic accident of a pedestrian and a bicycle leads to the risk of life immediately. It is considered that the reduction of the traffic accident by the AHS service makes the mental burden of the assailant ease as a result.

(e) The improvement in living environment

It becomes easy to live, because the reduction of the traffic accident brings about improvement in the living environment of a community.

3.2 The questionnaire

Each psychological effect was evaluated in five steps by the questionnaire which 155 students of Gifu University replied as a subject in December of 2001. We made them to watch the video of introducing the AHS which is "Infrastructure of the ITS age: Advanced Cruise-Assist Highway Systems" produced by the Integrate Institute of Land, Infrastructure Technical Policy in the Ministry of Land, Infrastructure and Transport, because there was the problem how the subjects are made to recognize correctly the AHS services which are still the experimental stage in the questionnaire.

3.3 The result of evaluating the psychological effects

The results given by the questionnaire are shown in Figure 3 - 6. These Figures show the evaluation of each psychological effects brought by each AHS service.

'(1) Prevention of collisions with obstacles' and '(3) Prevention of crossing collisions' have a great influence on '(a) the mitigation of the dangerous feeling to traffic accidents' and '(b) the relief of the feeling of strain in driving', but they have a little influence on '(e) the improvement in living environment'. Any psychological effect brought by '(2) Lane keeping' is smaller than that of other services. The subjects do not attach importance to '(2) Lane keeping' so much from the side of a psychological effect. However, '(2) Lane keeping' has an effect of making it easy to drive for an inexperienced person or elderly people. Since the subjects of this questionnaire were university students, the feeling of an elderly people or an inexperienced person may not fully have been reflected. '(4) Prevention of collisions with pedestrians crossing streets' has a great influence on '(d) the reduction of pedestrian and bicycle accidents' and '(e) the improvement in living environment' as compared with other AHS services. Therefore, it is thought that the reduction of the traffic accident to pedestrians is recognized to improve the safety and comfort in a community.

We give a score such as 'non' is 0 run, 'little' is 1 run, 'moderate' is 2 runs, 'enough' is 3 runs and 'great' is 4 runs to evaluate the psychological effect in Figure 3 - 6. Figure 7 shows the result of tallying those scores to compare the evaluations of the psychological effect.

Although it is meaningless for the absolute values of the scores, the order is relatively '(4) Prevention of collisions with pedestrians crossing streets', '(3) Prevention of crossing collisions', '(1) Prevention of collisions with obstacles' and '(2) Lane keeping'. This sequence is the same as the sequence of the death toll in the traffic accidents encountered on roads all over Japan, classified into causative types shown in Figure 2 except '(2) Lane keeping'. Therefore, it can be said that the psychological effect and an actual traffic accident occurrence situation are approximately correlated.

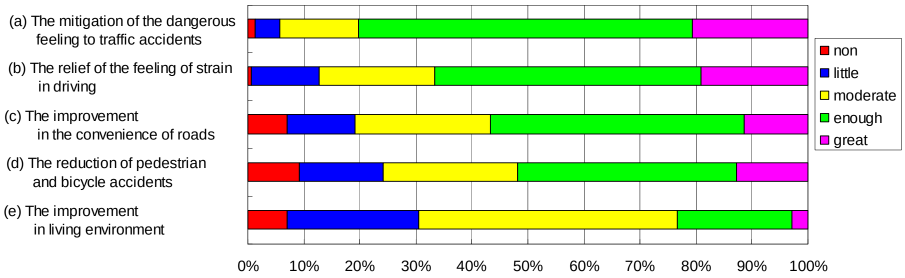

Figure 3 Psychological effects brought by '(1) Prevention of collisions with obstacles'

