Acceptability of ISA Based on a Field Experiment and a SP Survey:
Analyses from a Standpoint of Traffic Calming

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Abstract: Intelligent speed adaptation (ISA) has the possibility to be a drastic tool for traffic calming in Japan if they are disseminated once. The aim of this study is to examine the drivers’ acceptability for the three types of ISA associated with the types of target roads and some monetary incentive measures. To achieve the aim, a field experiment with Advisory ISA and a SP questionnaire survey were conducted. Based on the field experiment, the effectiveness of the combination of Zone30 regulation and Advisory ISA is presented. Next, by the SP survey and a model analysis, it is revealed that the types of ISA, the types of target roads on which ISA work, and the amount of monetary incentive measures affect the acceptability of relevant ISA. It is finally suggested that a Voluntary ISA working only on community streets has the potential to be disseminated for traffic calming.

Keywords: ISA, traffic calming, field experiment, monetary incentive measures, SP survey

1. INTRODUCTION

Traffic accident has been a serious social problem in today’s automobile-dependent society. In Japan, the number of traffic accident fatalities has decreased since 1992, fell below five thousand people in 2008, and recorded 4,373 people in 2013 (Cabinet Office, Government of Japan, 2014). However, the numbers of fatalities during walking and bicycle-riding have not been decreasing notably whereas that of motor vehicle occupants has decreased significantly.
Especially, the vulnerable road users, i.e. children under 15 years old and elderly over 65 years old, account for almost a half of all fatalities during walking and account for over one-third of all fatalities during bicycle-riding. In addition, almost a half of the fatalities under 15 years old and over 65 years old were involved in the traffic accidents at the locations less than 500m distance from their homes. Therefore, it is still an important issue to promote traffic calming more and more on community streets. Especially, to manage vehicles’ speed less than 30km/h is one of the important points of traffic calming because it has been established that the chance of speed-related crashes and the probability of fatal injury for a pedestrian colliding with a vehicle increase rapidly as the vehicle’s speed become faster with the border of 30km/h (Global Road Safety Partnership (GRSP), 2008).

Regarding the traffic calming issues, a certain degree of the effectiveness of some physical devises, such as a hump or chicane, has been confirmed with many previous researches and practices (e.g. Lines, 1993; Grosso et al., 2002). Recently, on the other hand, the concern over intelligent speed adaptation (ISA) has been growing, particularly in European countries (Jamson et al., 2006). Carsten and Tate (2005) has explained that “ISA is the generic name for advanced systems in which the vehicle “know” the speed limit and is capable of using that information to give feedback to the driver or limit maximum speed”. According to them, ISA systems have been grouped into three types by the External Vehicle Speed Control (EVSC) project begun in 1997 in UK as follows:

(a) Advisory - display the speed limit and remind the driver of changes in the speed limit;
(b) Voluntary (“Driver Select”) – allow the driver to enable and disable control by the vehicle of maximum speed;
(c) Mandatory – the vehicle is limited at all time.

Moreover, the ISA design had been assumed to be based on roadside dedicated short-range communication (DSRC) beacons since the EVSC project began, but then it have been changed to the design based on a global positioning system (GPS) and digital road maps (DRM). In Sweden, the UK, Netherland, etc., some field trials using ISA-vehicles had already been conducted, which reported the merit of introducing ISA and some issues relating to prevailing ISA (Jamson et al., 2006). Vlassenroot et al. (2007) analyzed the results of the first ISA-trial in Ghent, Belgium in which 34 cars and 3 buses were equipped with Voluntary ISA called “active accelerator pedal”. They showed that there was a reduction in the amount of speeding due to the Voluntary ISA but there was still a large remaining percentage of distance speeding, especially in low speed zones. They also showed that average speed tends to decrease for more frequent speeders while average driving speed almost always increases for less frequent speeders. Warner and Åberg (2008) analyzed the driving behavior of 61 test drivers in total who had an Advisory ISA device installed in their vehicles between 2000 and 2003. They showed that the amount of time the majority of test drivers spent above the speed limit initially reduced due to the Advisory ISA, but this effect decreased with time. Carsten and Tate (2005) has also carried out a cost-benefit analysis considering the social cost for prevailing ISA and the benefit of the reduction of accidents. The result has shown that Mandatory ISA has the largest benefit-to-cost ratios of the three types of ISA.

