Evaluation of Advanced Cruise-Assist Highway Systems with Fuzzy Integral in Terms of Non-market Value

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***Abstract* – The Advanced Cruse-Assist Highway Systems(AHS) improve the safety of road traffic by assisting the operational work of drivers. The AHS is expected not only to decrease the damage cost of traffic accidents but also to improve comfortableness and reduce feeling of dangerous or anxious which we call non-market value. At first, we clarify the existence of non-market value by carrying out the questionnaire survey. Next, we analyze factors generating the non-market value, and evaluate the AHS in terms of non-market value by applying the fuzzy integral.**

***Keywords* - Advanced Cruise-Assist Highway Systems, Non-market Value, Fuzzy Integral**

I. INTRODUCTION

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 the brake and handle.

The traffic accidents decrease and the damage reduces, because the information needed for the instantaneous judgment is provided on real time by the AHS. 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. In this paper, we call a psychological effect the non-market value in order to distinguish from the regulatory effect of traffic accident cost. This means that economic evaluation of psychological effects is difficult.

Although the non-market value like psychological effects may not be so large with a moment, when it takes into consideration that they continues being generated intermittently during operation, total benefits are possible to become large amount. Therefore, non-market values are thought to be important elements when we analyze introducing effects of AHS. In addition, for exact analysis of its values, it is necessary to clarify the mental structure of drivers.

In this paper, at first, we clarify “Do the non-market value exists or not?” and “How much is the non-market value?” from the questionnaire results. Next we analyze factors generating the non-market value by carrying out the evaluation according to items. In addition, because it is thought that drivers finally give the evaluation for AHS after synthesizing the each item evaluation, we clarify the mental structure of driver by applying the comprehensive evaluation with fuzzy integral.

II. OUTLINE OF THE AHS

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 that are shown in Figure 1 [1]. The AHS provided by them for realization are shown as below.

1) Support for prevention of collisions with forward obstacles
2) Support for prevention of over shooting on curve
3) Support for prevention of lane departure
4) Support for prevention of crossing collisions
5) Support for prevention of right turn collisions

