MODIFICATION OF STATED PREFERENCE MODE CHOICE MODELS TO IMPROVE THE EXTERNAL VALIDITY

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INTRODUCTION

In forecasting the demand for travel modes, the most important advantage of models based on stated preference (SP) data is that the choice probability of new alternatives that could not yet exist can be easily obtained, whereas the conventional revealed preference (RP) models can not be applied to that context. However, it happens often that SP data which are a kind of intentional data are not consistent with the actual travel behaviors. It is true that this want of reliability for SP data discourages us from using them in practical transport studies. This paper discusses the modification methods to improve the reliability of mode choice models based on SP data. The external validity (see Green and Srinivasan (1978)) of SP models was examined by comparing the prediction of modal shares given by choice models based on SP data, in relation to the intention of using a newly planned rail station in the western suburb of Hiroshima, with the actual mode choice data collected after the opening of the station (i.e. after-RP data). Then, the external validity of updated SP models was also empirically investigated by using the following four methods;

i) Estimation of SP model using the scale parameter obtained with RP data collected before the opening of station (i.e. before-RP data);
ii) Bayesian updating of SP model using model coefficients based on before-RP data;
iii) Updating SP responses by using transfer price (TP) data; and
iv) Updating by making use of hierarchical choice structure in nested logit (NL) model incorporating before-RP data at higher level and SP data at lower level.

The empirical analysis for the purpose of examining the effectiveness of these updated models has been one of the primary subjects in recent SP transport research and some useful results have already been obtained. The objective of this study is to examine the external validitiy of above updated models, using the data given from the same respondents before and after the opening of the new rail station in August, 1989 (i.e. SP, TP, before-RP and after-RP data).

1. REVIEW OF EXISTING STUDIES

In order to test the external validity of discrete choice models based on SP data, three types of procedures are generally employed as follows;

i) Comparison of estimated coefficients between SP and after-RP models;
ii) Comparison of goodness-of-fit for after-RP data between SP and after-RP models;
iii) Comparison of aggregated shares predicted by SP model with observed shares given by after-RP data.

As a result of applying the above first testing procedure, Louviere et al.(1981) indicated that the difference of coefficients between these two models was not statistically significant. As Bates and Roberts (1983) pointed out, it is, however, not proper to conclude the validity of models by only such a simple comparison, since the variance of coefficients of SP model incorporating experimentally designed attributes is often smaller than that of RP model. On the other hand, Wardman (1988) revealed that the values of time obtained by segmented SP and after-RP models depending on socioeconomic characteristics were similar to each other. The comparison of relative importance of coefficients such as value of time may be more reasonable rather than the former, because the effect of the variance of coefficients could be canceled in the latter case.

Some studies using the second procedure have been also undertaken by, for examples, Couture and Dooley (1981) who examined the reliability of stated intention for the use of new transit service, besides Louviere et al. and Wardman as mentioned earlier. Although some of them indicated that SP model was significant in terms of the external validity, a common result of these studies was that the preference for new travel services was over-stated as compared with the actual choice behavior. This non-commitment bias inherent in SP data (Chatterjee and Wegmann (1983)) makes the external validity of SP model worse. The second testing procedure requires panel data from same respondents to compare the estimate of SP model individually with actual choice behavior.

On the contrary to the comparison at the individual level employed in the second approach, the third procedure is to compare the estimates of SP model with after-RP data at the aggregated level. Since it is not necessary to collect the before and after panel data, there are many studies using this approach. According to the review concerning conjoint models given by Louviere (1988), many choice models have been developed dealing with not only travel mode but also residential location, shopping destination and travel route, and it was demonstrated that the prediction of these SP models has a high correlation with RP data.

There are more other studies analyzing the external validity of SP model in addition to the above cases, and they were well summarized by Pearmain et al.(1991).

Recently, a new modification of SP model to improve its external validity has been attempted as can be seen in the development of models combining SP data with other data sources, especially including before-RP data. The combined SP and before-RP models are specified by estimating coefficients sequentially (e.g. Ben-Akiva and Morikawa (1990a), Bradley and Kroes (1990), Wardman (1991) and etc) or simultaneously (e.g. Ben-Akiva and Morikawa (1990a,1990b), Bradley and Kroes (1990)).