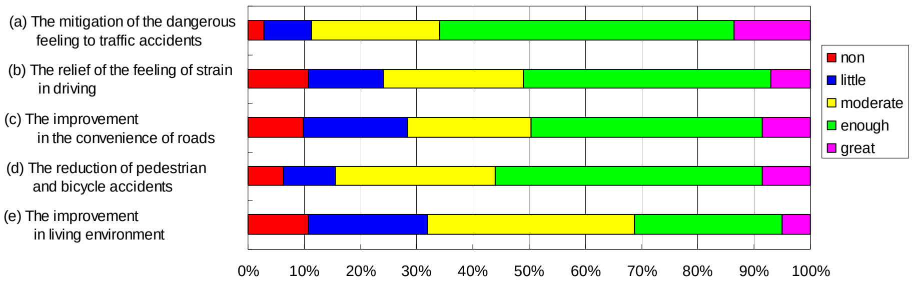

Figure 4 Psychological effects brought by '(2) Lane keeping'

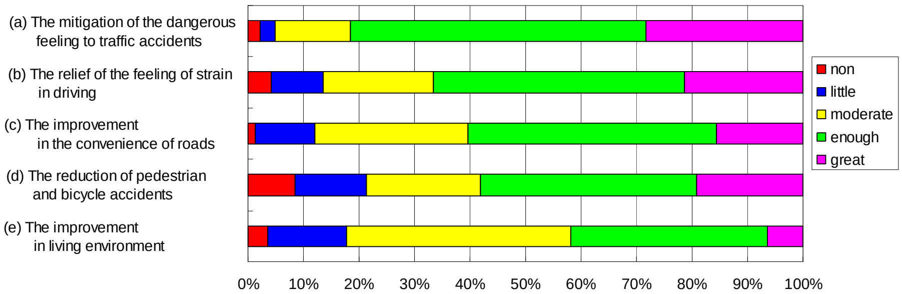

Figure 5 Psychological effects brought by '(3) Prevention of crossing collisions'

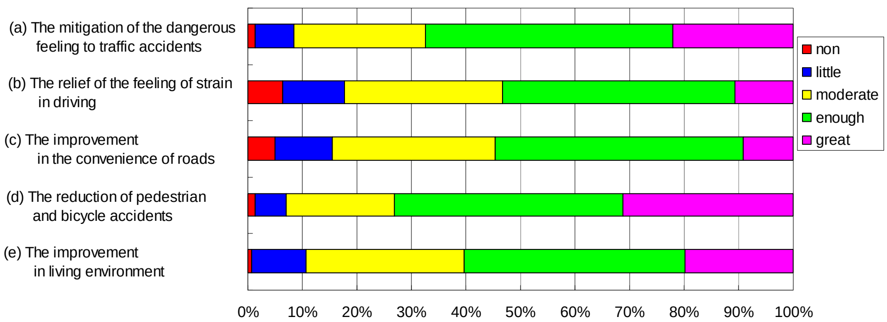

Figure 6 Psychological effects brought by '(4) Prevention of collisions with pedestrians crossing streets'