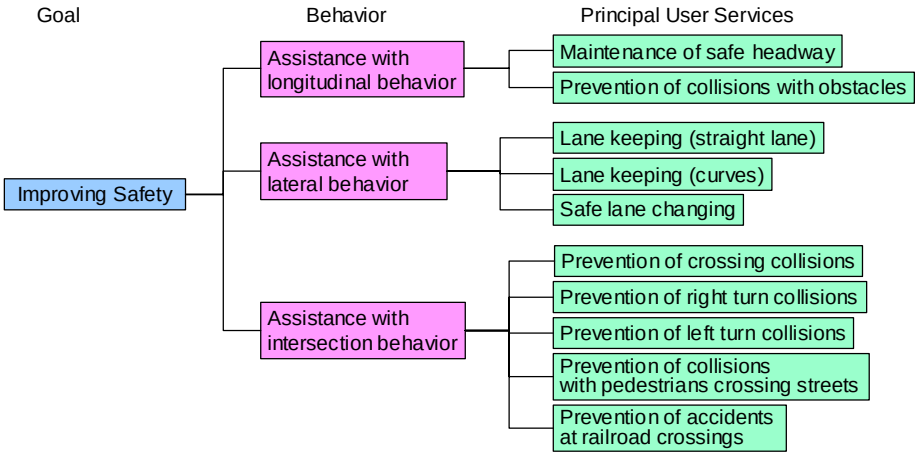

Figure 1. AHS services for improving traffic safety in Japan

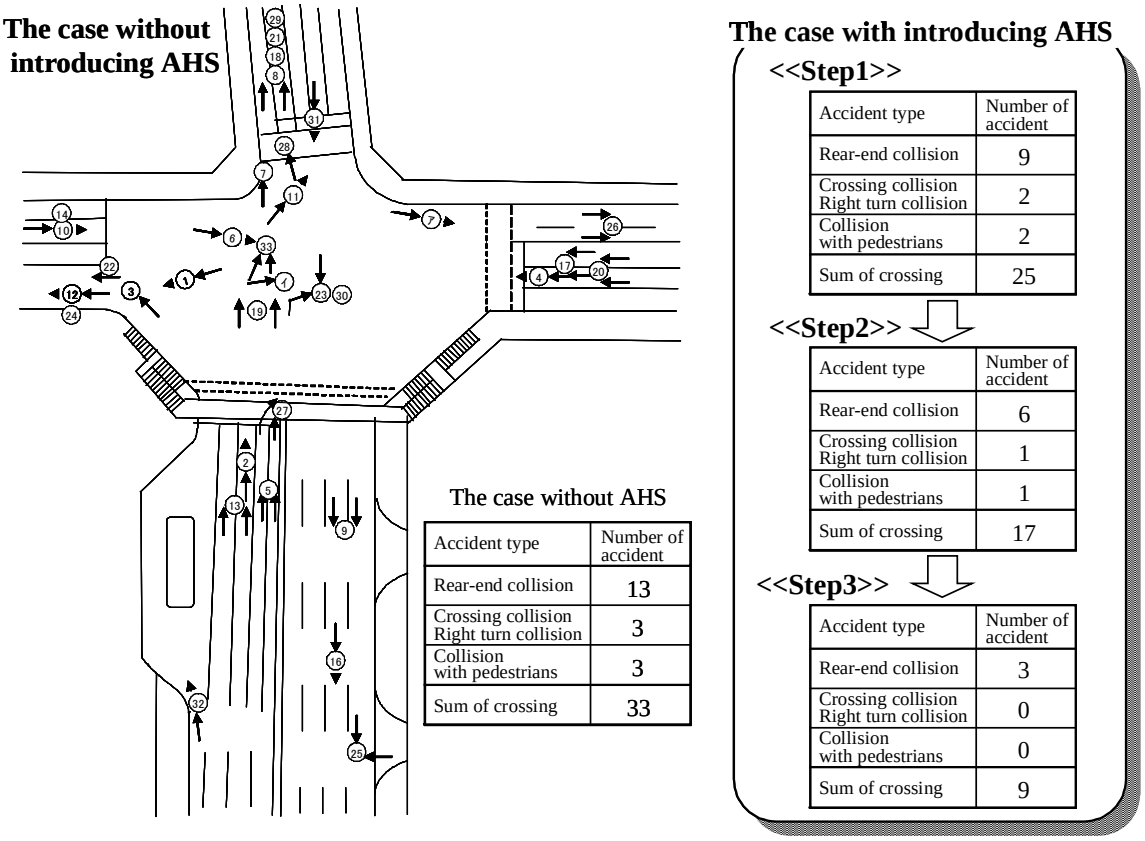

Figure 2. Assumed numbers of accident reduction for fictitious AHS

6) Support for prevention of collisions with pedestrians crossing streets

7) Support for road surface condition information for maintaining headway etc.

III. NON-MARKET VALUE BY INTRODUCING AHS

We confirm the existence of non-market value generated by introducing the AHS with a questionnaire survey. After giving the reduction number of traffic accident assumed by introducing fictitious AHS to subjects of questionnaire, we asked whether they would have the non-market value obtained through improvement comfortableness or the mitigation of dangerous and anxious impression, and how much non-market value they would find out for the AHS.

A. Outline of questionnaire survey

Here, the reduction number of accident by introducing the AHS into a crossing in three steps is set up as Fig.2. And, to the setting of Fig.2, we performed the following questions[2][3].