The sequential estimation consists of the following three steps;

Step 1 : Estimate the coefficients of SP model with SP data;
Step 2 : Calculate a composite variable by summing the product of attribute values in the before-RP data and estimated SP coefficients from step 1;
Step 3 : Estimate the scale parameter by taking the above composite variable as an independent variable, and before-RP data as a dependent one.

In the simultaneous estimation presented by Ben-Akiva and Morikawa, the difference between SP and RP data was taken as being caused by the bias and random error contained in each data, supposing that the individual's preference for travel alternatives (i.e. utility) was stable between before and after. The relation between the variances of disturbance term for discrete RP and SP choice models was assumed as follows;

$$\mathrm{Var}(\varepsilon^{RP}_{ij}) = \mu^2 \mathrm{Var}(\varepsilon^{SP}_{ij}) \tag{1}$$

where, $0 < \mu < 1$.

This assumption makes it possible to combine SP and before-RP data. Since the disturbance terms of models with SP and RP data obtained from the same individual cannot fundamentally be independent of each other, Morikawa and Yamada (1991) introduced the concept on state dependence and serial correlation of error terms in the combined model, indicating that it makes the model validity much higher.

2. UPDATING METHODS OF SP MODELS

2.1. Estimation of SP model with Scale Parameter (SCALE)

Supposing the relative importance of coefficients in terms of travel attributes in SP model would be more reliable, the scale parameter and alternative specific constants in SP model are reestimated with before-RP data by three sequential steps as explained in the former section. The model used is of Logit type (MNL);

$$P_{ij} = \exp(U_{ij}) / \sum_{j'} \exp(U_{ij'}) \tag{2}$$

$$U_{ij} = \alpha \sum_{k} \hat{\beta}^{SP}_{jk} X^{RP}_{ijk} + \gamma^{RP}_{j} \tag{3}$$

where, P_{ij} : the probability that individual i will choose alternative j,
U_{ij} : the utility of alternative j for individual i,
α : scale paramrter,
$\hat{\beta}^{SP}_{jk}$: estimated coefficient of k'th variable in SP model,
X^{RP}_{ijk} : k'th attribute of alternative j for individual i in before-RP data,
γ^{RP}_{j} : specific constant of alternative j.

2.2. Bayesian Updating (BAYESE)

Bayesian updating which Atherton and Ben-Akiva (1976) employed to transfer the discrete choice model from region to region is introduced to modify the SP model. It is assumed in this procedure that the updated coefficient is a weighted average of the original coefficient and the coefficient estimated from the new sample (see Ben-Akiva and Lerman (1985)). In our study, two groups of coefficients for SP and before-RP models are estimated independently and then new estimated coefficients will be given by weighting the average of these two as follows;

$$\sigma = (\sigma_{SP}^{-1} + \sigma_{RP}^{-1})^{-1} \tag{4}$$

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$$\hat{\beta} = (\sigma_{SP}^{-1}\,\hat{\beta}_{SP} + \sigma_{RP}^{-1}\,\hat{\beta}_{RP})\,\sigma \tag{5}$$

where, $\hat{\beta}$, σ : vector of updated coefficients and its variance-covariance matrix,
$\hat{\beta}_{SP}$, $\hat{\beta}_{RP}$: vectors of estimated coefficients of SP and before-RP models,
σ_{SP}, σ_{RP} : variance-covariance matrices of $\hat{\beta}_{SP}$, $\hat{\beta}_{RP}$.

While these two procedures do not necessarily need SP and before-RP data from the same respondents, the model structure including a set of explanatory variables must correspond between SP and after-RP models.

2.3. Updating SP Responses by Using TP Data (TRANS)

In TP survey associated with the introduction of new rail station, the individuals are asked questions in the form of "How much of a reduction (or shortening) in cost (or time) of the actual rail station would be sufficient to make you switch to rail from your actual travel mode?". The boundary value of switching mode can be measured in this question and the design of TP question is simpler than SP experiment based on the factorial design. Oppositely, the following objections to the reliability of TP data are most frequently expressed (Bonsall (1985));

i) The individuals' decisions are not made depending on all a matter of price; and
ii) Because of the novelty of stating one's own TP, some respondents may be unable to express the strength of their preference in those terms.

