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Customer Satisfaction Analysis for Evaluating Winter Driving Environment

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ABSTRACT

The deterioration of driving environments in cold, snowy regions during winter causes unfavorable traffic characteristics such as reduced travel speeds, winter-type traffic accidents and lower user satisfaction. Road administrators work to maintain a safe, smooth flow of road traffic in winter by carrying out road maintenance. However, under the constraints of the current financial crisis, there is a need for further improvements in the appropriateness and efficiency of winter road maintenance. To achieve this, it is important to understand how the deterioration of road conditions affects user satisfaction and driving behavior. In this study, the authors sought to evaluate winter driving environments by simultaneously carrying out evaluation of road conditions, a user satisfaction survey and a driving behavior test both in autumn and in winter. As elements of driving behavior, driving speed and longitudinal acceleration were measured. Customer Satisfaction (CS) portfolio analysis was applied for the user satisfaction survey. The test results indicated a tendency for driving speeds and acceleration rates to decrease in winter. However, it remained unclear whether these changes in driving behavior were caused by the deterioration of road surfaces or by the narrowing of roads due to the presence of piled snow. Meanwhile, results corresponding to the characteristics of changes in road conditions were attained in the user satisfaction survey, thereby confirming the effectiveness of subjective assessment.

Keywords: Winter maintenance, Customer satisfaction, Driving behaviour, Customer Satisfaction portfolio analysis

1 INTRODUCTION

The Japanese archipelago is situated between the latitudes of 20 and 45 degrees north. Even though the islands are farther south than the majority of the world's cold, snowy countries, most of Japan's regions are affected by snow in winter. Hokkaido, the northernmost major island of Japan, is particularly cold and snowy, with many municipalities of Hokkaido experiencing sub-zero average temperatures from December to March. Hokkaido's capital city of Sapporo, has a population of approximately 1.9 million [1]. The annual snowfall total there is approximately 6 m, and the maximum snow depth reaches up to 1 m. It is rare for a city this large to be so cold and snowy. In order to support economic activity and everyday life, Sapporo's municipal government allocates about 11 billion yen per year to road snow removal [2]. However, despite the best efforts of road administrators, driving environments deteriorate in winter due to road narrowing caused by snow piles on road shoulders, slippery road surfaces, uneven surfaces covered with snow, and poor visibility in drifting snow. As a result, the deterioration of driving environment induces unfavorable traffic characteristics such as reduced travel speeds, winter-type traffic accidents and lower user satisfaction.

According to polls conducted by the Sapporo municipal government, snow removal ranks first in terms of measures and policies considered to need improvement [3]. In order to enhance resident satisfaction under the constraints of the current financial crisis, there is a need to seek further improvements in the appropriateness and efficiency of winter road maintenance. To achieve this, it is important to understand how the deterioration of road conditions affects driving behavior and user satisfaction.

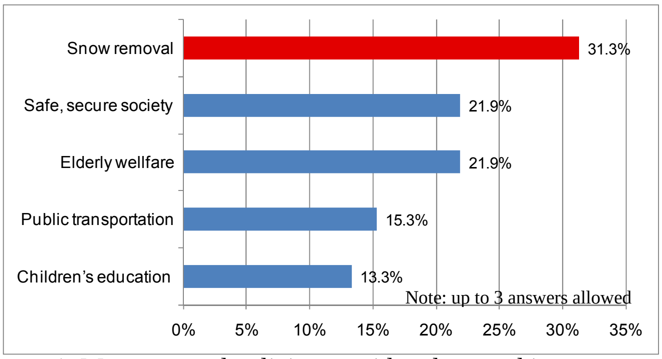

Figure 1. Measures and policies considered to need improvement

2 STUDY METHOD

In this research, road conditions were evaluated to determine how changes in autumn and winter driving environments affect driving behavior and driver satisfaction. Simultaneously, a user satisfaction survey and a driving behavior test were conducted. In the evaluation of winter road conditions, the dimensions of snow piles on road shoulders and friction number were measured. Additionally, in order to enable the simultaneous performance of the driving behavior test and the user satisfaction survey, the driving tests were conducted using a test vehicle equipped with observation instruments.