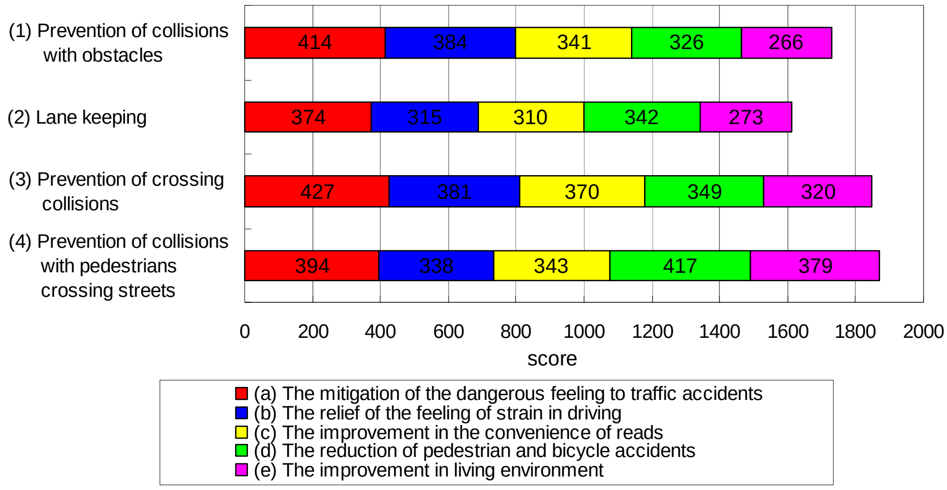

Figure 7 Scored evaluation of psychological effects

4. Economic evaluation of the AHS service with Conjoint Analysis

4.1 Outline of Conjoint Analysis

The conjoint analysis was developed in the field of measurement psychology in the 1960s, and then has been researched in the field of marketing survey. On the other hand, the basic theory is the same as the disaggregate model (Japan Society of Civil Engineers, 1995) researched in the field of the transportation planning in the 1980s. Recently, the conjoint analysis is applied as the analysis method for compensating the weak point of CVM (Contingent Valuation Method) which is one of the non-market evaluation methods used in the field of environmental economics (Ohno, E., 2000).

The value of attribution is estimated by asking the preference while some cards called the profile which consists of attributions, are shown to a subject in the conjoint analysis.

4.2 Making the profile

The example of the profile used in the questionnaire is shown in Figure 8. We make the profile with assuming the hypothetical market of the AHS service as the substitute market of vehicle. The profile consists of some of four kinds of the AHS services introduce and the additional cost that is paid to use the AHS service with the price of vehicle when purchasing the vehicle. The example in Figure 8 assumes as follows.

The AHS services of ‘(1) Prevention of collisions with obstacles’ and ‘(2) Lane keeping’ will be introduced if the additional cost of 0.3 million yen is paid in the profile A.

The AHS services of ‘(3) Prevention of crossing collisions’ and ‘(4) Prevention of collisions with pedestrians crossing streets’ will be introduced if the additional cost of 0.4 million yen is paid in the profile B.

The price of vehicle is 1.8 million yen.

The additional cost per one AHS service is set as 0.15 - 0.55 million yen per vehicle in the questionnaire.

The subjects answer which of profile A or B or neither is preferred. We showed subjects ten sets of the combination of such a profile per one person and made them reply. In this study, since the substitute market of vehicle is assumed, the subject replies to the questionnaires from the viewpoint of the automobile buyer's, i.e., the driver. Although the evaluation from a viewpoint of a pedestrian or a local resident is also important, we would like to make it into a future subject.

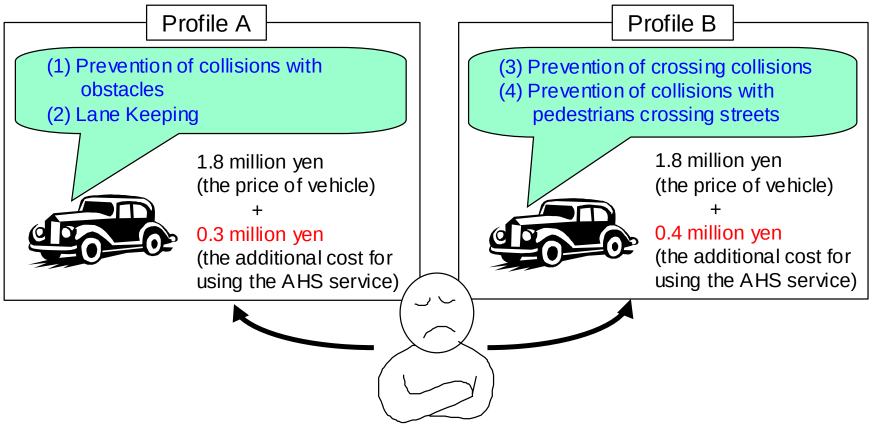

Figure 8 Example of profile in questionnaire

4.3 Formulization of willingness to pay the AHS service

This study formulizes the probability of choosing a profile with a logit model. The probability of choosing the profile A is represented as follows.