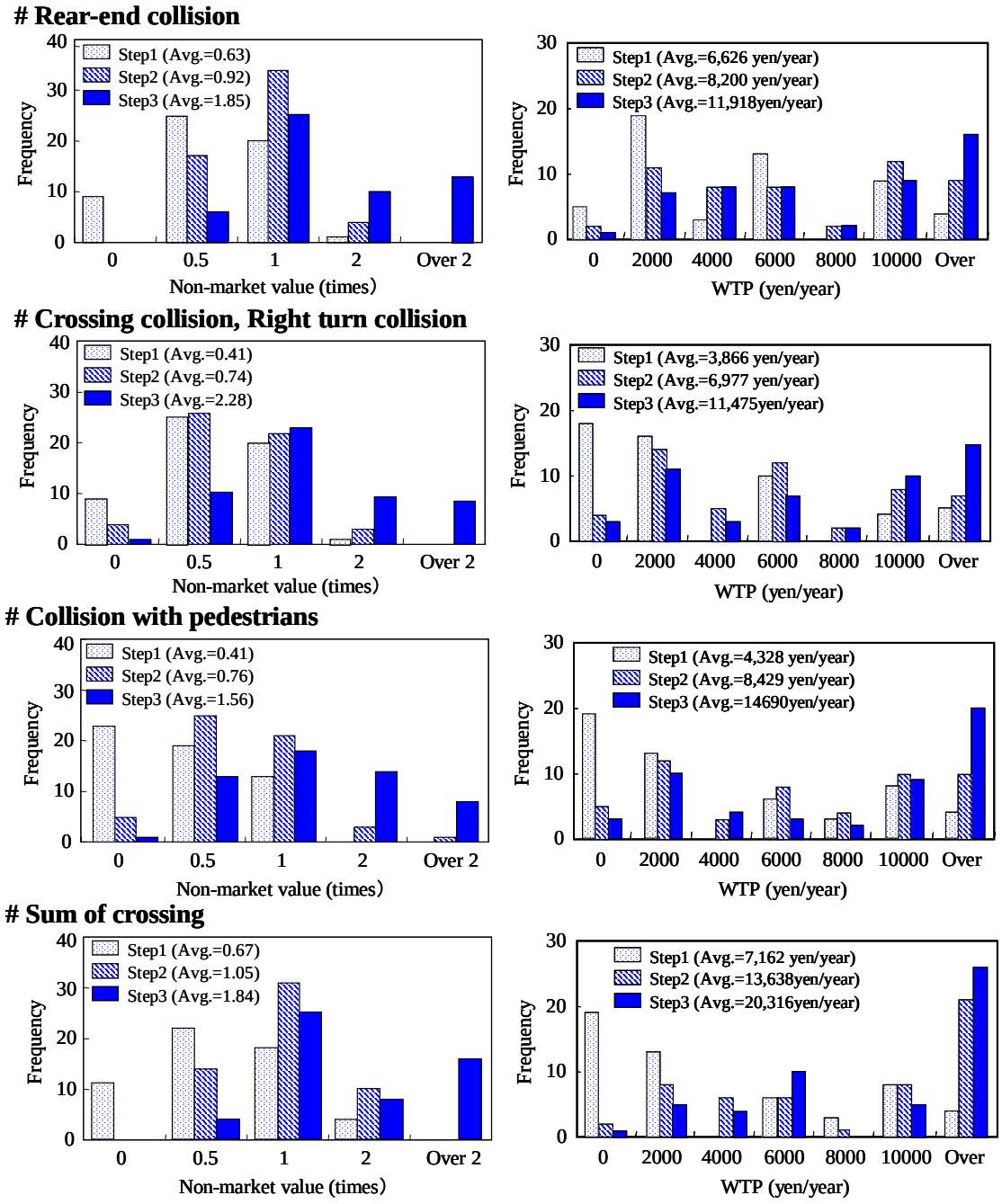

Figure 3. The results of measured non-market value

Question 1: How much the non-market value do you feel as compared with the reduction damage costs of traffic accidents? Please answer that it is a number of times of the reduction effect.

Question 2: How much may you pay annually in order to acquire the non-market value?

Here, before asking above questions, we informed the details of AHS to subjects by showing the introduction VTR of AHS.

B. Result of questionnaire survey

The results of measured non-market value are shown in Fig.3. The ratio of non-market value to the reduction damage costs and willingness to pay (WTP) for its value are clarified to each step introducing AHS.

These results indicate that the non-market value exists surely. Seeing the ratio result of non-market value to reduction damage costs, it turns out that distribution has shifted rightward from step 1 to 3. Especially, at step 3, they seem to feel the non-market value more than the amount of reduction damage costs. On the other hand, it seems that distribution of WTP is shifted rightward, although its spread is large. And the average value of

WTP to each step is increasing.

From the above result, although it is difficult to specify the amount of non-market value, it will be allowed to accept its existence.

IV. MODEL TO EVALUATE NON- MARKET VALUE

A. Outline of evaluation of the non-market values

First, we set up five kinds of the non-market values by introducing the AHS. We evaluate them with weight using the AHP. The AHP finds the value of evaluating each factor by asking the preference between evaluation factors in a questionnaire based on the one-pair comparison method and can find the value of comprehensive evaluation by summing the value of evaluating each factor with weight as follows.

$$z^j = \sum_{i=1}^{n} w_i \cdot h^j(i) \qquad (1)$$

where j : the superscript that means the alternative plan, w_i : the important degree (= weight) of evaluation factor i, $h^j(i)$: the value of evaluation factor i.

