DRIVERS' MENTAL BURDEN REDUCTION EFFECTS OF THE OPENING THE EXPRESSWAY IN MOUNTAINOUS AREA

Kunihiro KISHI, Faculty of Engineering, Hokkaido University, JAPAN

Keiichi SATO, Hokkai School of Commerce, JAPAN

ABSTRACT

In Hokkaido, Japan, we are often required to pass mountainous area during intercity traveling. As for Nissho Pass, Route 274 whose maximum altitude is over 1,000 meters, there are many sharp curves and steep angles. Therefore it is very severe situation for drivers. In winter, because of icy road surfaces, many traffic accidents have occurred and drivers feel mental burden a lot.
The Doto Expressway between Tokachi-Shimizu and Tomamu was opened in October 2007. Now we can travel between central Hokkaido and eastern Hokkaido without passing Nissho Pass. It seems that drivers' mental burden reduction effect has recognized by the opening of the Doto Expressway.
The purpose of this study is to analyze drivers' mental burden reduction effects of the opening of the Doto Expressway. This study clarifies how drivers evaluate improvement of safety by opening of the Doto expressway.
This study proposes the Index of Mental Burden for Driving (IMB) for evaluation of drivers' mental burden. IMB is the index whose explaining variables are curve, gradient and road width; it quantifies the relation between mental burden for driving in a mountainous area and road structures. This study applied Kishi's Logit PSM (KLP) for analyzing the value of safety. It is improved from Price Sensitivity Measurement (PSM), and is based on willingness to pay and can analyze the "reasonable price" from the viewpoint of marketing research.

Keywords: mental burden, expressway, IMB, KLP

INTRODUCTION

In Hokkaido of Japan, drivers are often required to pass mountainous area during intercity traveling. As for Nissho Pass, Route 274, maximum altitude is over 1,000 meters, it has many sharp curves and steep angles. Therefore it is very severe situation for drivers. In winter, because of road surface, many traffic accidents have occurred and drivers have mental burden a lot.

Doto expressway between Tokachi-Shimizu and Tomamu was opened in October 2007. Now we can travel between central Hokkaido and eastern Hokkaido without passing Nissho Pass. It seems that drivers' mental burden reduction effect has appeared by the opening of the Doto Expressway.

The purpose of this study is to analyze drivers' mental burden reduction effects of the opening of the Doto Expressway. This study clarifies how drivers evaluate improvement of safety by opening of the Doto expressway. Index of Mental Burden for Drives (IMB) and Kishi's Logit PSM (KLP) are applied for the analysis.

THE DOTO EXPRESSWAY BETWEEN TOKACHI-SHIMIZU AND TOMAMU

Doto Expressway between Tokachi-Shimizu and Tomamu was opened in October 2007. As shown in Figure 1, when we travel between "A" and "B", we have two routes. One is Nissho Pass, National Route 274, the other is Doto Expressway. Maximum altitude of the Doto Expressway is about 600 meters, it is about 400 meter lower than that of Nissho Pass.