$$P_A = \frac{\exp(\theta V_A)}{\exp(\theta V_A) + \exp(\theta V_B)}, \qquad (1.a)$$

$$V_j = V_j\left[h^k(x_k),\ Z_j\right] \quad , \qquad (1.b)$$

where P_A: the probability of choosing the profile A, V_j: the utility level of choosing the profile j (=A, B), $h^k(\cdot)$: the index that standardizes the reduction of traffic accidents by the AHS to 0-1, x_k: the dummy variable that shows with or without the AHS k (with: $x_k = 1$, without: $x_k = 0$), Z_j: the willingness to pay for choosing the profile j, θ: the parameter of logit ($\theta = 1$). $h^k(\cdot)$ of the equation (1.b) expresses the influence of the AHS represented by the dummy variable as the actual reduction effect of traffic accident.

The willingness to pay is given by developing the utility function of the equation (1.b). The total differential of the utility function, V_j, represents

$$\sum_k \frac{\partial V_j}{\partial h}\frac{\partial h^k}{\partial x_k}dx_k + \frac{\partial V_j}{\partial Z_j}dZ_j = dV_j\,. \qquad (2.a)$$

If the utility level in the equation (2.a) is fixed ($dV_j = 0$) and the dummy variables, x_l, of the AHS services other than the introduced AHS service k are fixed ($dx_l = 0$, $l \neq k$),

$$\frac{\partial V_j}{\partial h}\frac{\partial h^k}{\partial x_k}dx_k + \frac{\partial V_j}{\partial Z_j}dZ_j = 0 \qquad (2.b)$$

is obtained. Therefore, the marginal willingness to pay (MWTP) is obtained as follows.

$$MWTP_k = \frac{dZ_j}{dx_k} = -\left(\frac{\partial V_j}{\partial h}\frac{\partial h}{\partial x_k}\right)\Bigg/\frac{\partial V_j}{\partial Z_j} \qquad (2.c)$$

On the other hand, the willingness to pay to introduce two or more AHS services can be derived so that the compensating variation (CV) is usually derived. We are able to calculate the value of the willingness to pay based on the following equation,

$$V_j\left[h(x_k = 0), Z_j\right] = V_j\left[h(x_k, x_l = 1), \left(Z_j + WTP\right)\right]\,. \qquad (3)$$

The left part of the equation (3) represents the situation that any AHS service is not introduced, in other words, the utility level substituted $x_k = 0$ for every AHS dummy variable. In the right part of the equation (3), 1 is substituted for x_k and x_l as introducing the AHS service k and l, and the additional cost, Z_j, which is the willingness to pay the AHS service added to the price of vehicle.

4.4 Specification of utility function

The kinds of utility function used in this study are linear, CES type and fuzzy integral (Sugeno integral and Choquet integral) type, because nonlinear utility function can grasp the synergistic effect and the offsetting effect.

The fuzzy integral determines the value of comprehensive evaluation by comparing the importance of some evaluation criteria based on the one-pair comparison method etc. This is also able to estimate the synergistic effect and the offsetting effect between the plural AHS services. Here, we evaluate the AHS service with the conjoint analysis by considering that the comprehensive evaluation value of the fuzzy integral corresponds with the utility in economics. We adopt Sugeno integral and Choquet integral out of several types proposed now.

4.4.1 Linear utility function

The linear utility function has been used in many previous researches on conjoint analysis, because of getting a good handle. The linear utility function is represented as follows.

$$V_j = \sum_k \alpha_k h^k(x_k) + \beta Z_j , \tag{4}$$

where α_k, β: the parameters estimated by questionnaire.

In the case of using the linear utility function, the willingness to pay the AHS service, $WTP_{(L)}$, is given by the following equation.

$$WTP_{(L)} = -\frac{1}{\beta}\sum_k \alpha_k h^k , \tag{5}$$

where k: the kind of the introducing AHS service.