Similarly to SP experiment, unless a new alternative is close to the respondents' existing experience, it will be also difficult for them to have a secure image of the consequences of a change. In this study, however, the intention of switching to the rail which they had fully experienced is analyzed, so there seems to be less of such a problem here. TP responses are used as a complementary information to modify SP responses. Supposing that TP responses are the boundary value of switching, and it would work as a constraint on stating respondents' preference, SP data are modified depended on the following rule;

IF SP (cost) is higher than TP (cost) AND SP (time) is longer than TP (time)
THEN IF SP response = "Yes" THEN SP response = "No"
IF SP response = "No" THEN SP response = "No".
where SP (cost), SP (time) : rail cost and travel time set up in SP experiment,
TP (cost), TP (time) : TP responses of rail cost and travel time.

2.4. Updating by using hierarchical choice structure in Nested Logit Model

The nested logit (NL) model is specified in which the lower level is a binary choice between new and existing rail stations using SP data, and the higher level is a marginal choice among car, bus, tram and rail using before-RP data (see Figure 1). The same sequential estimation as shown in the first scale parameter procedure is employed. A different point between these two procedures is that different sets of choice alternatives and variables will be accepted in this procedure opposed to the first one. Thus, even if the context of SP experiment is the choice within a mode (e.g. different services of new travel mode), the choice model between modes can be estimated by assuming the hierarchical choice structure with before-RP data.

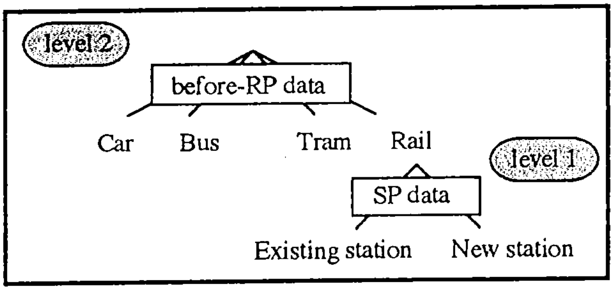

Figure 1 Hierarchical structure of nested logit model

3. SP EXPERIMENT AND ESTIMATION OF SP MODEL

3.1. Outline of SP Experiment

The object of SP survey was work and school travelers who lived in Ajina, which is a residential area located west of Hiroshima. There were four travel modes available in this area (i.e. car, bus, tram and rail as shown in Figure 2), and the residents had been obliged to use the inconvenient stations to access before the opening of new rail station.

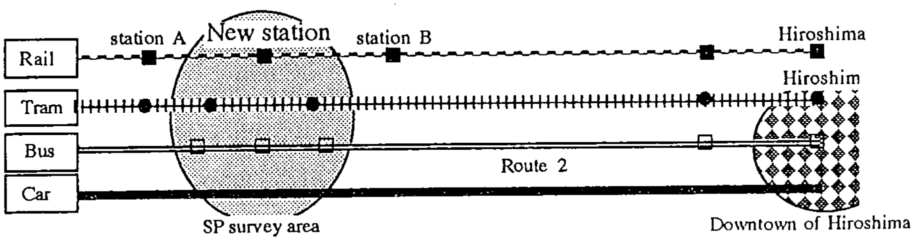

Figure 2 Travel mode in SP survey area

The attributes and their levels-of-service for the new station selected in SP experiment were shown in Table 1. Nine profiles combining these levels were set up using the fractional factorial design. Only four profiles were randomly drawn out and presented to each respondent. A combination of the most expected levels of attributes after the opening of the new station was also presented besides these profiles. Before-RP questions which asked the actually chosen travel mode and its alternatives were jointly included in the SP questionnaire distributed two months before. After-RP data was collected from the same respondents of SP survey three months after the opening of the station based on the same format as the before-RP questionnaire. The number of individuals whose responses were usable all through three surveys accounted for 224. The 'captive-choice' respondents who had no alternatives were excluded from the samples. Because five responses were obtained at most from each one in SP experiment, the number of samples in SP data amounted to 1120.

Table 1 Attributes and levels-of-service of rail set up in SP experiment

Variable	Level 1	Level 2	Level 3
Access time	- 12 min	- 6 min	actual time
Waiting time	- 3 min	+ 2 min	+ 5 min
In-vehicle time	- 5 min	- 3 min	actual time
Cost	- 80 yen	- 40 yen	actual cost

-12 min : 12 min shorter than actual rail station

Table 2 Comparison of shares of travel mode (%)

Data	Car	Bus	Tram	Existing rail station	New rail station
before-RP	40.6	12.1	23.2	24.1	----
SP	31.3	8.3	15.6	6.5	37.8
after-RP	43.8	9.8	19.6	4.0	22.8