For the user satisfaction survey, Customer Satisfaction (CS) portfolio analysis was applied. This analysis technique is based on the product portfolio method proposed by Boston Consulting Group (BCG), and uses a scatter chart to rank business units on the basis of their relative market share and market growth rate (Figure 2). The BCG matrix is divided into the four categories of *Stars*, *Cash Cows*, *Question Marks*, and *Dogs*. Stars are high-growth businesses or products competing in markets where they are relatively strong compared with the competition. Cash Cows are low-growth businesses or products with a relatively high market share. Question Marks are businesses or products that have a low market share but operate in higher-growth markets. Finally, Dogs are businesses or products that have a low relative share in unattractive, low-growth markets.

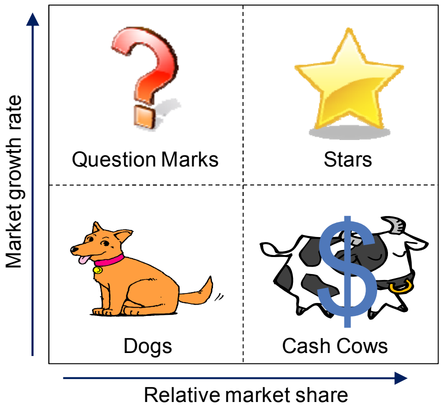

Figure 2. The BCG matrix

Instead of employing the market growth rate and the relative market share, CS portfolio analysis uses a scatter chart based on user satisfaction and expectation. This approach has been widely used in the field of marketing, and is designed to clarify user needs. In the field of civil engineering, the technique has been applied for purposes such as contributing to the improvement of safety at roadworks sites [4]. Under this approach, to quantify satisfaction with the current situation, for example, scores on a five-point scale are totaled and averaged. Also, the degree to which each improvement influences overall satisfaction is used as an explanatory variable for multiple linear regression analysis. A partial correlation coefficient is obtained for each sub-item.

The scatter chart is divided into the four quadrants of Maintenance, Non-improvement, Improvement and Priority Improvement. The Maintenance quadrant contains items characterized by high levels of satisfaction and expectation, meaning that the current level of satisfaction must be maintained. The Non-improvement quadrant contains items for which users' expectation is low and their satisfaction level is high, meaning that no improvement is required. The Improvement quadrant contains items characterized by low levels of satisfaction and expectation, meaning that improvement is required. The Priority Improvement quadrant contains items that are regarded as important by users but do not satisfy their expectations, meaning that immediate improvement in related levels of service is necessary. The first step in effective enhancement of overall satisfaction is the improvement of items in this quadrant.