4.4.2 CES type utility function

The CES type utility function is represented as follows (Japan Society of Civil Engineers, 1995).

$$V_j = \left[\sum_k \alpha_k^1 h^k(x_k)^{-\rho}\right]^{-\frac{1}{\rho}} + \beta^1 Z_j \tag{6}$$

where α_k^1, β^1: the parameters which we have to estimate afresh because of using a utility function as a CES type, ρ: the parameter of showing alternative elasticity between the AHS services. The CES type function corresponds with the linear function in the case of $\rho = -1$, the synergistic effect shows up in the case of $\rho > -1$, and the offsetting effect shows up in the case of $\rho < -1$. In the equation (6), only the part of the AHS service is described by nonlinear, the part of Z_j represented the willingness to pay is linear.

The willingness to pay the AHS service, $WTP_{(N-L)}$, is represented as follows.

$$WTP_{(N-L)} = -\frac{1}{\beta^1}\left[\sum_k \alpha_k^1 h_k{}^{-\rho}\right]^{-\frac{1}{\rho}} . \tag{7}$$

4.4.3 Fuzzy integral (Sugeno integral) type utility function

Firstly, in the Sugeno integral, the fuzzy measure, g, is represented having only monotonicity instead of the weight parameter, α_k, to the AHS service in the linear utility function. If the AHS services from x_1 to x_k is introduced, the fuzzy measure is represented as follows (Sugeno, M., Murofushi, T., 1993).

$$g_\lambda\left(\bigcup_{k=1} x_k\right)=\frac{1}{\lambda}\left[\prod_{k=1}\{1+\lambda g(x_k)\}-1\right], \tag{8}$$

where λ : the parameter which specifies the additive property between the plural AHS services, $\lambda > 0$: additive (synergistic), $\lambda = 0$: additive identity, $\lambda < 0$: additive inverse (offsetting). The fuzzy integral (Sugeno integral) type utility function using the fuzzy measure, g, of the equation (8) is represented as follows.

$$V_j = \bigvee_k \left[h(x_k)\wedge g_\lambda(X_k)\right]+\beta^2 Z_j, \tag{9}$$

where $X_k=\{x_1,\cdots,x_k\}$, $\wedge$ and $\vee$ mean that maximum and minimum are chosen, respectively, $h^k(x_k)$ satisfies the condition of $0\le h^1(x_1)\le h^2(x_2)\le\cdots\le h^k(x_k)\le\cdots\le 1$. g, λ and β^2 are the unknown parameter estimated by the questionnaire.

The willingness to pay, $WTP_{(FI-S)}$, is given as follows.

$$WTP_{(FI-S)} = -\frac{1}{\beta^2}\cdot\bigvee_k\left[h^k(x_k)\wedge g_\lambda(X_k)\right]. \tag{10}$$

4.4.4 Fuzzy integral (Choquet integral) type utility function

The fuzzy integral (Choquet integral) type utility function is represented as follows (Asai, Y., Negoita, C.V., 1978).

$$V_j = \int_0^1 g_\lambda(X_k)dh+\beta^3 Z_j, \tag{11}$$

The willingness to pay, $WTP_{(FI-C)}$, is given as follows.

$$WTP_{(FI-S)} = -\frac{1}{\beta^3}\cdot\int_0^1 g_\lambda(X_k)dh. \tag{12}$$

4.5 The result of estimating the willingness to pay

Firstly, the result of estimating the h^k is shown in Table 1. The index, h^k, that denotes the effect of reducing the traffic accident by the AHS service is estimated by assuming the following.

The effect of reducing the traffic accident is defined as the amount of reducing the damage cost of traffic accident by the AHS service.

The damage cost of traffic accident is measured by which the number of traffic accidents and the original unit of damage cost for every type of traffic accident reduced by the AHS service are multiplied after classifying the present traffic accident condition using the annual report of traffic accident statistics

The number of traffic accidents decreases 25% by the AHS service.