ISA has the possibility to be a drastic tool for promoting traffic calming in Japan if they are widely disseminated once. Ma and Andreasson (2005) has carried out a simulation analysis to evaluate the impacts of ISA on pedestrian safety in a single lane road, and have presented that raising ISA penetration will reduce both the probability of head-on collision between vehicle and pedestrian and the risk of death in the accidents. Since, however, ISA is
also a system to repress drivers’ freedom of driving, the acceptability or willingness of drivers to equip their own cars with the function of ISA must be very important. In particular, as shown in Figure 1, although the acceptability for Advisory ISA which has lower repression level of freedom of driving may be the highest followed by Voluntary ISA and Mandatory ISA, the effect of Mandatory ISA on speed management may be the largest followed by Voluntary ISA and Advisory ISA. Because of this situation, the discussions of monetary incentive measures to uplift the drivers’ acceptability for ISA equipment have started. Matsuo et al. (2011) has theoretically described the drivers’ burdens due to Mandatory ISA based on the speed selection model developed, in order to estimate the amount of monetary incentive measures which is enough for drivers to accept Mandatory ISA. Chorlton et al. (2012) has examined drivers’ acceptability for Voluntary ISA and Mandatory ISA, given a number of alternative monetary incentives and non-monetary measures, using a stated preference (SP) questionnaire survey. On the other hand, the acceptability may depend on the extent to which the function of ISA is working (called “targeted road” in this paper). For example, the acceptability of an ISA which works only on community streets may be higher than an ISA which works on all roads. If so, the ISA system only for traffic calming on community streets might be relatively diffusive. However, previous researches have not focused on this point.

The aim of this study is to examine the drivers’ acceptability for the three types of ISA associated with the types of target road and some monetary incentive measures, which will be important knowledge to implement more effective and efficient incentive measures. To achieve the aim, a field experiment with Advisory ISA and a SP questionnaire survey were conducted in this study. The field experiment had two objectives: 1) to analyze the behavioral acceptability for the function of Advisory ISA associated with road attributes; 2) to make participants experienced in the concept in which the in-vehicle device knows, and has sort of interventions based on, the speed limit of the road the driver is driving, for the next SP questionnaire survey. The SP survey was used for analyzing the willingness to equip the participants’ cars with the function of several ISA under the combinations of some conditions including the target road types and the types and amounts of monetary incentive measures. Then the relationships were modeled and discussed.

![Figure 1](Image)

**Figure 1.** Trade-off between the effects on speed management and the freedom of driving (in turn positively related to the drivers' acceptability) with regard to the types of ISA

2. METHODS

2.1 Advisory ISA Application

In order to conduct the field experiment with Advisory ISA, a mobile application for a
smartphone with the android operating system was developed. This application had a DRM of Japan (assembled by TOYOTA MAPMASTER INCORPORATED), and stored the road attributes data including the posted speed limit (as of March, 2014) and the road width of each link in the network in the central area of Toyota-city, shown in Figure 2, where was the field experiment area in this study. Also, the application could get the geographical coordinates, i.e. longitudes and latitudes, of the smartphone per second using GPS. When driving with this application, therefore, it could match the coordinates of the vehicle to the each link on the DRM using a map matching (MM) algorism, and then could know the attributes of the road segment that the driver is driving right now.

The application had the function of Advisory ISA which worked only in the field experiment area. The posted speed limit of the road segment on which the driver is driving was always shown on the top of the smartphone display, as shown in Figure 3. Also, the change of the speed limit when moving to another road segment was informed once by a sound like “pon”. Figure 4 shows the various speed limit images which were set in the application by the types of posted speed limits and road width. It should be noted that the mark meaning “Narrow road” was shown for the road segments where there was not any posted speed limit but the road width was less than 5.5m.