However, the simple weighted sum may not sufficiently correspond with a real comprehensive evaluation because there may be an interaction between evaluation factors in which case people make decisions. The fuzzy integral is developed as a model similar to the structure of human decision-making. The fuzzy integral which is built in this study, finds the value of comprehensive evaluation by applying the value of evaluation with fuzzy measure to the evaluation factor used in the AHP. Although the fuzzy integral is a kind of model that determines a weighted average, it is useful in the respect that it can estimate the synergistic effect or the offset effect which cannot be estimated by a simple weighted average.

The fuzzy measure is a measure that is introduced a fuzzy property into the criterion of evaluating a factor. In this paper, the fuzzy property is monotonous but need not be additive. The additive is represented by the following equation.

$$\mu(A \cup B) = \mu(A) + \mu(B) \quad [\text{where} \quad A \cap B = \phi] \qquad (2)$$

We have to separately determine the value of $\mu(A \cup B)$, because the equation (2) need not be formed in the fuzzy measure. However, there is a problem that the number of measures which should be determined, exponentially increases according to the additional number of evaluation factors such case as evaluation factors are added except A and B. Therefore, the fuzzy measure λ was developed. The fuzzy measure λ is represented as follows.

$$\mu_\lambda(A \cup B) = \mu_\lambda(A) + \mu_\lambda(B) + \lambda\, \mu_\lambda(A)\, \mu_\lambda(B) \quad [\text{where} \quad A \cap B = \phi] \qquad (3)$$

The fuzzy measure λ has the following characteristics.

$$\text{If} \quad \lambda > 0 \quad \text{then} \quad \mu_\lambda(A \cup B) > \mu_\lambda(A) + \mu_\lambda(B) \quad [\text{synergistic}], \qquad (4a)$$

$$\text{If} \quad \lambda = 0 \quad \text{then} \quad \mu_\lambda(A \cup B) = \mu_\lambda(A) + \mu_\lambda(B) \quad [\text{additive}], \qquad (4b)$$

$$\text{If} \quad \lambda < 0 \quad \text{then} \quad \mu_\lambda(A \cup B) < \mu_\lambda(A) + \mu_\lambda(B) \quad [\text{offset}]. \qquad (4c)$$

The model that defines the value of comprehensive evaluation to the equation (1) using the fuzzy measure, is the fuzzy integral [4]. There are several kinds of fuzzy integral proposed until now. This paper uses the Choquet integral. The Choquet integral is represented as follows.

$$z^j = (C)\int h^j d\mu = \sum_k \mu_\lambda(k)\left[h^j(k) - h^j(k-1)\right] \qquad (5)$$

B. Evaluation of AHS with fuzzy integral

Japanese Ministry of Land, Infrastructure and Transport is working on seven kinds of AHS services for utilization in order to improve the traffic safety now. In this paper, we try to evaluate the following AHS services.

(1) Support for prevention of collisions with forward obstacles

(2) Support for prevention of lane departure

(3) Support for prevention of crossing collisions

(4) Support for prevention of collisions with pedestrians crossing streets

We aim at evaluating the non-market value by introducing the four kinds of the AHS service. We try to evaluate five kinds of factor as follows.

(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.

Each factor of the non-market value was evaluated in five levels by the questionnaire. 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 the evaluation of each factor of the non-market value. Figure 4 shows the result of tallying those scores to compare the evaluations of each factor. 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'.

The important degrees between factors were evaluated by the questionnaire of one-pair comparison. As this result, the one-pair comparison matrix was made and the proper vector was determined, and then the values of weighted evaluation between all factors were determined in Table 1.