The decreased damage cost of traffic accident is scaled from 0 to 1.

Secondly, the result of estimating the parameter is shown in Table 2. We estimated the parameter using the maximum likelihood estimation method and the 1,221 sets (the valid response rate is 78.8%) of available data which show the preference relation to the introducing AHS service and the willingness to pay obtained by the questionnaire.

It was given the result that the synergistic effect is obtained by the plural AHS service, because the value of the parameter, ρ, of the CES type showing the alternative elasticity is larger than –1 ($\rho > -1$). However, it was given the reverse result that the offsetting effect is obtained by the plural AHS service, because the value of the parameter, λ, of the fuzzy integral (both of Sugeno integral and Choquet integral) type utility function is smaller than 0 ($\lambda < 0$).

Table 1 Effect of reducing traffic accidents

AHS service	effect
(1) Prevention of collisions with obstacles (h^1)	0.211
(2) Lane keeping (h^2)	0.044
(3) Prevention of crossing collisions (h^3)	0.624
(4) Prevention of collisions with pedestrians crossing streets (h^4)	0.120

Table 2 Estimation of parameters

Normal type Utility Function			Fuzzy Integral type Utility Function		
	Linear	CES type		Sugeno integral	Choquet integral
α_1	1.612(9.938)	1.612(12.460)	g_1	0.343	0.343
α_2	0.605(0.502)	0.609(0.339)	g_2	0.028	0.028
α_3	0.622(4.812)	0.643(4.462)	g_3	0.391	0.391
α_4	5.003(9.603)	5.031(35.258)	g_4	0.602	0.602
β	-0.016(-4.116)	-0.016(-0.639)	β	-0.013	-0.029
ρ	-	-0.927(-9.998)	λ	-0.033	-0.149
Hitting ratio	58.0%	51.6%	Hitting ratio	52.4%	55.7%
Likelihood	0.0957	0.0719	Likelihood	0.0417	0.0720

*( ): t-value

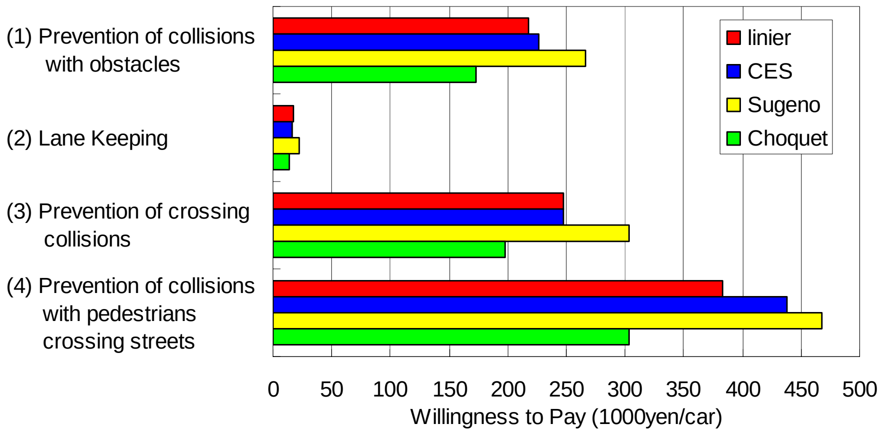

Figure 9 Willingness to pay for introducing AHS

Finally, the result of estimating the willingness to pay the AHS service is shown in Figure 9. The value of willingness to pay '(4) Prevention of collisions with pedestrians crossing streets' is the largest and the value of willingness to pay '(2) Lane keeping' is extremely the smallest in the result of any type function. This results that the willingness to pay '(2) Lane keeping' is small is the same as the result of the psychological effect, and it is considered that the reason is also the same. However, one of the reasons bringing such an extreme result is whether the subject has correctly recognized the AHS service of '(2) Lane keeping'.