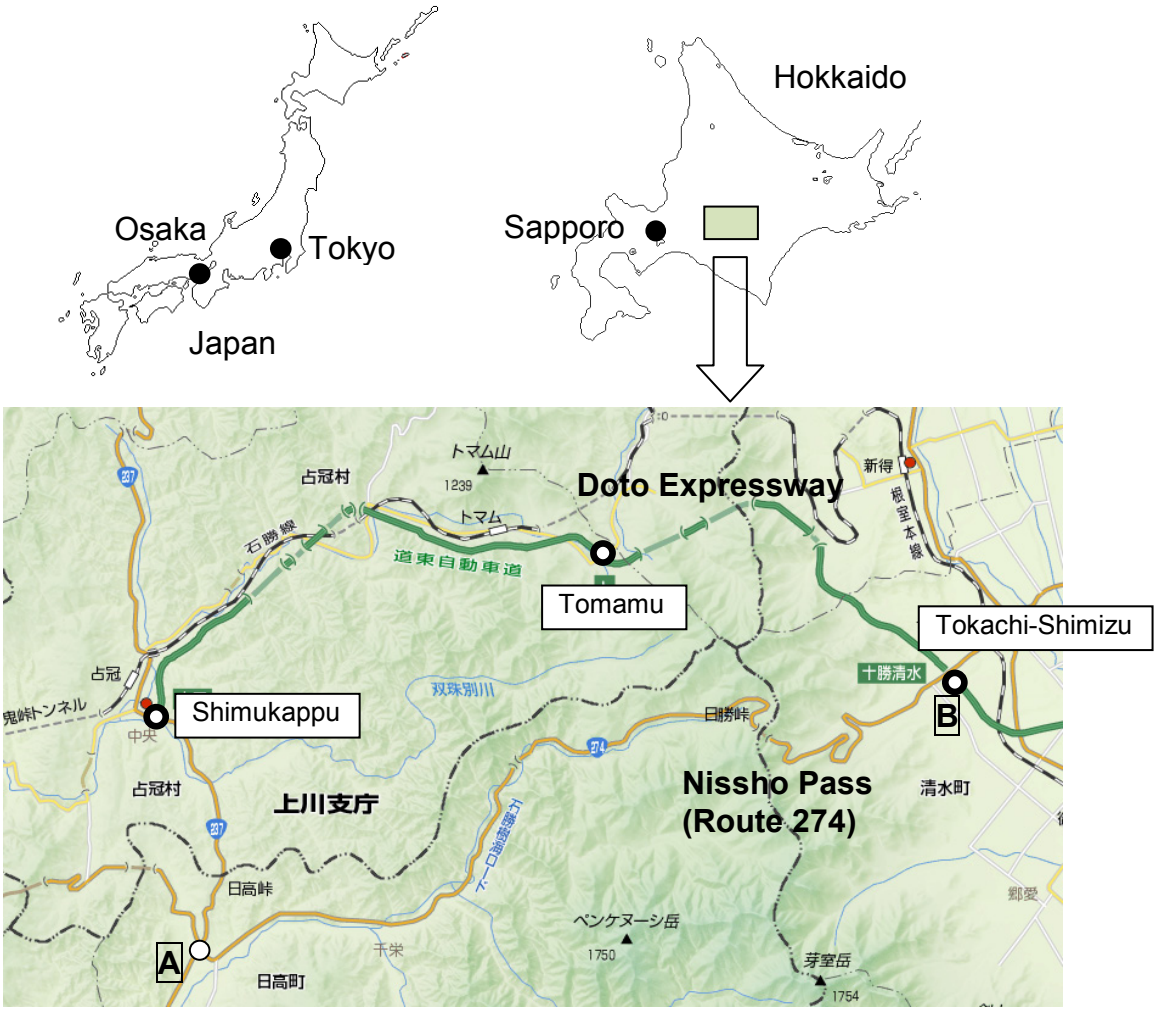

Figure 1 Location of Doto Expressway and Nissho Pass

Figure 2 Picture of Nissho Pass (Left) and Doto Expressway (Right)

As for road structure, expressway is much more excellent than national route, so road user can drive more safety and comfortably than before. The section between Tomamu and Shimukappu was opened in October, 2009. It is scheduled that the section between Yubari and Shimukappu will be opened by March 2011 and we can go to Obihiro from Sapporo directly using expressway. This study focuses the section between Tokachi-Shimizu and Tomamu of the Doto Expressway. The distance of this section is 20.9km and it is 47.1km from Tokachi-Shimizu to Shimukappu.

OUTLINE OF THE QUESTIONNAIRE SURVEY

This study conducted a questionnaire survey on road structure among drivers who use Doto Expressway and Nissho Pass, Route 274. Table 1 shows the outline of the survey. Roadside Station of Table 1 is the point "A" in Figure 1. Tokachi-Shimizu interchange toll gate is the point "B" in Figure 1. The percent of heavy vehicles on Doto Expressway was very low and most of them did not stop at Nissho Pass, we could not deliver enough questionnaire sheets. Therefore another questionnaire survey was conducted among carriers in Obihiro and Kushiro in order to get answers from drivers of heavy vehicle (Table 2).

Table 1 Outline of the Questionnaire Survey

Respondents	Driver of Nissho pass		Drivers of Doto Expressway	
Date	November 11 and 12 , 2007			
Place	Roadside station		Tokachi-Shimizu IC toll gate	
Method	Distribute by hand and collect by mail			
Vehicle type	Standard-sized vehicle	heavy vehicle	Standard-sized vehicle	heavy vehicle
Number of distributions	150	49	788	41
Number of collections	75	15	258	5
Collect rate	50.0%	30.6%	32.7%	12.2%

Table 2 Outline of the Additional Questionnaire Survey

Investigation object	Carriers in Obihiro	Carriers in Kushiro
Date	January 16～23 , 2007	
Method	Distribute and collect by mail	
Distributed number of companies	127	30
Number of distributions	254	60
Number of collections	51	18
Collect rate	20.1%	30.0%