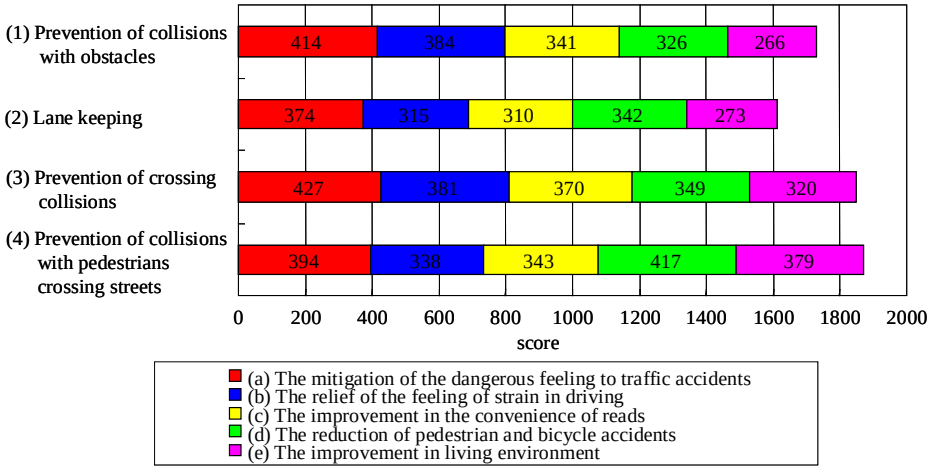

Figure 4. Scored evaluation of each factor of the psychological effect

Table 1. One-pair 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

Table 2. Comprehensive evaluation by summing with weight

	(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 accidents (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	<1>
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	<2>
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	<3>
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	<4>

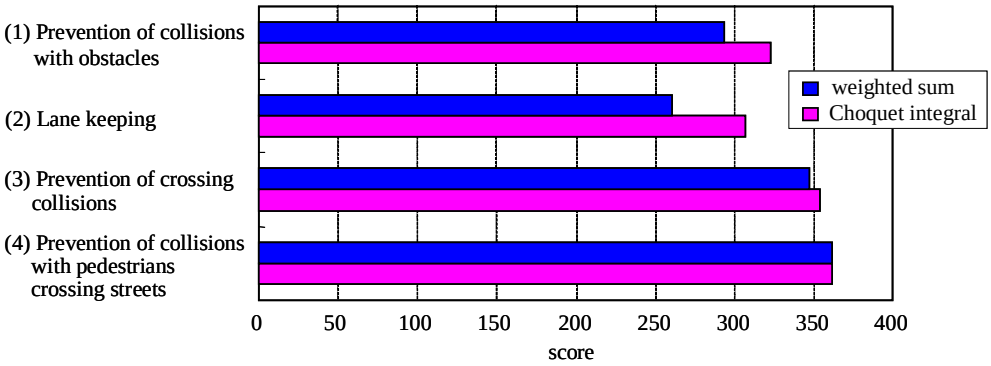

Figure 5. Comparison of the comprehensive evaluations with the Choquet integral and the weighted sum

The value of comprehensive evaluation with the traditional AHP can be determined by the important degrees between factors are the proper vector and the value of evaluating each factor those are shown in Table 1. This corresponds to the case that λ equals 0 in the fuzzy integral.

The result of comprehensive evaluation by the simple weighted sum is shown in Table 2. The value of comprehensive evaluation that is determined by the simple weighted sum and the ranking are shown on the most right column in Table 2.

Finally, the values of comprehensive evaluation were determined by using the fuzzy integral (Choquet integral). Figure 5 is shown comparing the values of comprehensive evaluation with the Choquet integral and the weighted sum. Here, the result of the Choquet integral is calculated as $\lambda = 3.199$.

The values of comprehensively evaluating the psychological effect by introducing the AHS to crossing such as '(3) Prevention of crossing collisions' and '(4) Prevention of collisions with pedestrians crossing streets' are higher. It seems that a driver feels the largest psychological load at the crossing during driving. Especially, many drivers feel a large load for the psychological factors such as (d) The reduction of pedestrian and bicycle accidents and (e) The improvement in living environment.

V. CONCLUDING REMARKS

We proposed the evaluation technique based on fuzzy integral in order to evaluate the AHS in terms of non-market value. It is thought that the proposed model makes possible to evaluate non-market value paying attention to mental structure of drivers, because its model permits us to take into consideration the relationship among the factors of evaluation.

It has not resulted in quantitative evaluation yet. Future, when we try to judge the rationality for introducing the AHS in which the non-market value is also considered as an object, the calculation of non-market value seems to be required by using our proposed model.

ACKNOWLEDGHMENT

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