Analysis on Effects of Social Experiment of Smart IC at Kamigo Service Area

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In Japan, the social experiment of Smart IC has been introduced in order to utilize existing expressway effectively, to ease traffic congestion around urban area and to activate local community since 2004. In this paper, we focus on the social experiment of Smart IC at Kamigo service area and analyze the factors affecting choice behavior of Smart IC, inhabitants' consciousness for the continued operation of Smart IC and users' satisfaction for the Smart IC by a questionnaire survey. As a result, both serviceability and issues by introducing Smart IC were clearly shown from the viewpoint of users and residents.

Keywords: *Smart IC, social experiment, Kamigo Service Area*

1. Introduction

1.1 Background of this study

As for the construction of expressway in Japan, the utilization ratio is lower than the U.S and European countries though about 60% of the contemplated route has been developed. Moreover, the average IC interval in Japan is about 10km, and this value is twice as the U.S. and European countries. Besides, 30% of local authority which had been maintained the expressway has not placed IC, so the additional demand of IC has been existed [1]. Because of this situation, the social experiments for introducing the simplified interchanges called "Smart Interchanges (hereinafter called Smart IC)" for ETC users only have been conducted since 2004 in 28 places in Japan. It can be said that the advantage of Smart IC is to need lower land and construction costs compared with ordinary interchanges, therefore smart IC can be placed in Service Area (hereinafter called SA), Parking Area on the expressway, or urban area, flexibly. The other merits of the IC installation are to ease traffic congestion around urban area, to promote revitalization of the regional economy and to utilize existing expressway effectively [2].

As an example for research about the ETC, Kawai et al. analyzed the way of introducing ETC systems to urban expressway by using the queuing simulation model [3]. And Horiguchi et al. described about a theoretical analysis for the capacity of toll plaza with both ETC and non-ETC tollgates [4]. In addition, Kawakami et al. discussed that the value of the environmental improvement by ETC are quantified in monetary terms by CVM [5].

Table.1 Outline of the social experiment of Smart IC at Kamigo SA

Implementation term of social experiment	From October 15, 2004 to January 31, 2005
Test duration	From 7am up until 8pm
Experiment objects	light vehicle, passenger vehicle and medium-size car with ETC equipments

On the other hand, for the effect of introducing Smart IC, quantitative evaluations intended for the users and residents haven't yet done, although Yoshida considered the characteristics of Smart IC and the construction effect from the theory of space [6] and Hirai et al. described the functions of the ETC roadside system for social experiment of Smart IC and reported evaluation results of the system in 15 places [7].

The aim of this study is to clarify the utility and the problem of Smart IC introduction by the analysis of the questionnaire survey data from the viewpoint of both residents around the Smart IC and ETC users. We focus on the social experiment of Smart IC at Kamigo SA (hereinafter called "Kamigo Smart IC experiment").

1.2 Outline of Kamigo Smart IC experiment and the questionnaire survey

The main purpose of the Smart IC experiment was to spatially disperse the concentrated traffic that go to the center or around of Toyota city from the Tomei expressway and to improve both convenience and user-friendliness for the expressway drivers. There are many