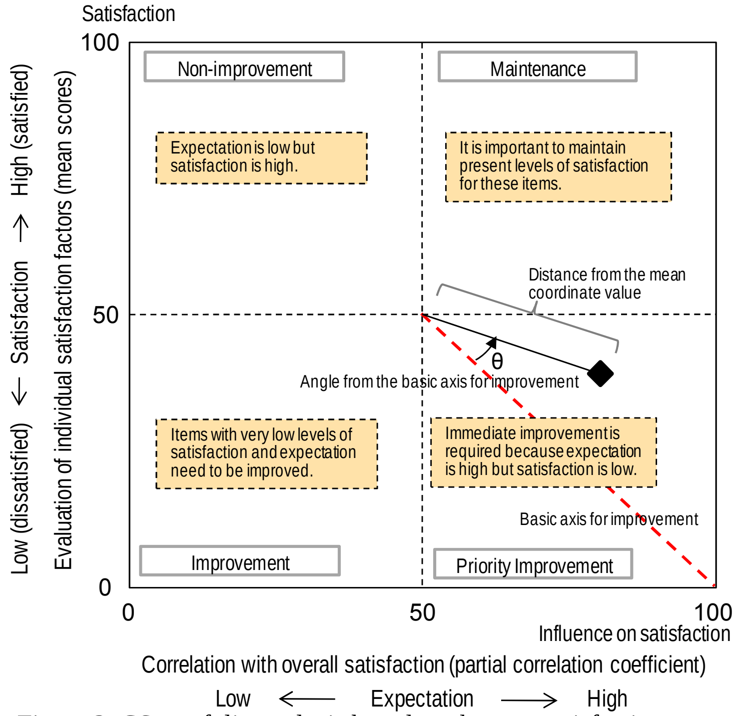

Figure 3. CS portfolio analysis based on the user satisfaction survey

Next, we explain how improvement priority is determined. To deal with this consideration, Improvement Necessity Factor (IMF) is introduced in relation to both satisfaction and expectation. A line drawn from the coordinates of the mean value (50, 50) to the coordinates (100, 0) where the influence on satisfaction is the greatest and the satisfaction level is the lowest can be used as a basic axis to determine IMF values. Then, the distance between the coordinates (50, 50) and the coordinates of each item, and the angle between the basic axis and the line connecting the coordinates (50, 50) with the coordinates of each item is used to calculate the IMF (Equation 1). Improvement of items whose IMF values are relatively large is the most effective approach for enhancing overall satisfaction.

$$\text{IMF} = \text{Modified exponent} \times \text{Distance from coordinates (50, 50)}$$

$$= \left(\frac{90° \text{ - angle from boundary line}}{90}\right) \times \sqrt{(x - \bar{x})^2 + (y - \bar{y})^2} \quad , (\bar{x}, \bar{y}) = (50, 50) \qquad (1)$$

3 CASE STUDY

3.1 Driving test

The driving test was conducted in the autumn of 2009 and the winter of 2010 to clarify changes in satisfaction related to the deterioration of driving environment. The road used was National Highway Route 230, and the two test sections were in a downtown area and a suburban area (Figure 4). Table 1 shows the weather conditions on the test dates. Ten licensed non-professional drivers in their thirties and forties were chosen as test subjects. All of them drove on a daily basis, and their annual driving distances ranged from 10,000 to 20,000 km. The tests in both seasons were carried out with the same subjects.

As the test vehicle, a typical sedan-type car with a 1,500 cc engine and front-wheel drive was used. As elements of driving behavior, driving speed and longitudinal acceleration were measured at intervals of one second. The satisfaction survey was carried out immediately after the test so that drivers could record their impressions while they were still fresh. In the satisfaction survey, the test subjects were asked to indicate their levels of satisfaction with the following considerations:

- Overall satisfaction
- Road surface condition
- Traffic flow
- Road surface flatness
- Road width

- Sight distance
- Intersections (starting and stopping)

The subjects were asked to gauge their levels of satisfaction on a five-point Likert scale are totaled and averaged: 1 = dissatisfied, 2 = somewhat dissatisfied, 3 = neither satisfied nor dissatisfied, 4 = somewhat satisfied, 5 = satisfied.

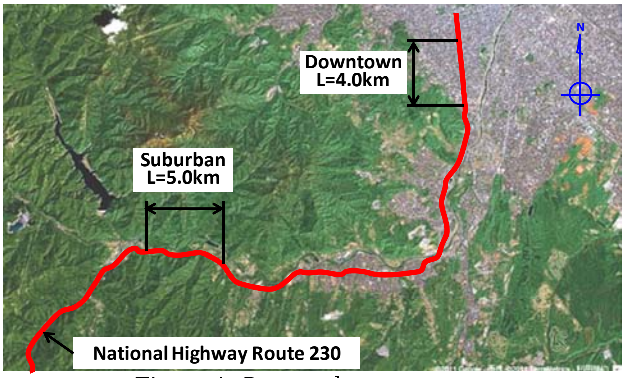

Figure 4. Case study route map

	Date	Weather	Air temperature (°C)		
			Lowest	Highest	Average
Autumn	Nov. 26, 2009	Cloudy	2.9	5.8	4.1
Winter	Jan. 15, 2010	Mostly sunny	-8.7	-3.8	-6.5