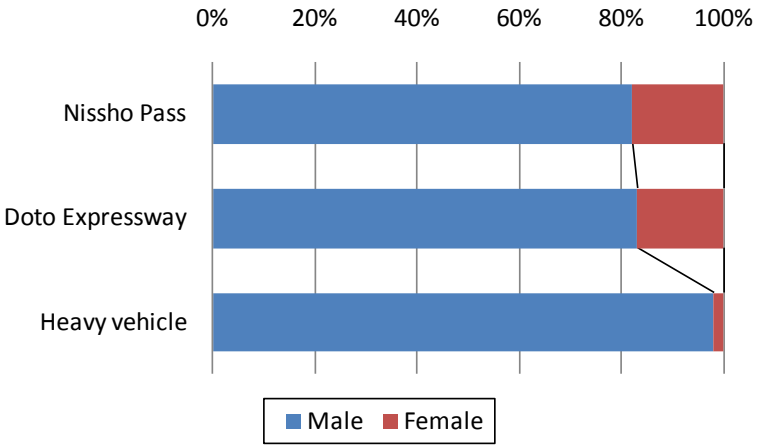

Figure 3 Respondents' Sex

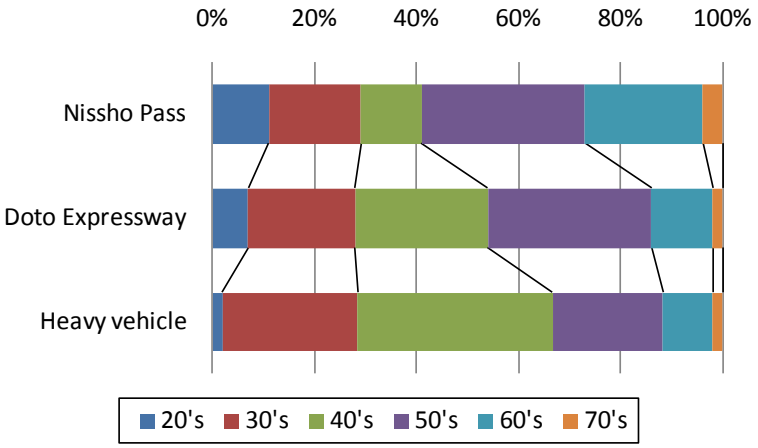

Figure 4 Respondents' Age

Figure 3 is sex of respondents, Figure 4 is age and Figure 5 is respondents' experience of driving Nissho Pass. Many respondents have driven Nissho Pass more than 11 times. It is considered that this study evaluates Nissho Pass from the viewpoint of drivers who know that pass very much.

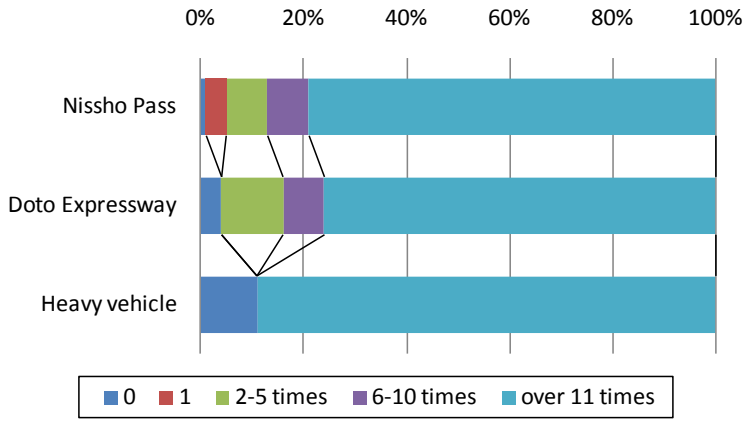

Figure 5 Respondents' Experience of Driving Nissho Pass

QUANTITATIVE EVALUATION OF MENTAL BUDRDEN FOR DRIVING IN MOUNTAINOUS AREA

Importance Evaluation of Route Choice by Pair Comparison Experiment

This study analyzed which factor was important for route choice between Nissho Pass and Doto Expressway by pair comparison experiment. Four factors are applied; "Drivers can pass through mountainous area safely", "Travel time is short", "Landscape is beautiful" and "Travel cost is cheap".

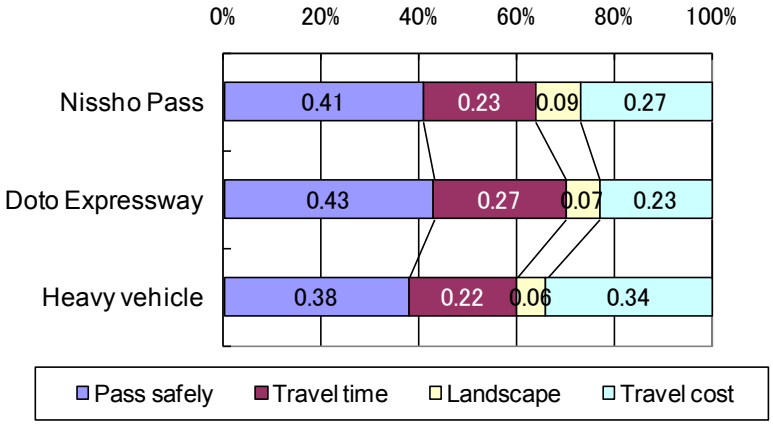

Figure 6 Important Factor for Route Choice

As shown in Figure 6, "Drivers can pass through mountainous area safely" is the most important, "Travel cost is cheap" and "Travel time is short" follow that. As for heavy vehicles, "Travel cost is cheap" is important.

Evaluation about Road Structure of Nissho Pass and Doto Expressway

This study analyzed drivers' mental burden when they are driving on Nissho Pass or Doto Expressway (Figure 7).

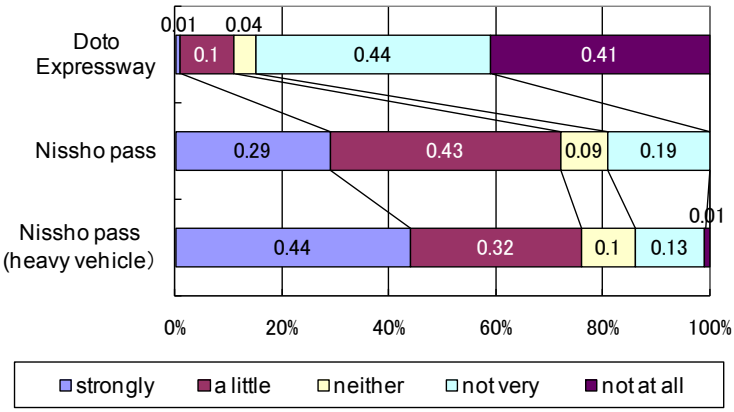

Figure 7 "Do you feel mental burden for driving in mountainous area ?"