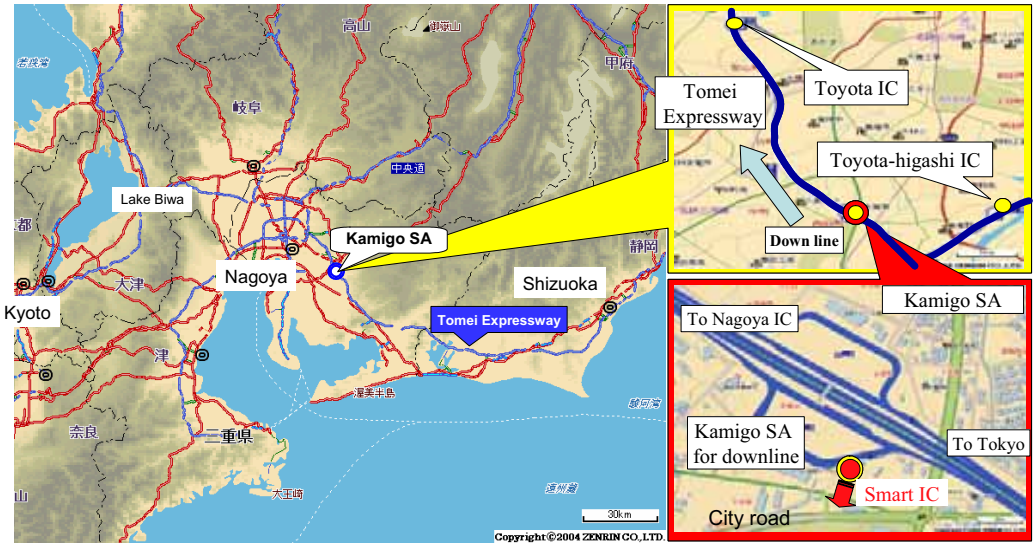

Figure.1 Location of Kamigo SA

Table.2 Contents of the questionnaire survey

Subjects of this analysis	a)Kamigo Smart IC users b)Adjacent IC users (-Drivers who use Toyota IC or Toyota-higashi IC)	Residents living around Kamigo SA
The number of samples (Number of distribution)	a) 473 (1400) b) 331 (5200) { 61 of them are with on-board ETC equipment, and the data are used in this study as adjacent IC users }	210 (210)
Collection rate [%]	a) 33.8 , b) 6.4	100
Contents of the questionnaire	-Attributes -OD -Trip purpose -Time lag that drivers delayed or hastened by using smart IC -Travel time (both cases when drivers use smart IC or don't use the IC) -Intention to use Kamigo smart IC in the future -Degree of satisfaction (5-point scale, 14items such as safety, traveling performance, operational procedures, and so on)	-Attributes -Change of living environment around Smart IC -Hope for the continued operation of Smart IC
Method of distribution / recovery of the questionnaire	a)By hand at the smart IC exit / By mail b)By hand at each toll gate / By mail	Door-to-door survey, Random sampling
Surveyed date	a) From December 1st to the 14th b) On December 2nd	On December 5th

large-scale establishments in Toyota-city, especially around Kamigo SA, so heavy traffic congestion has always been occurred during morning commute.

In this experiment, the only one ETC gate was set in the SA for down line (from Toyota-Higashi IC to Toyota IC) and installed an exit gate as shown in Figure.1. And this Smart IC required vehicles one stop at the exit gate for safety operation though the ordinary ETC gate is not necessary to stop. The outline of Smart IC experiment is shown in Table.1.

The questionnaire surveys on the Smart IC were executed to the residents around the Smart IC, Smart IC users and the drivers who use Toyota IC or Toyota-higashi IC located next to the Smart IC. The contents of the questionnaire survey are shown in Table.2. From the table, it can be thought that sufficient quantities of data was ensured for the statistical analysis though the collection rate of the survey for adjacent IC users is slightly low.

In this paper, we try to clarify the factor of choice behavior whether drivers use Smart IC or not by using disaggregate logit model and to analyze the consciousness of residents by using covariance structure model. In addition, the inappropriate data such as answered by the respondents who did not understand the content of the question has been excluded from the analysis.

2. Fundamental analysis on the questionnaire of Smart IC users and residents

2.1 Analysis on the utilization of Smart IC

In this section, it clarifies the utilization of Smart IC based on the result of fundamental analysis of the questionnaire to Smart IC users.

Figure.2 shows the positional relationship between Kamigo smart IC and the other IC where locate upstream of the IC. A part of the IC from Hamamatsu IC to the east side is omitted because the figure becomes complex. Utilizing ratio of departure IC for smart IC users is shown in Figure.3. From this figure, it can be said that about 50% of smart IC users had left from Okazaki, Otowa-gamagori or Toyokawa IC. Moreover, it is also understood that there are about 6% smart IC users who drove less than 10km, such as Toyota-minami IC and Toyota-higashi IC.

Figure.4 shows the number of Smart IC use according to the time-of-day and the trip purpose.

From the figure, it is shown that many users chose the Smart IC from seven to nine o'clock and seventeen to eighteen o'clock. The main purpose of the former period is commute trip and that of the latter period is return trip. In addition, the many users of business purpose are distributed every hour.

Furthermore, the ratio of destination area after getting off the smart IC is shown in Figure.5. As a result, the usage of Toyota-city with Kamigo smart IC is 64%, and the ratio exceeds 80% including neighboring municipality of Toyota-city, such as Kariya, Anjo, Okazaki, Chiryu, Shinshiro and Miyoshi.

On the whole, it can be described that the trip purpose of Kamigo Smart IC users is mainly not non-daily trips as sightseeing but daily trips as commute or business and they utilize the smart IC for relatively short trip.