The driving speed was calculated once a second using the Doppler effect (DE) of the GPS radio waves and shown on the top of the display too (see again, Figure 3). When the driving speed exceeded the speed limit by 1km/h, the application warned the driver with a female’s voice and a blinking image in Japanese meaning “~ km/h limit”. Figure 4 also shows the various types of the warning images and voice messages. It should be noted that when driving at over 30km/h on road segments where there was not any posted speed limit but the road width was less than 5.5m, the warning message meaning “please drive attention to speed” would happen. This was introduced because in Japan, there are lots of community streets with no posted speed limits where drivers can legally drive at 60km/h. From the problematic situation, it is important to clarify the effects of the Advisory ISA with 30km/h limit on the roads with no posted speed limits because it have been established that driving at less than 30km/h is needed to reduce the chances and damages of vehicle-pedestrian crashes on the narrow road segments as mentioned in the introduction of this paper.

These functions of Advisory ISA could be switched ON/OFF as the configuration. And more, the application recorded some driving log data, per second on a SD card, including the geographical coordinates, driving speed, and the attributes of the road segments, even when the function of Advisory ISA was switched OFF, and could be imported to PC.
In this study, a field experiment with the Advisory ISA application developed was conducted in the central area of Toyota-city, Aichi, Japan, where there have been three Zone30 areas (see Figure 2). Because this experiment was the first trial, participants were only 20 people who live in the Zone30 areas and drive their own cars at least three times a week. They were collected through a recruitment agency. Their ages ranged from 20 to 48, the average was 37, and the half of them was females and the others were males.

In the 5-month-long experiment period, the participants equipped their own cars with a given smartphone with the Advisory ISA application and attended the consecutive three
phases as follows:

1) in phase 1, the function of Advisory ISA was switched OFF and the participants drove as usual for about two months;
2) in phase 2, the function of Advisory ISA was switched ON and the participants drove by utilizing the information from the application for about two months;
3) in phase 3, the function of Advisory ISA was again switched OFF and the participants drove as usual for about a month.

After the phase 2, the participants responded to a questionnaire about the evaluation of the Advisory ISA.

2.3 SP Survey Regarding Acceptability of ISA

After the phase 2 and phase 3, the participants were also asked to respond to stated preference (SP) questionnaires which were designed to analyze the effects of the types of ISA and monetary incentive measures on the acceptability or willingness to equip their own cars with the ISA systems. Four conditional factors with three levels shown in Table 1 were prepared, and then 18 cases of SP questions (9 cases for the questionnaire after phase 2 and the others for the questionnaire after phase 3) were made by using the orthogonal table (L9) to avoid the correlation between each factor. The participants responded whether to equip their own cars with the ISA system under the condition of each case with initial cost of 10,000(Yen) and running cost of 1,000(Yen/year). The one case of the SP questionnaire is shown in Table 2 as an example.

The types of ISA were included because there may be the trade-off relationship between the effects on speed management and drivers’ acceptability with regard to the types of ISA, and the monetary incentive measures should be implemented by comparing the effects and the costs. The types of target road were included because if the acceptability of an ISA which works only on community streets may be higher than an ISA which works on all roads, the ISA system only for traffic calming on community streets will be relatively diffusive. The types of monetary incentive measures were included because the effect of monetary incentive measures may differ between how the incentive is given (particularly between the eases of existing costs such as insurance fee or tax fee and the new rewards such as the fuel token), and the difference will be important to select more effective incentive measures.