Table 3 Percentage of respondents who switched their travel modes between before- and after-RP data

[switching travel modes]	No.of samples = 222
Car to rail (new station)	0.9%
Bus to car	0.5%
Bus to tram	0.9%
Bus to rail (new station)	1.8%
Tram to car	1.8%
Tram to rail (new station)	2.7%
Rail (existing station) to car	1.4%
Rail (existing station) to bus	0.9%
Rail (existing station) to tram	0.9%
[switching stations]	
Rail (existing station) to Rail (new station)	4.1%
[unswitched]	84.2%

The shares of travel mode for three sets of data are compared in Table 2. The share of new rail station in SP data was 37.8%, which was 15% larger than that of after-RP data. The rail percentages were not significantly different in number between before-RP and after-RP data, indicating 24.1% and 26.8% (=4.0+22.8), respectively. Nevertheless, the respondents who actually switched their modes and rail stations from before to after totally accounted for 11% and 4% of all, respectively as shown in Table 3.

3.2. External Validity of SP Data

SP responses were individually compared with the actual choice behaviors after the opening of the new station, and the result of which is shown by actual travel mode in Table 4. All cases except one in which SP responses were in accordance with actual choice data were "no" in SP and accordingly "unused" in after-RP data, which indicated 76.9, 63.0 and 62.3% for car, bus and tram users, respectively. Conversely, the percentage of "no" in SP and "unused" in after-RP data was only 11.5% for rail users and the case of "yes" and "used" indicated the highest percentage, 52.2%. These results seem to imply that the choice inertia will be remarkably effective in SP responses. The percentages of over-stated responses, in which the respondents actually did not use the new station in spite of their affirmative responses for that use in SP questions (i.e. the case of "yes" in SP and "unused" in after-RP), were not more than 25% for each mode.

Table 4 Comparison between SP and after-RP data (%)

[Car users] 455 samples

SP response	after-RP used	after-RP unused
yes	1.3	20.9
no	0.8	76.9

[Bus users] 135 samples

SP response	after-RP used	after-RP unused
yes	8.9	22.2
no	5.9	63.0

[Tram users] 260 samples

SP response	after-RP used	after-RP unused
yes	8.5	24.2
no	5.0	62.3

[Rail users] 270 samples

SP response	after-RP used	after-RP unused
yes	52.2	18.1
no	18.1	11.5

3.3. External Validity of SP Model

SP models are used to have a new alternative besides the choice set for before-RP models. It is, however, essential to have a common set of alternatives and explanatory variables between SP and before-RP models, in order to modify the SP model based on information from before-RP data such as the reestimation of model using a scale parameter and Bayesian updating procedure. The set of alternatives for SP model was, therefore, redefined into four travel modes including car, bus, tram and rail using a new station. When a respondent did not have any intention to use the new station in SP experiment, rail using the existing one was incorporated as an alternative of travel mode. Further, when he/she expressed that rail was not available in before-RP survey, it was excluded from a set of alternatives in SP model. Thus, the number of alternatives in SP mode choice model became four modes as large as that in before-RP model.

A MNL model based on SP data was specified as shown in Table 5. The models with before-RP and after-RP data were also shown in the same way for the sake of comparison. The number of samples in SP model decreased to 1107 after redefining work of alternatives, by excluding unsuitable 13 samples. All the estimated coefficients excepting cost had correct signs and the value of the adjusted likelihood ratio index (i.e. rho-squared bar) of model represents a good degree of fit. In particular, we must note that the parameters of mode specific constants (i.e. car, bus and tram dummy) indicated higher t-values. This implies that the choice inertia effect will be significant in SP model, because these constants were highly correlated with the actual mode dummy variable (i.e. =1 if car was actually used, =0 otherwise). The coefficient of cost had incorrect sign, which can be often seen in the models dealing with the travel to work. Since the company usually bear the cost for work, commuters might not hesitate to choose more expensive mode if it is convenient for them.