Table 1. Weather conditions

3.2 Evaluation of road conditions

In order to assess the impact of changes in road conditions such as snow accumulation and icy road surfaces, the dimensions of snow piles on road shoulders and road surface friction were measured at the time of the driving test. The height and width of snow piles were measured using photos taken from the sidewalk so as not to interfere with traffic flow. Road surface friction was measured using a continuous friction tester (CFT), which consists of a measuring wheel fixed to a frame towed by a vehicle. The measuring wheel is offset by 1 to 2 degrees from the vehicle's direction of travel to produce a lateral force that can be measured to indicate the level of road surface friction. CFT enables continuous measurement of road surface friction without braking or otherwise manipulating the measuring wheel. Friction number measured using CFT is called Halliday Friction Number (HFN), which is originally determined by the device's designer. HFN scale usually ranges from 0 (no lateral force) to 100 (the lateral force on a dry road surface at -17.8 degrees Celsius).

Figure 5. Continuous friction tester (CFT)

3 STUDY RESULTS

3.1 Road conditions

Road surface was dry in autumn, while in winter there was a combination of icy, slushy and wet surfaces in the downtown area and icy or compacted-snow-covered surfaces in the suburban area. Measurement result of the dimensions of snow piles on road shoulders showed that they were 1.1 m to 1.3 m in height and narrowed the road by 1.25 m to 1.45 m (1.35 m on average) in the downtown area during winter (Figure 6). This indicates that the road width was, on average, 79% of the 6.50 m value seen in autumn. In the suburban area, narrowing of roads due to snow piles was seen only on bridges.

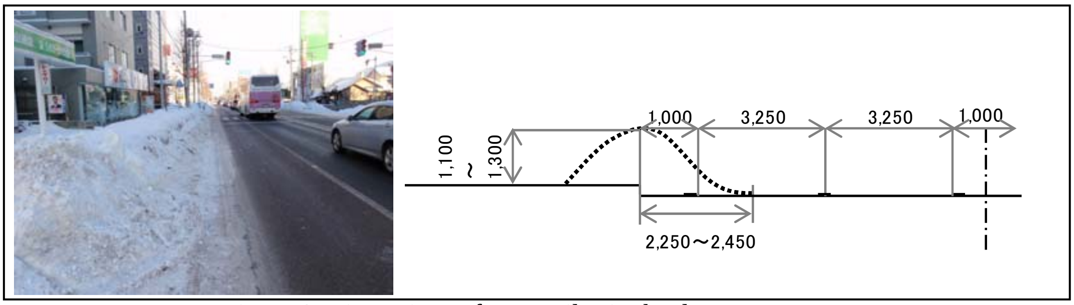

Figure 6. Dimensions of snow piles in the downtown area

Figure 7 shows road surface conditions (HFN values) on the test dates. In autumn, the averages were as high as 93 in the downtown area and 101 in the suburban area. Meanwhile, in winter, these HFN values fell to 64 in the downtown area and 47 in the suburban area, where the road surface was particularly slippery.