In order to model the relationships between the four factors introduced in the SP questionnaires, the binary logit model, that is the simplest discrete choice model, was assumed:

\[
P_{ij} = \frac{1}{1 + e^{-\Delta V_{ij}}}, \tag{1}
\]

\[
\Delta V_{ij} = \alpha_0 + \sum_{k=1}^{3} \alpha_k \cdot X_{ijk}, \tag{2}
\]

where \(P_{ij}\) is the probability that an individual \(i\) accepts the relevant ISA under case \(j\), \(X_{ijk}\) are each condition of case \(j\) and \(\alpha_0, \alpha_k\) are parameters. The interaction effects between the explanatory variables were considered. The model was estimated by MLE based on the responses of the SP questionnaire surveys.
Table 1. Factors and levels or items for the SP questionnaire survey

<table>
<thead>
<tr>
<th>Types of ISA</th>
<th>Types of target road</th>
<th>Types of monetary incentive measures</th>
<th>Amounts of monetary incentive measures</th>
<th>Willingness to equip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisory ISA</td>
<td>All roads</td>
<td>Insurance reduction</td>
<td>6,000 (Yen/year)</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Voluntary ISA</td>
<td>Community streets only</td>
<td>Tax reduction</td>
<td>12,000 (Yen/year)</td>
<td></td>
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<tr>
<td>Mandatory ISA</td>
<td>Arterial roads only</td>
<td>Fuel token</td>
<td>18,000 (Yen/year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1,000 (Yen/year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12,000 (Yen/year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24,000 (Yen/year)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. An example case of the SP question

<table>
<thead>
<tr>
<th>Types of ISA</th>
<th>Types of target road</th>
<th>Types of monetary incentive measures</th>
<th>Amounts of monetary incentive measures</th>
<th>Willingness to equip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisory ISA</td>
<td>Community streets only</td>
<td>Tax reduction</td>
<td>12,000 (Yen/year)</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>

This question means "will you equip your own car with the Advisory ISA which works only on community streets if your auto tax will be reduced by 12,000 Yen a year for the equipment?"

3. RESULTS

3.1 Results of Field Experiment

Because 14 of the 20 participants were assigned an additional rule with driving (this paper do not cover this program), the driving speed data of remaining 6 participants collected in the three phases are compared in this section.

Table 3 and Figure 5 show the total distances driven by the 6 participants and the ratios of distances driven at under the speed limits (adherence distance ratios; ADRs), respectively, for each phase by the speed limits (including road width < 5.5m too). For all the speed limits except for the 30km/h limit, the ADRs in the Phase2 where the Advisory ISA was working were increased compared with those in the Phase1 where the Advisory ISA was NOT working. Here, the result for the 30km/h limit was not clear with the few total distances driven in the three phases because the segments with 30km/h limit are few in the field.
experiment area. It was also shown that for the Zone30 areas, the increase in the ADRs from the Phase1 to Phase2 (+19%) was relatively bigger than the other speed limit segments (averagely +8%).

Focusing on the Phase3 where the Advisory ISA was again switched OFF, the ADRs were decreased compared with the Phase2 for all the speed limit. However, it should be pointed out that the ADRs for Zone30 in the Phase3 kept higher than that in the Phase1 (+15%).

| Table 3. Total distances driven by the 6 participants in each phase by the speed limits |
|-----------------------------------|------------------|------------------|-------------------|------------------|------------------|
| Road width < 5.5m | 30km/h | Zone30 | 40km/h | 50km/h |
| Phase 1 | 99.2 km | 15.0 km | 71.6 km | 803.9 km | 396.7 km |
| Phase 2 | 81.6 km | 18.1 km | 61.2 km | 747.2 km | 398.6 km |
| Phase 3 | 33.1 km | 6.7 km | 16.9 km | 289.2 km | 139.9 km |

Figure 5. Ratios of distances driven at over and under the speed limits in each phase by the speed limits
(“Narrow” means road width < 5.5m, and 30km/h is used as the speed limit for this group)

3.2 Result of SP Questionnaire Survey

All the 20 participants responded to the 18 SP questions, thus the 360 responses were collected. Since the number of respondents was small, the results below have some limitations. It is difficult to clarify the effects of individual attributes on the acceptability of ISA. Also, the results from these respondents do not necessarily mean representing the population. However, it will be worth analyzing factors affecting the acceptability of ISA based on these results as a fundamental study because the results were collected from currently rare respondents who experienced in the concept in which the in-vehicle device knows, and has sort of interventions based on, the speed limit of the road.