The rate for which each four kinds of AHS services accounts to the whole in the average of the willingness to pay evaluated by four kinds of functions, the scored evaluation of the psychological effects, and the number of fatalities in accidents is shown in Figure 10 in order to compare this evaluation result. The sequence of the willingness to pay corresponds to the relative sequence of the scored evaluation of psychological effect. It is considered that the subjects have consistently judged between the willingness to pay and the psychological effect. Therefore, we would like to insist that we were able to estimate the willingness to pay reflecting the psychological effect. The sequence of willingness to pay is also the same as the sequence of the number of fatalities in the traffic accidents classified into causative types except '(2) Lane keeping.' Therefore, we have approximately estimated the willingness to pay reflecting the actual traffic accident occurrence situation.

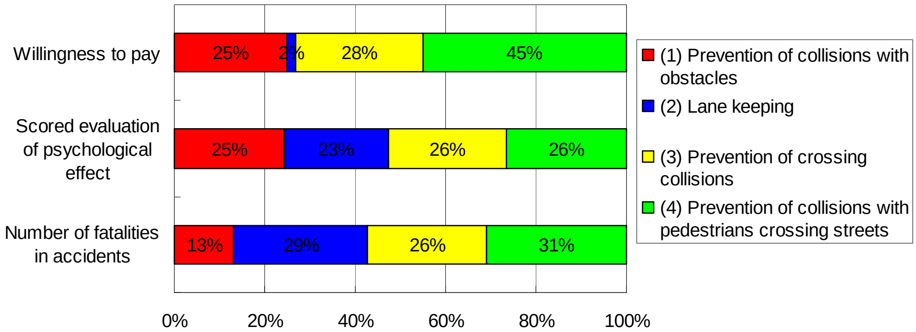

Figure 10 Comparison of evaluation of AHS service

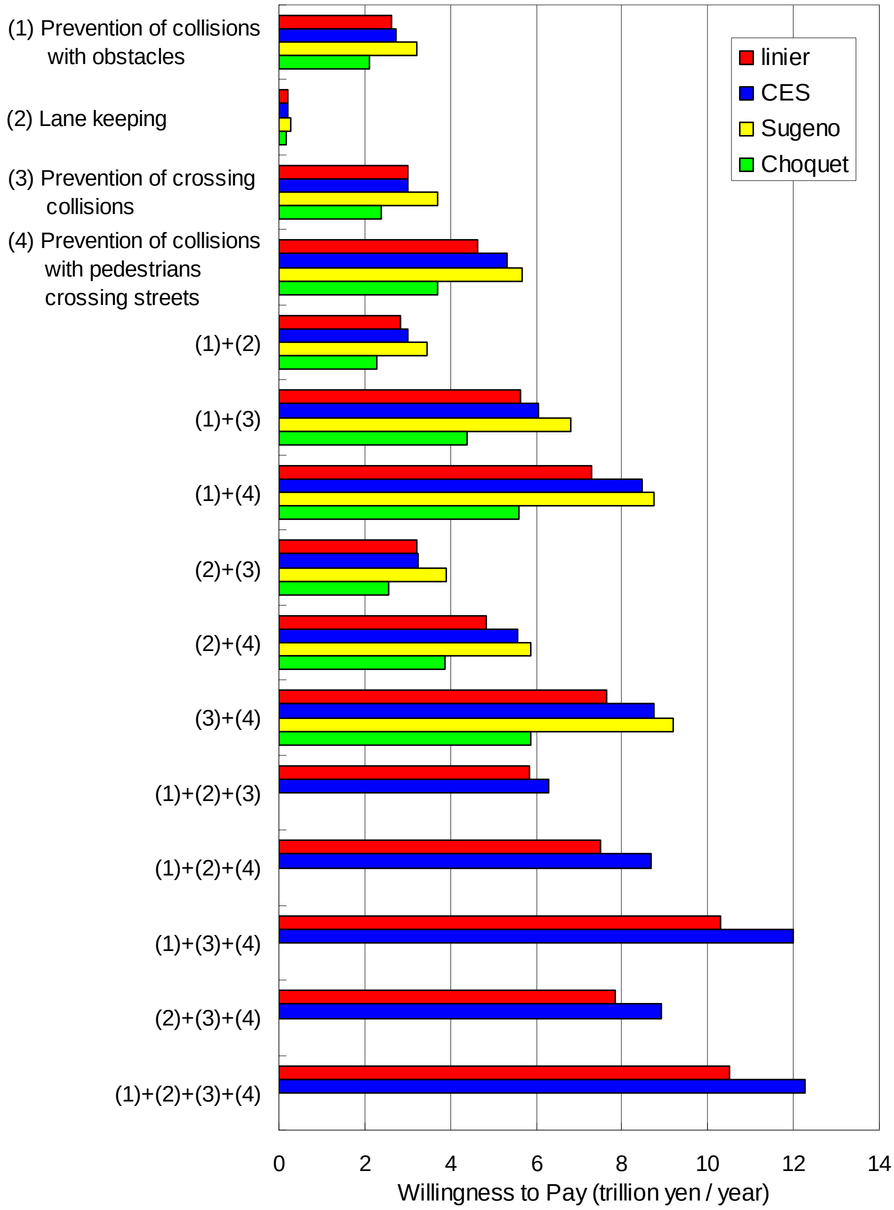

Figure 11 Economic evaluation of introducing AHS service

4.6 The result of economic evaluation of the AHS service

We try to economically evaluate the AHS service in Japan whole country based on the willingness to pay shown in Figure 9. Firstly, it converts into the willingness to pay per year by assuming the period of using a vehicle to be seven years and the social discount rate to be 4 %. Next, the sum of the willingness to pay is calculated by multiplying the annual amount of money per car by the number of the vehicle ownership in Japan (Road Economic Research Institute, Road Traffic Economy Research Association, 2001). Furthermore, if the plural kinds of AHS services are introduced together, it evaluates similarly using the estimated formula. However, the fuzzy integral cannot estimate three or more kinds of AHS services together because of a questionnaire design. The result is shown in Figure 10.