2.2 Preference on the Smart IC use after the social experiment

Firstly, the preference on the Smart IC use after the social experiment is quantified by the questionnaire to Smart IC users. Here, we have heard that "Will you use this smart IC after the social experiment in the current state (described as preceding chapter, shown in Figure.1 and Table.1)?" The result is shown in Figure.6.

It is cleared that about 90 percent of the users want to use it in the future. And the respondents' purposes of the Smart IC use are shown in Figure.7. From the figure, it is understood that most of the users who want to use it in the future were satisfied with the advantages which could shorten the travel time and get off the expressway near their destination.

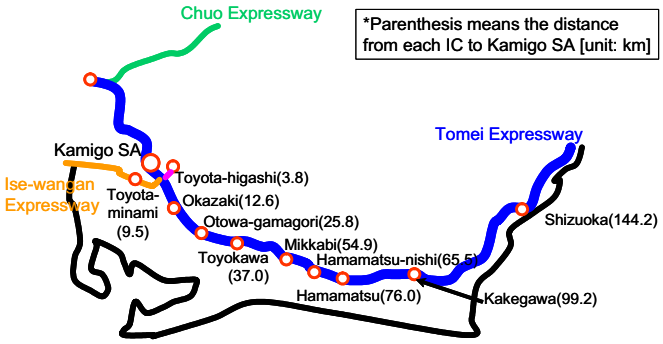

Figure.2 Positional relationship between Kamigo SA and the other IC

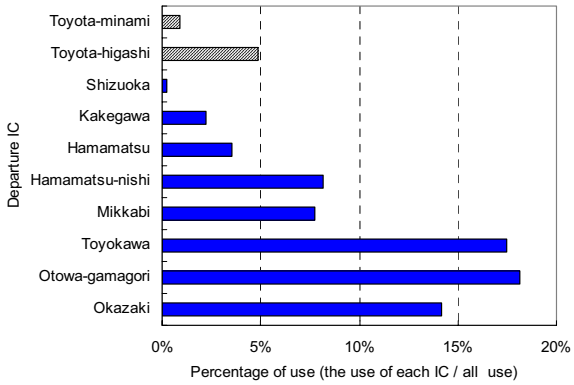

Figure.3 Utilizing ratio of departure IC for smart IC users (Samples :452)

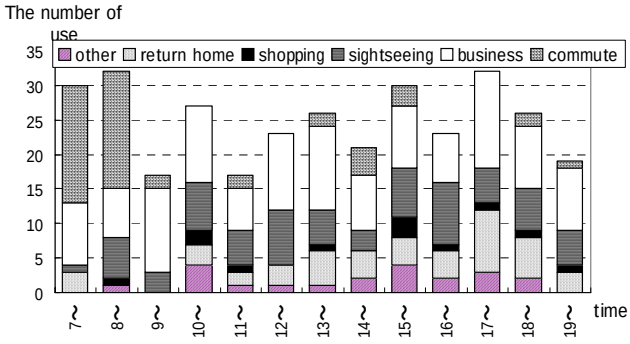

Figure.4 The Number of Smart IC use according to the time-of-day and the trip purpose

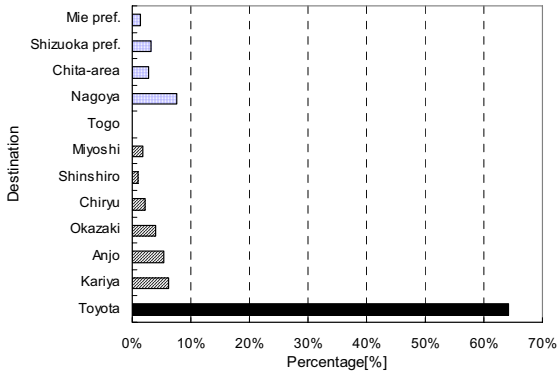

Figure.5 Ratio of destination area for smart IC users [Samples: 405]

Secondly, the reasons for not using the Smart IC in the future are shown in Figure.8. It is cleared that the respondents who could not shorten the travel time and had the long distance from the IC to arterial road feel dissatisfied.

From these results, it is shortening travel time that the drivers hope most to the Smart IC in those factors. Moreover, it can be said that the ease of connection from the exit gate of Smart IC to a main arterial road is also a critical factor.

2.3 Results of consciousness survey for the residents around Kamigo SA

In this section, it analyzes the resident consciousness about operating the Smart IC at Kamigo SA with questionnaire data. As shown in Table.2, this questionnaire was conducted by the random sampling from the residents who live around Kamigo SA.