Figure 6 shows the acceptance ratios aggregated by the four factors, i.e. types of ISA; types of target road; types of monetary incentive measures; amounts of monetary incentive measures, respectively. For the types of ISA, the acceptance ratio to equip the own car with Advisory ISA was the highest while that with Mandatory ISA was lowest. For the amounts of monetary incentive measures, on the other hand, the acceptance ratio was increased as the amount became higher, but the gradient became lower. There were not large differences of the acceptance ratios for the types of target road and the types of monetary incentive measures.
Since these results by the simple aggregation ignored the interaction effects between the factors, the effects were considered in estimating the model of various ISA acceptances. As a result of estimation, the model considering the interaction effects between the types of ISA and the amounts of monetary incentive measures had the highest $\rho^2 (=0.34)$ and the lowest AIC (=347) of the models which considered the other interaction effects and which did not consider any interaction effects ($\rho^2=0.32$; AIC=349). Table 4 shows the estimated model. The strong statistical significance for the positive effect of the amount of monetary incentive measures on the willingness to equip own car with relevant ISA was shown as resulted in the simple aggregation. Regarding the types of ISA, the acceptance ratio for the mandatory ISA was significantly low compared with that for the Advisory ISA while the difference of the acceptance ratios between Advisory ISA and Voluntary ISA was not statistically significant. Focusing on the interaction effect of the amount and the Voluntary ISA, however, the effect of the amount for the Voluntary ISA was significantly smaller than that for the Advisory ISA. This was also found for the Mandatory ISA, but the statistical significance was somewhat weak. Looking at the types of target road, next, the acceptance tendency of the ISA working only on the community streets (i.e. road segments with 30km/h limit, Zone30, or width < 5.5m) was significantly higher than that of the ISA working on all road segments while such the significant difference for the ISA working only on arterial road segments was not seen. And more, there were slight tendency that the acceptance ratio of the ISA with the fuel token was small compared with that of the ISA with the other type of incentive measures, but the statistical significance was not enough. Besides, although the effect of the additional rule in the field experiment assigned to the 14 respondents and the effect of daily driving behaviors (e.g. CDR of each driver for all types of road in Phase 1) were checked, there were no enough statistical significance ($p=0.156$ for the former and $p=0.358$).

In order to understand the estimated model visually, the curves of the acceptance ratio drawn by the model under the various conditions considered in the SP survey are shown in Figure 7. It can be scanned that the acceptance ratios for both the Advisory ISA and Voluntary ISA which are working only on the community streets were about 20% to 30% without any monetary incentive measures while such the ratios for the Mandatory ISA was almost zero. Also, these ratios became roughly 80% with the incentive measures of 10,000 (Yen/year) and 20,000 (Yen/year) for the Advisory ISA and Voluntary ISA, respectively. For the mandatory ISA, however, even the condition of the community street only and the maximum amount prepared in the SP survey, the acceptance ratio was still less than 50%.
Table 4. Estimation result of the model of various ISA acceptance

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Parameters</th>
<th>S.E.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
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<td>5.84e-01</td>
<td>0.006**</td>
</tr>
<tr>
<td>Types of ISA</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Advisory ISA</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Voluntary ISA</td>
<td>-1.36e-01</td>
<td>6.99e-01</td>
<td>0.857</td>
</tr>
<tr>
<td>Mandatory ISA</td>
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<td>1.09e-00</td>
<td>0.024*</td>
</tr>
<tr>
<td>Amount of monetary incentive measures</td>
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<td></td>
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<tr>
<td>Amount * Advisory ISA</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amount * Voluntary ISA</td>
<td>-1.50e-04</td>
<td>6.71e-05</td>
<td>0.025*</td>
</tr>
<tr>
<td>Amount * Mandatory ISA</td>
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<tr>
<td>Interaction effects</td>
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<td>Types of target road</td>
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<td></td>
</tr>
<tr>
<td>All roads</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Community streets only</td>
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<td>4.00e-01</td>
<td>0.029*</td>
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<td>4.20e-01</td>
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<td>Types of monetary incentive measures</td>
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<td>Insurance reduction</td>
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<td>Fuel token</td>
<td>-6.35e-01</td>
<td>4.30e-01</td>
<td>0.139</td>
</tr>
</tbody>
</table>