'(4) Prevention of collisions with pedestrians crossing streets' is the largest in the annual social benefit brought by the single AHS service. The annual benefit of (4) is estimated at 4 - 5.5 trillion yen and that of '(1) Prevention of collisions with obstacles' or '(3) Prevention of crossing collisions' are estimated at 2 - 3.3 trillion yen. In the viewpoint of comparing the type of function, the benefit estimated by using the Sugeno integral is the largest and that by the Choquet integral is the smallest. In the result of evaluating two kinds of AHS services, the Sugeno integral is the largest in spite of having the offsetting effect, because the benefit by the single AHS service is larger than the degree of offsetting. The annual social benefit by the all four kinds of AHS services is estimated at 10 – 12 trillion yen.

5. Conclusions

This paper economically evaluated the Advanced Cruise-Assist Highway Systems (AHS) that improves the traffic safety by using the advanced information technology.

We evaluated the AHS service focusing on the psychological effects brought with the conjoint analysis, after evaluating the psychological effects by the questionnaire directly. The result that the sequence of the willingness to pay had consistency in the relative sequence of the scored evaluation of psychological effects was obtained. The sequence of the willingness to pay is also the same as the sequence of the number of fatalities in the traffic accidents classified into causative types on roads all over Japan except '(2) Lane keeping.' Therefore, we have approximately estimated the willingness to pay reflecting the psychological effect and the actual traffic accident occurrence situation.

We evaluated the plural kinds of AHS services considering the synergistic or offsetting effect between them by applying not only a linear function but also nonlinear functions such as the CES type function and the fuzzy integral (Sugeno integral and Choquet integral) type function to the utility function in the conjoint analysis. As the result of this study, the synergistic effect is appeared in the case of using the CES type utility function, but the offsetting effect is appeared in the case of using the fuzzy integral type utility function. We have to investigate the cause of such a difference more in the future.

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