As a result of the questionnaire survey, it became clear that about 70 percent of the residents wish the continued operation of Smart IC. That is, the percentage of hoping continued operation for the residents is lower than that of the Smart IC users in Figure.6. It can be considered that this difference was arisen by the existence of non-user.

The change in the living environment for the residents around Kamigo SA is shown in Figure.9. From this figure, it is shown that the opinion, which 4 percent of respondents stated the dissatisfaction with the noise from vehicles, the air pollution caused by automobile emissions and the roadside living environment worse by increasing traffic jam, exists though the opinion which the living environment has not changed exists about 90%.

3. Model analysis on the choice structure of Smart IC use and the potential use in the future

3.1 Model analysis on the choice structure of Smart IC use

The probability of the choice whether expressway drivers use Smart IC or the other IC can be explained by using disaggregate binary logit model as shown in Equation (1) and (2). In this study, two kinds of questionnaire data are used for developing the model: one is the questionnaire of Toyota IC users or Toyota-higashi IC users and the other is the questionnaire of Smart IC users at Kamigo SA. In addition, only ETC users' data are used from the former questionnaire.

$$P_y = \frac{e^{V_y}}{e^{V_y} + e^{V_n}} \quad (1)$$

$$P_n = 1 - P_y \quad (2)$$

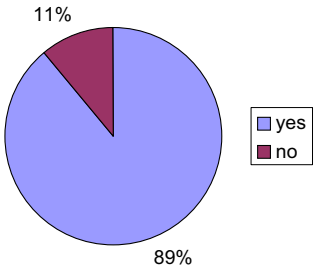

Figure.6 Preference on the Smart IC use after the social experiment (number of samples: 473)

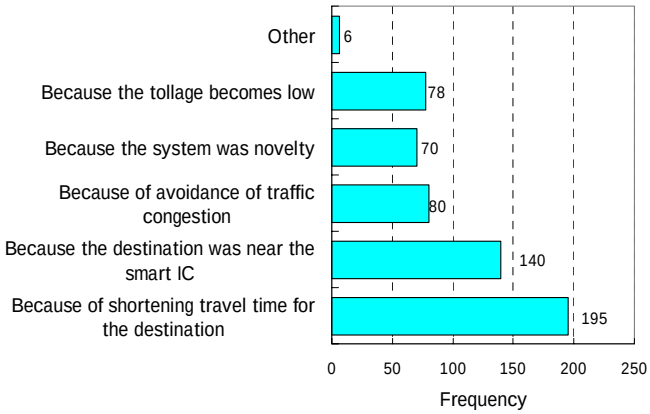

Figure.7 Respondents' purposes of the Smart IC use (Multiple answers allowed)

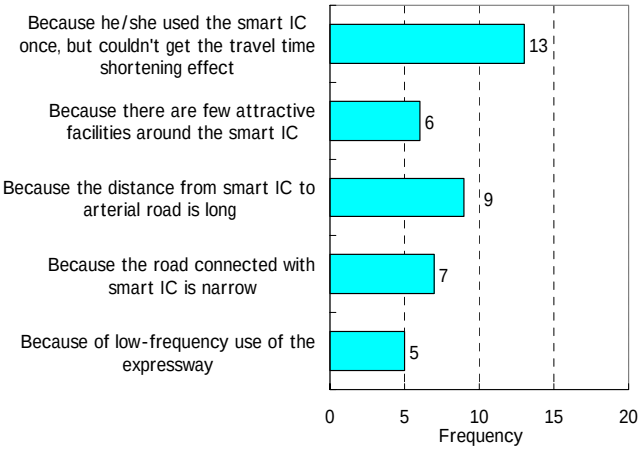

Figure.8 Reasons for not using the Smart IC in the future (Multiple answers allowed)

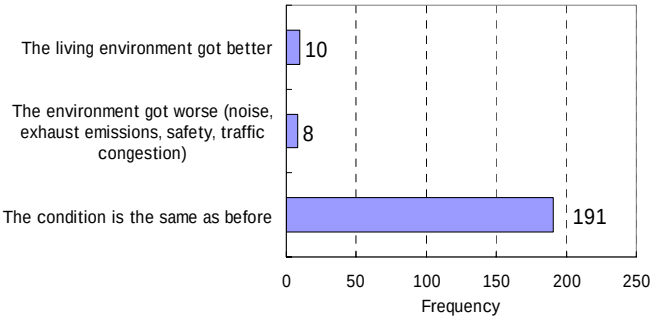

Figure.9 The change in the living environment around Kamigo SA (Multiple answers allowed)

where
P_y: probability of Kamigo Smart IC use
P_n: probability of Kamigo Smart IC non-use
V_y: the utility of Kamigo Smart IC use
V_n: the utility of Kamigo Smart IC non-use