About 70% of drivers of Nissho Pass feel mental burden for driving "strongly" or "a little". On the other hand, those who answered "strongly" or "a little" among drivers of Doto Expressway is only about 10%. Focusing on heavy vehicle, about 50% of drivers of Nissho Pass feel mental burden "strongly".

In the same way, questionnaire survey asked about road structure; curve, gradient and road width. Results are shown in Figure 8, 9 and 10.

As for curve, about 70% of drivers of Nissho Pass answered that curve and gradient were "sharp" or "a little sharp" but many drivers of Doto Expressway answered that they are not sharp (Figure 8 and 9). Drivers of Nissho Pass feel road width is "narrow" or "a little narrow" (Figure 10).

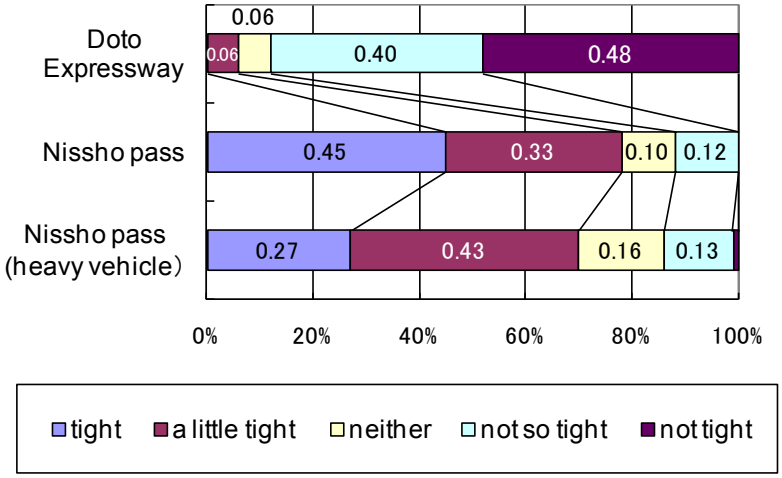

Figure 8 Evaluation of Curve

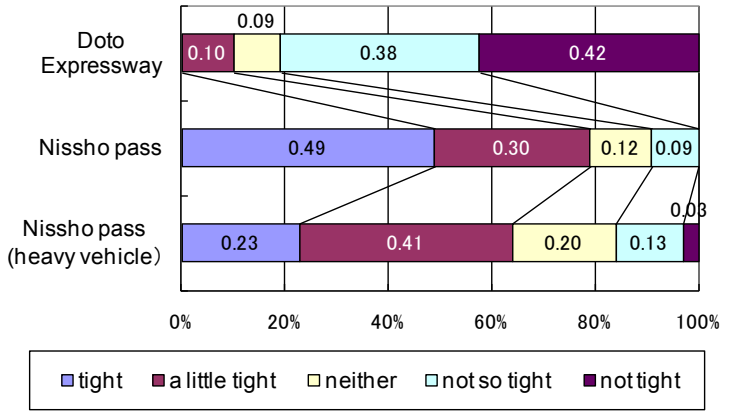

Figure 9 Evaluation of Gradient

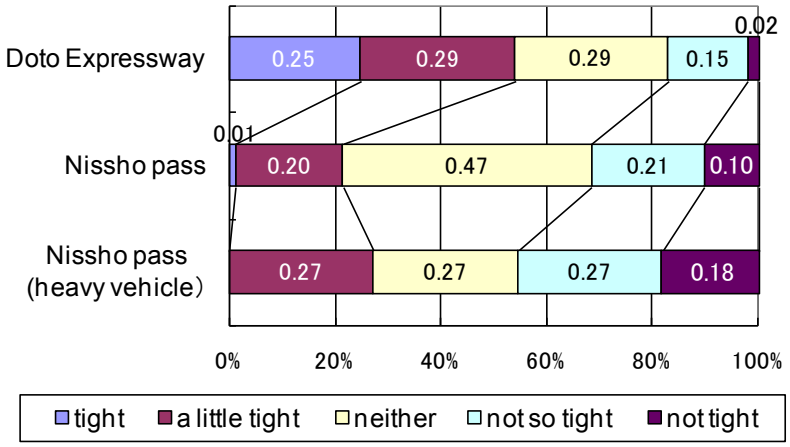

Figure 10 Evaluation of Road Width

Analysis by Hayashi's Quantification Theory II

This study analyzed the relation between mental burden and road structure by Hayashi's Quantification Theory II. Items of this method are curve, gradient and road width from Figure 5-7, and mental burden from Figure 4 is applied for external criterion. Among each factors, five-grade evaluation is replaced to three-grade evaluation.
Table 3 shows partial correlation coefficient of each items.

Table 3 Partial Correlation Coefficient by Hayashi's Quantification Theory II

	Curve	Gradient	Road Width
Nissho Pass	0.372	0.386	0.175
Doto Expressway	0.343	0.134	0.051
Nissho Pass (heavy vehicle)	0.795	0.185	0.148

As for Nissho Pass, curve and gradient have much effect on mental burden. Especially for heavy vehicle, curve influences mental burden strongly.