Table 5 Comparison of MNL mode choice models with SP, before-RP and after-RP data

Variable	SP		before-RP		after-RP	
Access time (min)	-0.034	(- 2.97)	-0.022	(- 0.72)	-0.002	(- 0.08)
In-vehicle time (min)	-0.006	(- 2.08)	-0.004	(- 0.71)	0.007	(1.01)
Egress time (min)	-0.026	(- 3.87)	-0.029	(- 1.79)	-0.001	(- 0.08)
Cost (100 yen)	0.135	(3.69)	0.150	(1.69)	0.131	(1.29)
Number of transfers	-1.058	(- 6.45)	-1.617	(- 4.19)	-0.741	(- 2.29)
Car dummy	-2.114	(-10.43)	-1.289	(- 2.20)	-0.253	(- 0.65)
Bus dummy	-2.865	(-15.00)	-1.965	(- 3.86)	-1.584	(- 4.31)
Tram dummy	-2.022	(-12.86)	-1.224	(- 3.29)	-0.838	(- 2.79)
L(0)	-1051.3		-200.9		-221.6	
$L(\hat{\beta})$	-792.9		-165.6		-187.9	
Rho-squared bar	0.243		0.156		0.135	
No. of samples	1107		222		222	
PC (%)	55.0		58.1		57.2	
OV (%)	32.4		16.2		11.7	

t-value in parentheses, PC : % of samples correctly estimated for RP-after data,
OV : % of samples over-estimated for RP-after data

The external validity of SP model was measured with two indicators as follows;

i) the percentage of samples whose travel modes predicted by SP model agreed with the actually chosen modes (i.e. PC), and
ii) the percentage of samples whose travel modes predicted by SP model were rail though the actual modes were non-rail (i.e. OV).

The PC of SP model (=55.0%) indicated that nearly a half of predicted results were incorrect. The OV (=32.4%) became larger than the percentage of over-stated responses (=25%) in SP data. This means that the estimation accuracy of SP model might be worse than the simple application of modal shares of original SP data, if any updating procedure could not be incorporated.

Comparing SP model with before-RP and after-RP models, all the t-values of estimated coefficients of SP model were higher than those of both RP models. This is caused by smaller variance of coefficients and larger number of samples in SP model based on data obtained by the orthogonally fractional factorial design. The higher PC and smaller OV of before-RP model indicated that this model was superior to SP model in estimation accuracy. Thus, it is apparent that the SP model is not practical for use in this context without any updating.

4. EXTERNAL VALIDITY OF UPDATED SP MODELS

4.1. Estimation of Updated SP Models

The SP models using the three updating procedures, consisting of SCALE, BAYESE and TRANS, were developed as shown in Table 6. TRANS+SCALE means the model combining the first and third updating procedures as described in INTRODUCTION.

Table 6 Comparison of updated SP models

Variable	SCALE a)	BAYESE c)	TRANS	TRANS+SCALE b)
Access time (min)	-0.044	-0.046	0.010	0.011
In-vehicle time (min)	-0.008	-0.006	-0.003	-0.003
Egress time (min)	-0.034	-0.025	-0.028	-0.032
Cost (100 yen)	0.178	0.136	0.113	0.128
Number of transfers	-1.390	-1.088	-1.392	-1.572
Car dummy	-1.547	-2.115	-1.226	-0.807
Bus dummy	-2.119	-2.802	-1.998	-1.591
Tram dummy	-1.199	-1.908	-1.494	-1.077
L(0)	-200.9	----	-1024.4	-200.9
$L(\hat{\beta})$	-166.4	----	-849.6	-166.3
Rho-squared bar	0.162	----	0.167	0.163
No. of samples	222	----	1100	222
PC (%)	54.1	52.7	59.0	58.6
OV (%)	16.7	31.5	20.7	16.2

a) scale parameter = 1.314 (t-value = 5.52)
b) scale parameter = 1.129 (t-value = 5.53)
c) the internal validity indices cannot be directly obtained.

The number of samples of SCALE and TRANS+SCALE models accounted for 222, because those models were estimated with before-RP data. And that of TRANS model decreased to 1100 by redefining the alternatives after updating SP data with TP data. The value of the rho-squared bar representing the goodness-of-fit of each model for its own data was nearly similar to each other. The estimated coefficients of cost had incorrect sign for all four models, because of the same reason stated earlier in section 3.3. The coefficients of access time in TRANS and TRANS+SCALE models had incorrect signs, indicating that it became less important in the model by the TRANS updating procedure. Note that the goodness-of-fit indicators in BAYESE model could not be directly measured.