The utility function of the model is shown as follows.

$$V_y = \beta_1 Z_1 + \beta_2 Z_2 \quad (3)$$

$$V_n = \beta_0 + \beta_2 Z_3 + \beta_3 Z_4 \quad (4)$$

where:
Z_1: the dummy variable of high frequency use of Tomei Expressway (over three times per week: 1, otherwise: 0)
Z_2: travel time from Smart IC to the destination
Z_3: travel time from usual IC except for Smart IC to the destination
Z_4: the dummy variable of Toyota IC use (if drivers choose Toyota IC in the absence of Kamigo Smart IC: 1, otherwise: 0)
β_0, β_1, β_2, β_3: parameter

The questionnaire data of Smart IC non-use within Tomei Expressway users doesn't include the value of Z_2. In this case the value of Z_2 is estimated from Smart IC use data in the following methods:

・Firstly, the OD pairs of Smart IC non-use data and those of Smart IC use are compared, and if the similar OD pairs are detected, the value of Z_2 for the Smart IC use data detected is utilized as the value of Z_2 for Smart IC non-use data.

・Secondly, if the similar OD pairs are not detected, we estimate the value of Z_2 in the following steps: Calculating the mean value of difference between Z_3 and Z_2 by using all the Smart IC use data. And we subtract the difference (four minutes) from the value of Z_3 and the obtained value is regarded as Z_2. In fact, these imputation were only 8.2% of all sample, therefore we considered it has an insignificant effect on the analysis.

The result of parameter estimation is shown in Table.3.

From the parameter of Z_1 takes negative sign, it means that if the person with high frequency use of the expressway tends not to use Kamigo Smart IC. In other words, it can be said that the users who use expressway frequently are difficult to change their usual paths.

It is also found that the parameter of the travel time from IC to the destination is negative. It is rational though t-statistics is not enough a significant level.

And for the parameter of the dummy variable of Toyota IC, it means that the drivers who usually use Toyota IC also tend to choose Toyota IC more than Kamigo Smart IC. It is thought that the drivers who usually use Toyota IC place more emphasis on the convenience of the accessibility to their destination after they get off expressway.

Table.3 Result of parameter estimation for Smart IC use model (number of samples: 352)

Explanatory variables	Parameter	t-statistics
Constant: β_0	-3.28	-7.90
the dummy variable of high frequency use of Tomei Expressway (over three times per week :1, otherwise:0): β_1	-0.95	-2.77
the travel time from IC to the destination: β_2	$-5.17*10^{-3}$	-0.27
the dummy variable of Toyota IC use (if drivers choose Toyota IC in the absence of Kamigo Smart IC: 1, otherwise:0) : β_3	1.16	2.88
hit ratio [%]	88.64	
log-likelihood ratio	0.52	

Table.4 Result of parameter estimation for the intention to use of Smart IC in the future (number of samples: 307)

Explanatory variables	Parameter	t-statistics
Constant: β_0	-2.22	-6.10
the time lag to have delayed departure time by using the Smart IC: β_1	0.13	1.37
travel time from IC to the destination: β_2	$-6.66*10^{-2}$	-2.85
the dummy variable of Toyota IC use (if drivers choose Toyota IC in the absence of Kamigo Smart IC :1, otherwise:0) : β_3	0.64	1.48
hit ratio [%]	89.25	
log-likelihood ratio	0.56	

3.2 Model analysis on the intention to use Kamigo Smart IC in the future

As well as the previous section, the probability of the choice whether Kamigo Smart IC users want to use the Smart IC in the future or not can be explained by disaggregate binary logit model. The utility function of the model is shown below.

$$V_y = \beta_1 Z_1 + \beta_2 Z_2 \quad (5)$$

$$V_n = \beta_0 + \beta_2 Z_3 + \beta_3 Z_4 \quad (6)$$

where
V_y: the utility of Kamigo Smart IC use in the future
V_n: the utility of Kamigo Smart IC non-use in the future

Z_1: the time lag that drivers delayed their departure time by using the Smart IC
(Based on questionnaire data, "Time lag that drivers could delay or hasten by using smart IC")
Z_2: travel time from Smart IC to the destination
Z_3: travel time from usual IC except for Smart IC to the destination
Z_4: the dummy variable of Toyota IC use (if drivers choose Toyota IC in the absence of Kamigo Smart IC: 1, otherwise: 0)
β_0, β_1, β_2, β_3: parameter

The result of parameter estimated is shown in Table.4.