INDEX OF MENTAL BURDEN FOR DRIVING

This study proposes the Index of Mental Burden for Driving (IMB). IMB is the index whose explaining variables are curve, gradient and road width, it quantifies the relation between mental burden for driving in mountainous area and road structures. Equation (1) shows the IMB.

IMB = "Weight of Curve's Range" × "Bendiness" +
"Weight of Gradient's Range" × "Hilliness" +
"Weight of Road Width's Range" × "Inverse Number of Road Width" (1)

Bendiness is obtained by dividing sum of crossing angles by distance of that section as shown by Equation (2).

$$\text{Bendiness} = \frac{\Phi_1 + \Phi_2 + \Phi_3 + \cdots + \Phi n(\deg)}{\text{Distance}(km)} \quad (2)$$

Hilliness is shown by Equation (3). HR is obtained by dividing sum of vertical interval on a upgrade by distance of that section and HF is obtained by dividing sum of vertical interval on a down grade by distance (Equation (4) and (5)).

$$\text{Hilliness} = \text{HR} + \text{HF} \quad (3)$$

$$\text{HR} = \frac{h_1 + h_3 + \cdots + h_n(m)}{\text{Distance(km)}} \quad (4)$$

$$\text{HF} = \frac{h_2 + h_4 + \cdots + h_{n+1}(m)}{\text{Distance(km)}} \quad (5)$$

Weghts of explaining variables apply the ratio of range calculated by Hayashi's Quantification Theory II (Table 4)

Table 4 Ratio of Range calculated by Hayashi's Quantification Theory II

	Curve	Gradient	Road Width
Nissho Pass	0.399	0.433	0.167
Doto Expressway	0.751	0.194	0.055
Nissho Pass (heavy vehicle)	0.824	0.112	0.064

Bendiness and Hilliness are calculated as shown in Table 5 from the databases of road structures in Hokkaido. And those values are divided by the average of Hokkaido.

Table 5 Explaining variables for IMB

	Hilliness	Bendiness	Road width
Nissho Pass	33.8(1.10)	109.8(1.56)	0.17(1.01)
Doto Expressway	17.8(0.58)	18.6(0.27)	0.14(0.87)

Using data of Table 4 and 5, IMB is calculated as shown in Table 6. IMB of Doto expressway of heavy vehicle could not be calculated because of few respondents.

Table 6 IMB of Nissho Pass and Doto Expressway

	Nissho Pass	Doto Expressway	Reducing rate of IMB
IMB (standard vehicle)	1.27	0.36	71.4%
IMB (heavy vehicle)	1.15	-	-

Average IMB in Hokkaido is 1.0 in this study. As for Nissho Pass, IMB of standard-sized vehicle is 1.27 and that of heavy vehicle is 1.15, so drivers have much mental burden. On the other hand, IMB of Doto Expressway is 0.36 and reducing rate is 71.4%.
Therefore opening Doto expressway has much effect on reducing mental burden for driving from the viewpoint of road structures.
IMB can evaluate drivers' mental burden from the viewpoint of road structure. When we evaluate existing road, we can just ask "Do you feel mental burden?" in the same way with Figure 7. However, when we evaluate future improved road, IMB is useful for estimating drivers' mental burden.

QUANTITATIVE EVALUATION OF VALUE FOR SAFETY

Outline of Kishi's Logit PSM

Price Sensitivity Measurement

Price Sensitivity Measurement (PSM) is a method to measure consumers' perceptions of a price of a product or a brand. The Consumers' perceptive responses to a product price are epitomized as "reasonable", "expensive", "too expensive to buy" and "too cheap to buy". Prices are generally determined by factors such as, supply and demand; cost prices, and price competitiveness. PSM has been developed as a method to find solutions through psychological approach to pricing issues concerning consumers' price sensitivity and acceptability.

Four Prices in PSM

In the PSM method, consumers are asked to suppose product prices at four different levels: "reasonable," "expensive," "too expensive to be willing to buy," and "too cheap to be willing to buy." (Table 7)

Table 7 Four Prices and the Questions

(1)Reasonable "What price do you think would be reasonable for the product?"
(2)Expensive "What price do you think would be too expensive for the product?"
(3)Too expensive to be willing to buy "What price do you think would be too expensive to be willing to buy the product?"
(4)Too cheap to be willing to buy "What price do you think would be too cheap to be willing to buy the product, because of doubts about its quality?