Table 7 Estimation of nested logit model combining SP with before-RP data

Variable	level 1		level 2	
Employee	-0.518	(- 2.47)	----	----
Actual mode (car)	-0.440	(- 2.60)	----	----
Actual mode (rail)	1.554	(7.60)	----	----
Transfer 1)	-0.583	(- 3.66)	-1.602	(- 2.90)
Access time (min)	-0.083	(- 5.41)	----	----
In-vehicle time (min)	0.028	(0.72)	-0.009	(- 1.53)
Waiting time (min)	-0.041	(- 1.69)	----	----
Egress time (min)	----	----	-0.015	(- 0.94)
Cost (100 yen)	-0.969	(- 6.49)	0.222	(2.12)
Number of transfers	----	----	-1.454	(- 3.69)
New station dummy	-0.564	(- 7.77)	----	----
Car dummy	----	----	-0.050	(- 0.15)
Bus dummy	----	----	-0.963	(- 2.71)
log-sum	----	----	0.235	(2.20) [7.19]
L(0)	-769.4		-200.9	
$L(\hat{\beta})$	-594.6		-165.8	
Rho-squared bar	0.221		0.155	
No. of samples	1110		222	
PC (%)			52.7	
OV (%)			7.3	

1) = 1, if possible to transfer from rail to tram , 0 =, otherwise
( ) : t-value for hypothesis t = 0 [ ] : t-value for hypothesis t = 1

A result of sequential estimation of NL model assuming a hierarchical choice structure between SP and before-RP data (NESTED) is shown in Table 7. In the binary choice model between existing and new stations at lower level, all the estimated coefficients excepting in-vehicle time had reasonable signs and a higher level of goodness-of-fit was also indicated by the rho-squared bar. On the other hand, all the coefficients but cost had correct signs in the mode choice model with before-RP data at higher level, and the goodness-of-fit was as good as that of before-RP model which was presented in Table 5. Since the parameter of log-sum variable lay significantly within the range of 0 to 1, the assumption of hierarchical choice structure was statistically accepted.

4.2. External Validity of Updated SP Models

The actual choice behaviors (i.e. after-RP data) were finally estimated using the updated SP models in order to produce PC and OV of each updating procedure. The TRANS model indicated the highest percentage of PC as shown at the bottom of Table 6, while the SCALE and BAYESE models were inferior to the unupdated SP model presented in Table 5 with respect to estimation accuracy represented by PC. The lower percentages of OV indicated by SCALE and TRANS+SCALE models verify that the reestimation of model coefficients using a scale parameter is more efficient to suppress the over-prediction of SP model. The NESTED model shown in Table 7 was superior to all other models shown in Table 6 in terms of OV which represented the over-prediction of rail users. Conversely, the reason why the PC is lowest of all is probably that 85% of rail users chose the new station and consequently the hierarchical choice structure supposed in NL model would not be accepted in the case of using the after-RP data. Judging from these results, it is concluded that if SP and before-RP models could be managed to have a common set of explanatory variables and equivalent alternatives, the updating procedure combining the SCALE and the TRANS would be most efficient to improve the external validity of SP model. When a choice tree between SP and before-RP data could be logically formed, the NESTED procedure would be also useful in updating SP models. While the external validity of these updated SP models can be improved nearly up to the level of before-RP models, we must note that there still remains at least 7% of over-prediction.

5. Conclusions

The external validity of SP models was examined using the mode choice data collected before and after the opening of the new station and the following results were obtained by comparing four updating procedures of SP model;

i) The reestimation of specified model with a scale parameter based on the before-RP data is particularly effective to ameliorate the over-prediction of SP model. This supports the assumption that the relative importance of travel attributes obtained from SP model will be highly reliable;

ii) If TP data can be collected together with SP data, the updating of SP responses using TP data would effectively improve the external validity of SP model. The combination with the SCALE, say the SCALE+TRANS would make the updating more efficient. Since TP data can be easily obtained together with SP data, this procedure would be more practical for actual use;

iii) If a hierarchical choice structure between SP and before-RP data can be formed, the incorporation of nested logit model using SP data at lower level and before-RP data at higher level would be useful. This updating procedure makes it possible to estimate travel mode choice models, even if the context of the SP scenarios were related to the "within-mode" choice, where the different services of a single mode were compared against each other.

These results add confidence to use SP models for forecasting procedures. However, there still exists a significant level of over-prediction, so that more sophisticated updating procedures would be requested to apply the SP model to practical use with more certainty.

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These results add confidence to use SP models for forecasting procedures. However, there still exists a significant level of over-prediction, so that more sophisticated updating procedures would be requested to apply the SP model to practical use with more certainty.

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