It is shown that the parameter β_2 of the travel time after getting off expressway was negative. This means the users, who want to use Smart IC in the future, consider that the travel time after getting off the expressway is the intensive resistance more than the other factors.

Moreover, the parameter β_1 of the time lag that drivers delayed their departure time by using the Smart IC, which were calculated by the questionnaire result mentioned above in Table.2, is positive. It is understood that being able to change the departure time by using Smart IC is a positive effect for the users and it can be said that this was a reasonable result.

In addition, the correlation coefficient of these two variables (β_1, β_2) was 0.05. This result means that these two variables are recognized as a factor to represent an independent advantage for smart IC users.

3.3 Model analysis on the residents' wishes for the continued operation of Smart IC

In this section, the probability of the choice whether the residents living around the Smart IC wish for the continued operation of Smart IC after finishing the social experiment or not can be explained by disaggregate binary logit model. The utility function of the model is shown as follows.

$$V_y = \beta_0 + \beta_2 Z_2 \quad (7)$$

$$V_n = \beta_1 Z_1 + \beta_3 Z_3 \quad (8)$$

where
V_y: the utility of Kamigo Smart IC's continued operation
V_n: the utility of Kamigo Smart IC's continued non-operation
Z_1: the dummy variable of occupation (if the respondents is homemaker: 1, otherwise: 0)
Z_2: the dummy variable of the ownership of the vehicle with ETC system (if the respondents have the vehicle with ETC system: 1, otherwise: 0)
Z_3: the dummy variable of living environment (if the respondents feel getting worse in the living environment after setting up Smart IC: 1, otherwise: 0)
β_0, β_1, β_2, β_3: parameter

Table.5 Estimated model of the residents' wishes for the continued operation of Smart IC (number of samples:207)

Explanatory variables	Parameter	t-statistics
Constant: β_0	-0.86	-4.52
the dummy variable of occupation (if the respondents is homemaker:1, otherwise:0): β_1	0.65	2.00
the dummy variable of the ownership of the vehicle with ETC system(if the respondents have the vehicle with ETC system:1, otherwise:0): β_2	0.63	1.28
the dummy variable of living environment (if the respondents feel the living environment worse by the setting up Smart IC: 1, otherwise: 0): β_3	1.15	1.50
hit ratio [%]	68.10	
log-likelihood ratio	0.11	

The result of parameter estimation is shown in Table.5.

From the result of the table, it is found that the parameter of Z_3 is positive sign. In addition, the parameter of Z_1 is also positive. These mean that the residents tend not to be able to accept the deterioration of living environment by the introducing Smart IC, and especially, the homemakers, who are affected by the living environmental impacts in daytime, intensively have that inclination to Smart IC. On the other hand, from the Z_2, the drivers who are using the car equipped with ETC feel that being possible to get off the expressway nearby their home is an advantage.

4. Analysis on the degree of users' satisfaction of Kamigo Smart IC

4.1 Aggregate analysis on users' satisfaction

Firstly, the average score of the degree of satisfaction for each item is shown in Figure.10.

It is shown that comprehensive evaluation of Smart IC experiment scores 3.5 out of 5 points, and this means the experiment was generally accepted.

Moreover, the effect of travel time shortening and the location of the Smart IC are also highly evaluated. These are affected by the reducing heavily traffic congestion which is attributable to the presence of the automobile-related factories around the Smart IC, especially during rush hour.

In the meantime, it is cleared that the available time period and the available direction were lowly evaluated. It is considered that the former was affected by the available time period from seven o'clock to twenty o'clock. Because there are many commute drivers who want to use it before seven o'clock or after twenty o'clock, for that the evaluation value was slightly low. In addition, the latter is affected by the location of the Smart IC. In other words, the Smart IC was set up only one direction at the other side of city center and for getting off the expressway exclusive use, so that the users evaluated a little low. And the evaluation of safety for merging into the general road is also slightly low. Therefore, it is necessary for the practical use of Smart IC to improve the geometry of merging section based on the detailed analysis of vehicle behaviors at the section.