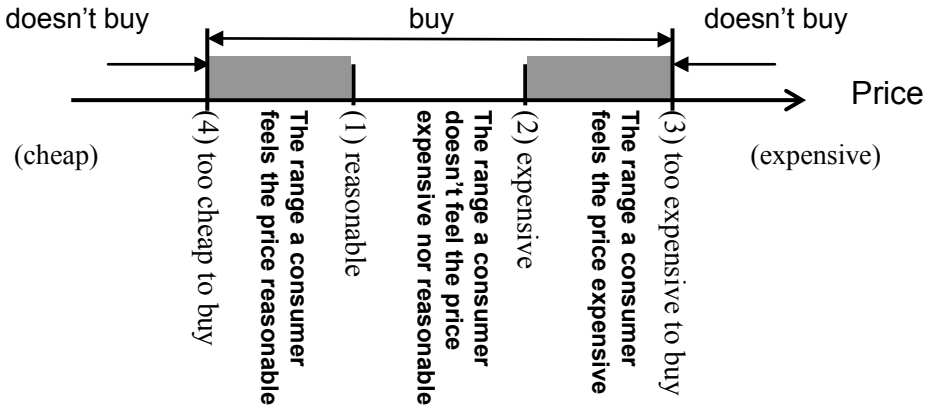

Figure 11 Consumers' Price Sensitivity and Willingness to Buy

The four prices are supposed to correlate as described in equation (6) and Figure 11.

$$(4) < (1) \leq (2) < (3) \qquad (6)$$

Based on the collected pricing data, frequency distributions were analyzed and relative cumulative frequencies were established as Figure 12. The prices given by the subjects as "Reasonable" and "Too cheap to be willing to buy" are depicted as decreasing curves, and "Expensive" and "Too expensive to be willing to buy" prices show increasing curves.

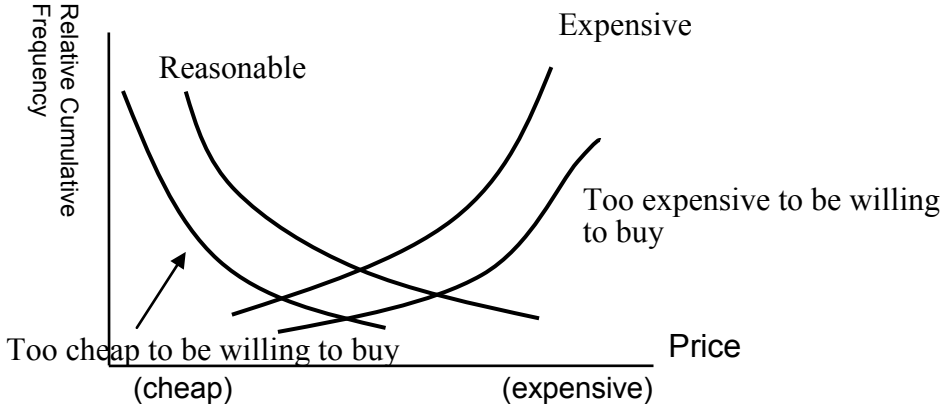

Figure 12 Relative Cumulative Frequencies of Four Prices

Complementary events of "Reasonable" and "Expensive" prices are established, and then the intersections in the graph are used as reference price indicators of PSM. The complementary event of the "Reasonable" price is "Should be less expensive" (Figure 13), and that of the "Expensive" price is "Should be more expensive" in a same way.

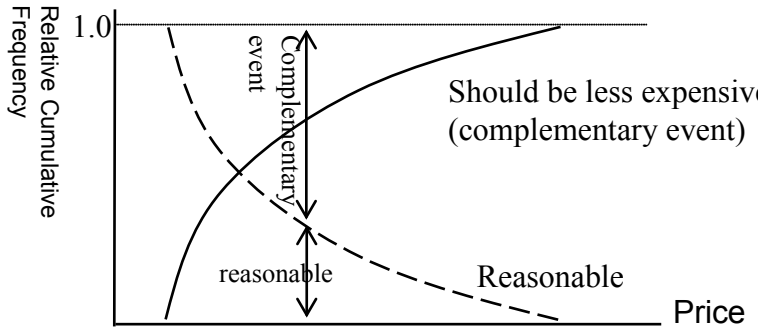

Figure 13 Complementary Event of the "Reasonable" price

Kishi's Logit PSM (KLP)

In the PSM analysis, relative cumulative frequencies of "Should be less expensive", "Should be more expensive", "Too expensive to be willing to buy" and "Too cheap to be willing to buy" are established and the intersections in the graph are used as reference price indicators of PSM.

However, we can't make detailed evaluations in PSM on the price range that is not included in the subjects' responses. Kishi's Logit PSM (KLP) has improved PSM applying four relative cumulative frequencies that are regressed by using the logit model as indicated by equation (7) and equation (8). The resulting curves are shown in Figure 11. When a dependent variable lies between 0 and 1, it is equal to the relative cumulative frequency. As the logit model is a continuous function, KLP can circumstantially analyze consumers' evaluation on any prices.

$$T = \frac{1}{1 + \exp F(x)} \tag{7}$$

$$F(x)=ax+b \tag{8}$$

where

T: relative cumulative frequency
x: price
T_1, F_1: should be less expensive
T_2, F_2: should be more expensive
T_3, F_3: too expensive to be willing to buy
T_4, F_4: too cheap to be willing to buy