$\rho^2$: 0.336   AIC: 349.2   Hit ratio: 77.2%

Figure 7. Curves of the acceptance ratio under various conditions by the estimated models

4. DISCUSSION AND CONCLUSION

The results of the field experiment indicated that the ADRs in the Zone30 areas was obviously increased with Advisory ISA, and kept the high ratio even after the Advisory ISA was switched OFF. Such tendencies were slight for the other levels of speed limits except for the 30km/h limits (the result for 30km/h limit except for Zone30 is not discussed in this paper because of the little reliability due to the few total distances driven). These imply that the
behavioral acceptability for Advisory ISA regarding Zone30 is high in comparison with that regarding the other levels of speed limits. For arterial road segments with 40km/h or 50km/h speed limit, drivers may have a priority to keep up a stream of traffic. For community streets, on the other hand, at least a part of drivers can be motivated to follow the speed limit or ISA by the information such as “you are driving in Zone30” with Zone30 regulation, while it is difficult to control vehicles’ speed only by the information such as “you are driving on a narrow road” without any regulation. Therefore, the combination of Zone30 regulation and Advisory ISA can be thought as relatively effective. However, it should be mentioned that further field experiments may be needed since these results were based on the small sample.

Although Advisory ISA can contribute to traffic calming in a limited way as mentioned above, the contribution of Voluntary ISA or Mandatory ISA must be stronger or promising. Thus, the acceptability of these stricter ISA will be very important. The results of the SP questionnaire survey and the model analysis of them indicated that the acceptability for Mandatory ISA is averagely lower than Voluntary ISA and Advisory ISA. This is partially consistent with the results in Chorlton et al. (2012) which only targeted Mandatory ISA and Voluntary ISA. This is because Mandatory ISA strongly represses the freedom of driving while Voluntary ISA can be deactivated by drivers’ will. It was also indicated that monetary incentive measures obviously increase the acceptability for ISA as previously expected, where the effects for Voluntary ISA and Mandatory ISA are somewhat smaller than that for Advisory ISA. The latter fact implies that the burdens due to the repression of freedom of driving by Mandatory ISA and Voluntary ISA vary widely by drivers in comparison with Advisory ISA. And more, it was found that an ISA which works only on community streets is more likely to be accepted by drivers than an ISA which works on all road segments. This may be because drivers tend to potentially think to be able to drive at less than 30km/h if it is limited on community streets. In addition, the tendency that monetary incentive measures are slightly more efficient with insurance reduction or tax reduction than that with fuel token was found, but not significant enough. This might imply that drivers attach a greater importance to the eases of existing costs such as insurance fee or tax fee than to the new rewards such as the fuel token.

Based on the estimated model, finally, the amounts of the monetary incentive measures which make the acceptance ratios 80% were predicted for the three types of ISA. The amounts for Advisory ISA and Voluntary ISA which work only on community streets (10,000 Yen/year and 20,000 Yen/year, respectively) may be thought as sensible or not so unrealistic value while the amount for Mandatory ISA may be difficult value. Therefore, a Voluntary ISA working only in community streets areas may have a potential to be disseminated for the contribution to the traffic calming. However, the costs for the monetary incentive measures should be evaluated by comparing with the benefit from the relevant ISA, which analyses are one of further studies. In addition, the analyses considering the effects of individual attributes on the acceptability of ISA were not covered in this paper because the number of SP questionnaire respondents was small (i.e. 20 respondents). Particularly, clear effect of respondents’ daily driving behaviors was not found. From the same reason, an issue that the results do not necessarily mean representing the population remains. These limitations should be solved in the further studies by conducting additional surveys.

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