4.2 Covariance structure analysis for the satisfaction of Smart IC users

Then, it clarifies the impact of Kamigo Smart IC on the users' comprehensive evaluation by using the covariance structure analysis. Latent variables and observed variables are shown in Table.6, and the path diagram of the optimum model is also shown in Figure.11. The number of data used in the analysis was n=527. Latent variables are "Operational procedures" which is regarded as an important of software factor, "Satisfaction of the safety" which is regarded as an important of hardware factor and "Satisfaction of the ease of driving" which is also regarded as a hardware factor.

From the figure, it can be said that the accuracy of this model is comparatively good because the GFI (Goodness of Fit Index) was 0.850 and the AGFI (Adjusted Goodness of Fit Index) was 0.793.

It is observed that satisfaction of the travel time shortening has most significant impacts on the comprehensive evaluation of Smart IC at Kamigo SA. And it is also revealed that "location of the Smart IC has positive effect on the comprehensive evaluation. This means that the proper setting of place of Smart IC is very important for the users.

In addition, it is shown that the satisfaction of the ease of driving, which is affected by the satisfaction of safety, has the second largest impacts on the comprehensive evaluation of the Smart IC. For the satisfaction of the ease of driving, it is observed that both ease of passing gate and time required for passing the gate are associated with the evaluation. This means Smart IC users could shorten the amount of travel time compared with the ordinary interchange though it was necessary for the users to pause at the ETC gate in this experiment. On the other hand, for the satisfaction of safety, both indices of approaching and passing the ETC gate indicate high value. It can be thought that stop-controlled at the ETC gate influences this result.

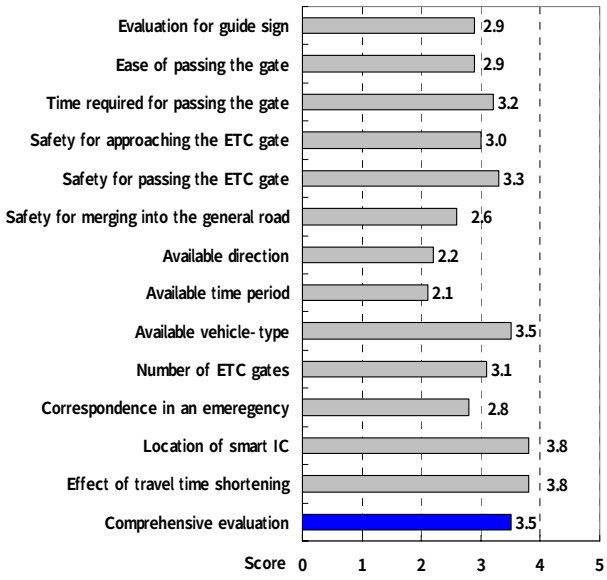

Figure.10 Average value of users' satisfaction of Smart IC

Table.6 Latent Variables and Observed Variables

Latent variables	Observed variables	Choices
Satisfaction of the ease of driving	Evaluation for guide sign	1 to 5 (5-point scale)
	Ease of passing the gate	
	Time required for passing the gate	
Satisfaction of the safety	Safety for approaching the ETC gate	
	Safety for passing the ETC gate	
	Safety for merging into the general road	
Operational procedures	Available direction	
	Available time period	
	Available vehicle-type	
	Number of ETC gates	
	Correspondence in an emergency	
	Satisfaction of the time required shortening	
	Location of the Smart IC	
	Comprehensive evaluation of Smart IC at Kamigo SA	

Additionally, for the operational procedure, the available time period and the number of ETC gates affect the satisfaction. In associated with the former factor, it is shown that the evaluation of available time period in this experiment was quite low from the previous section (as shown in Figure.10). Therefore, it is necessary to extend the available time period for putting the Smart IC to practical use in the future.