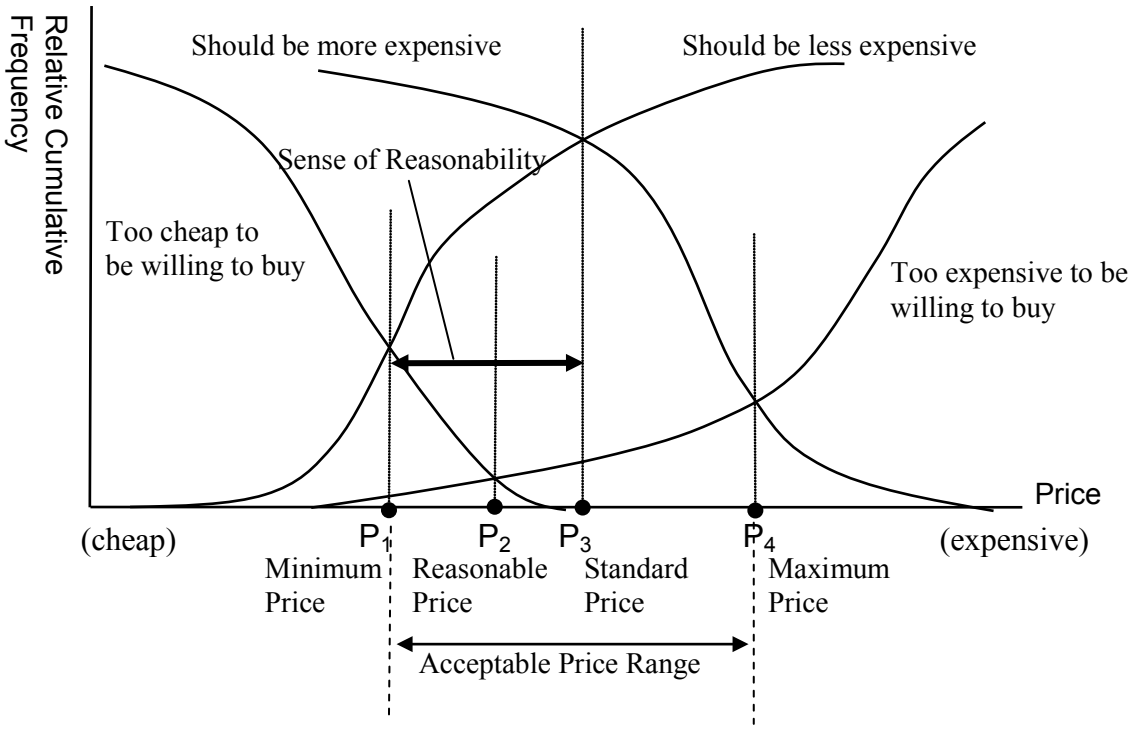

Figure 14 KLP Reference Price Indicators

From Figure 14, the following reference price indicators can be obtained:

a) **P_1 (Minimum Price)**
The two curves of "Should be less expensive" and "Too cheap to be willing to buy" are focused. The price should be discounted in order to decrease consumers who feel it should be less expensive, but the more price is discounted, the more consumers feel it is too cheap to be willing to buy, thus the product isn't accepted. When the price is below P_1 in Figure 12, more consumers think it is too cheap to be willing to buy. It is supposed to be the minimum price for the entire consumer population.
The reason why consumers think it is too cheap to be willing to buy is that they doubt the product quality. And "Should be less expensive" means that consumers are buying the product in spite of the expensive price, because they think the product quality is more important than the price. It indicates that the minimum price is the amount which consumers think it should not be lower to ensure the product quality.
b) **P_4 (Maximum Price)**
The intersection of the two curves, "Should be more expensive" and "Too expensive to be willing to buy" represents the maximum price. For prices higher than this price, more consumers think that they are too expensive to be willing to buy the product. As the both curves represent consumers' priority on price rather than quality, the maximum price is determined on the basis of their price conscious considerations.
c) **P_3 (Standard Price)**
The intersection of the curbs of prices "Should be less expensive" and "Should be more expensive" indicates that the number of consumers who are affirmative to either opinion is the same. That is to say, the same number of consumers think the price reasonable or

expensive from the viewpoint of the complementary event. In other words, the entire consumer population is regarded to think the price neither expensive nor cheap, because the price is reasonable.

The Standard Price represents the point where the product quality and the price well balance.

d) **P_2 (Reasonable Price)**

The intersection of the curves of "Too expensive to be willing to buy" and "Too cheap to be willing to buy" is focused. When a price is higher than the amount indicated by the intersection, more consumers think it is too expensive to be willing to buy than those who think it is too cheap. In the same way, when a price is lower than the price, more consumers think it is too cheap to be willing to buy than those who think it is "too expensive to be willing to buy". The price represents the border to differ customers' motivational factor for "not to be willing to buy a product" from "doubts about the quality" to "too expensive price". Accordingly, Reasonable Price indicated by the intersection can be defined as a price which consumers perceive reasonable considering the quality.

e) **P_1 to P_4 (Acceptable Price Range)**

Acceptable Price ranges between Maximum Price and Minimum Price. Distributors should set a price within the range that is acceptable for the entire consumer population.

f) **Sense of Reasonability**

Within the Acceptable Price Range, the entire consumer population feels a price more reasonable when it is placed between Standard Price and Minimum Price.

Evaluation of Safety by KLP

This study analyzed the value of safety by KLP.

In the questionnaire survey, it is assumed as follows;

"After opening Doto Expressway between Tokachi-Shimizu and Tomamu, drivers do not have to pass through Nissho Pass and they pay toll as the value that they can drive safe in mountainous area."

Respondents were asked three prices; "reasonable", "expensive" and "too expensive to be willing to use Doto Expressway". Questionnaire survey did not ask "too cheap to be willing to

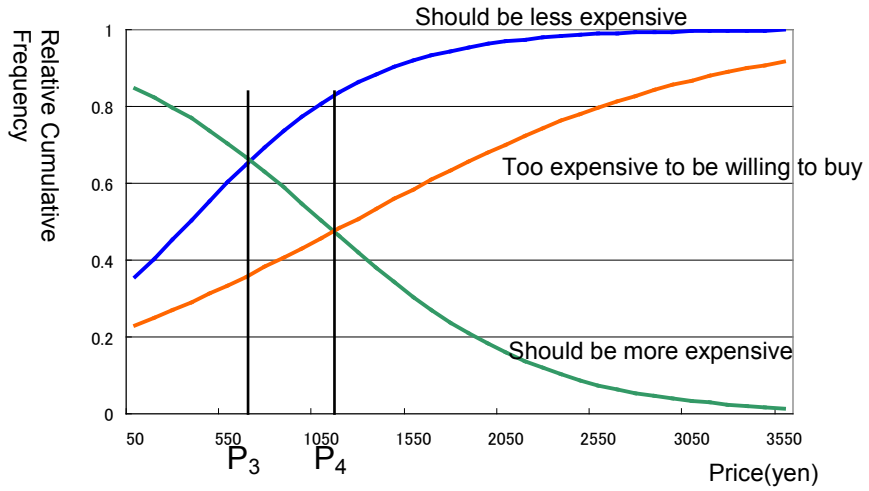

Figure 15 Evaluation of Value of Safety by Nissho Pass Drivers with KLP

Table 8 The Result of Analysis by KLP

	Driver of Nissho Pass	Driver of Doto Expressway	Heavy Vehicle driver
Standard Price	671 yen	957 yen	905 yen
Maximum Price	1,121 yen	1,342 yen	1,219 yen

use", because it is not appropriate for expressway toll. Because the curve of "too cheap to be willing to buy" is not described in Figure 14, only P3 "Standard Price" and P4 "Maximum Price" are analyzed by KLP.
As an example, Figure 15 is the evaluation of Nissho Pass drivers by KLP. The result of analysis by KLP is shown in Table 8.
About actual toll between Tokachi-Shimizu and Tomamu, it is 700 yen for standaed-sized vehicle and 1,050 yen for heavy vehicle.
KLP price reference indicators of drivers who use Doto Expressway are more expensive than those of drivers who use Nissho Pass. That is to say, drivers who use Doto Expressway evaluate safety of Doto Expressway higher than drivers who use Nissho Pass. It was also found that their willingness to pay for safety of expressway is almost the same with actual toll fare (700yen). Drivers recognize that expressway is the safe road, rather than the road that can shorten travel time in Hokkaido.
As for heavy vehicle drivers, Standard Price is cheaper than actual toll and they don't think it is reasonable even though it is the value of safety.

CONCLUSION

This study proposed IMB and analyzed driver's mental burden reduction effect in mountainous area quantitatively with IMB. This study also clarified the value of safety of expressway by KLP.
As a result of the section between Tokachi-Shimizu and Tomamu, drivers make the most priority for "Pass through mountainous area safely" (Figure 3) and they evaluate Doto Expressway as a safe route. It can be said that Doto Expressway reduces drivers' mental burden.
Moreover, it was found that their willingness to pay for safety of expressway is almost the same with actual toll fare. That is to say, drivers recognize that expressway is the safe road, rather than the road that can shorten travel time in Hokkaido.
From the viewpoint of safety, It is more desirable that drivers use Doto Expressway than they use Nissho Pass. Drivers of standard-sized vehicle evaluate safety of Doto Expressway highly, on the other hand, heavy vehicle drivers do not use Doto Expressway because toll is not acceptable for them.
After opening the section between Tomamu and Shimukappu in October, 2009, it seems that traffic volume of Doto Expressway is increasing and that of Nissho Pass is decreasing.
We evaluate Doto Expressway continuously for the future study, and evaluation of safety in winter season should be also analyzed.

REFERENCES

Depart for Transport, UK. (1996). The COBA Manual : Economic assessment of roads schemes-Rural single carrigeways

Kishi, K., Uchida, K., and Satoh, K. (1999). Price Sensitivity of Airfare from the Viewpoint of Passengers (in Japanese), Journal of Infrastructure Planning, Vol.16, 187-194

Kishi, K., Takahashi, Y., Hara, F. and Satoh, K. (2002). Level of Snow Removal Service and Residents' Willingness to Pay –Evaluation for Four Japanese Cities, Transportation Research Record, 1794, 72-76

Kishi, K., Hino, S. and Satoh, K. (2003). Location Planning of Elevators at Subway Stations Considering Transfer Resistances Based on Passengers' Physical and Conscious Resistance, Journal of the Eastern Asia Society for Transportation Studies, Vol.5, 3250-3260

Kishi, K. and Satoh, K. (2005). Evaluation of Willingness to Buy a Low-Pollution Car in Japan, Journal of the Eastern Asia Society for Transportation Studies, Vol.6, 3121-3134(2005)

Monroe, K. B. (2002). Pricing: Making Profitable Decisions, Third Edition, McGraw-Hill/Irwin