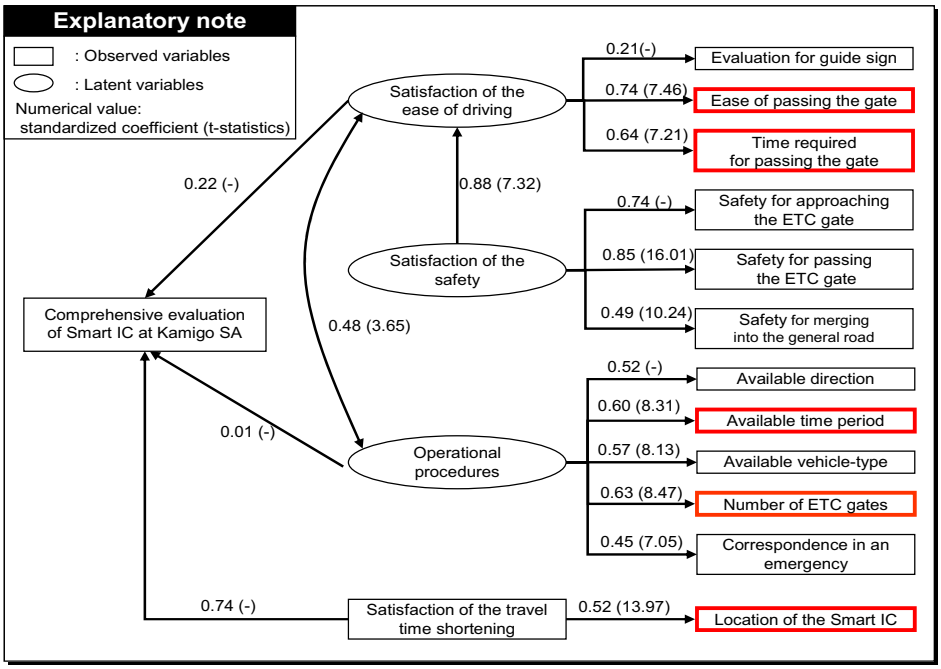

Figure.11 Path diagram for the satisfaction of Smart IC users (Number of samples: 527)
GFI: 0.850, AGFI: 0.793

5. Conclusion

In this paper, we discussed the usefulness of introducing Smart IC from the viewpoint of both users and residents through the analysis of the questionnaire survey data, which are conducted at the social experiment of Smart IC at Kamigo SA.

The conclusions of this paper can be summarized as below:

- It is found that Kamigo Smart IC was mainly used for the purpose of commuter trips as daily use and was easy to be used for the users who move to the destination near the Smart IC.
- It is shown that the availability of Smart IC for drivers is the travel time shortening effect and as a consequence, the departure time can be delayed.
- Through the questionnaire of residents around Kamigo SA, it is cleared that about 4 percent of respondents had the opinion that the living environment had deteriorated by setting up the Smart IC while about 70 percent of the respondents was hoping for continued operation of the Smart IC. To improve the environmental deterioration, it can be said that the countermeasures for safety, emissions and noise are needed than ever before.
- From the parameter of the choice behavior model whether using Smart IC or not, it was found that if the person who use the expressway frequently tends to not use Kamigo Smart IC. In other words, the users who use expressway frequently are difficult to change usual their paths. And it was also found that the travel time after getting off expressway increase, the utility of Smart IC use decrease.
- From the parameter of the choice behavior model whether using Smart IC or not in the future, it became clear that being able to delay the departure time by using Smart IC is a positive effect on Smart IC use in the future. Moreover, it is also shown that drivers place more emphasis on the convenience of the accessibility after they get off expressway and less on the tollage resistance.
- From the result of model analysis on the hope for the continued operation of Smart IC for the residents, it is found that the residents can't accept the deterioration of living environment by the introduction of Smart IC, and especially, the homemakers who are affected by the living environmental impacts in daytime underestimate the continued operation of Smart IC.
- From the aggregate analysis of users' satisfaction, it became clear that this social experiment was highly valued by the Smart IC users. It was also shown that both available time period and direction were lowly evaluated while the effect of travel time shortening and the location of the Smart IC are highly valued.
- As the result of covariance structure analysis for the user's satisfaction, it was revealed that satisfaction of the travel time shortening has most significant impacts on the comprehensive evaluation of Smart IC. And for the ease of driving, it was shown that both the ease of passing gate and time required for passing the gate are associated with the satisfaction though it had operated by stop-controlled at ETC gate in this experiment. Furthermore, for the

operational procedure, it was clarified that the available time and number of ETC gates affect the satisfaction of Smart IC.

In addition, four statistical models were developed in this study. For the scope of application of these models, it could be said that two models which explained for the choice structure of Smart IC use and the intention to use Kamigo Smart IC in the future are limited to apply to other area because the specific explanatory variable was included. Meanwhile it can be considered that the other models which explained for the residents' wishes for the continued operation of Smart IC and the satisfaction of Smart IC users could be applied to the other similar area though it should be considered that the additional comparison with the result of this study and those of the other social experiments of Smart IC are made.

For the future prospects of this study, a more detailed analysis on the relationship between each driver's characteristics and the satisfaction of Smart IC use for not only ETC users but also ETC non-users will be conducted. And the impacts of Smart IC on the traffic flow on the expressway and regional economy are also need to analyze. And the effects of Smart IC introduction should be shown more clearly in order to explain the IC users and residents.

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