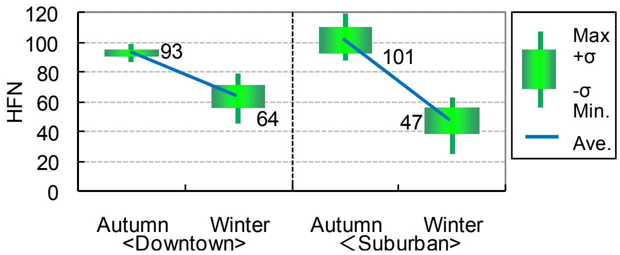

Figure 7. Road surface conditions (HFN values)

3.2 Driving behavior

The driving speeds of the test vehicle are shown in Figure 8. The minimum speed of 0 km/h indicates stoppage at signals or other traffic signs. Compared with autumn driving speeds, the maximum values for winter were 9.6 km/h and 6.9 km/h lower, and the average speeds were 5.8 km/h and 7.7 km/h lower in the downtown and suburban areas, respectively. The average driving speeds in winter were 78% and 85% of those in autumn in the downtown and suburban areas, respectively.

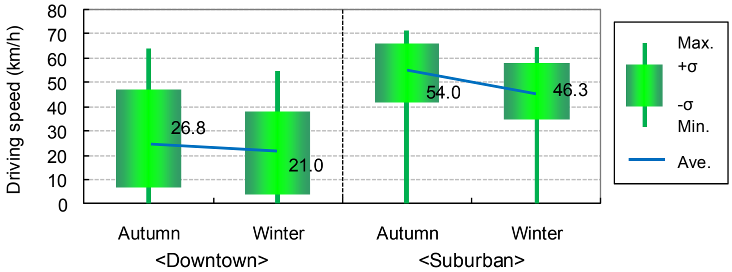

Figure 8. Driving speeds

Figure 9 shows the longitudinal acceleration of the test vehicle. The absolute value of acceleration was small in winter for both the downtown and the suburban areas, and the figure for negative acceleration was especially notable. It was confirmed that drivers accelerated and braked more carefully and paid more attention while braking, in winter than in autumn.

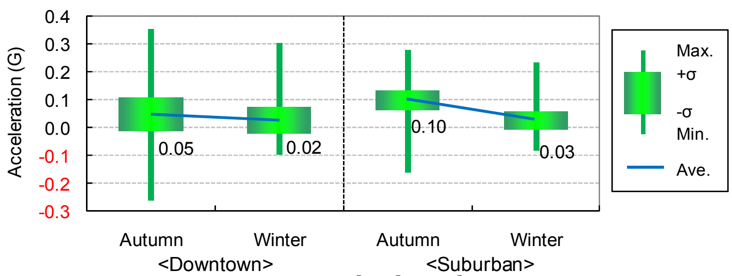

Figure 9. Longitudinal acceleration

3.3 Driver satisfaction

Figure 10 shows the results of the survey on overall driver satisfaction and the six factors affecting it in autumn and winter. Although some drivers gave low evaluations for traffic flow, sight distance and overall satisfaction for autumn in the downtown area, over 80% said they were satisfied or somewhat satisfied. In autumn, some drivers in the suburban area responded that they were somewhat dissatisfied with road flatness and width, but over 90% indicated that they were satisfied or somewhat satisfied in the categories of surface condition, traffic flow, intersections and overall satisfaction. For the winter test in the downtown area, the percentage of drivers indicating that they were satisfied or somewhat satisfied in the category of overall satisfaction fell to 50%. No subjects responded that they were dissatisfied for any of the categories, but 50% said they were somewhat dissatisfied with road width. This is considered to stem from the reduction in road width caused by snow piles.

In regard to surface conditions, flatness and intersections, no respondents chose the options of somewhat dissatisfied or dissatisfied. It can therefore be inferred that the snow piles on road shoulders and deterioration in surface conditions were not so severe to cause driver dissatisfaction. In winter, satisfaction with road conditions in the suburban area decreased: 30% of respondents said they were satisfied or somewhat satisfied in the category of overall satisfaction. Surface condition received especially low ratings, with 50% of subjects saying they were dissatisfied and no subjects choosing the options of satisfied or somewhat satisfied. This is considered to be a result of slippery road surface, as the average friction number for the suburban area was as low as 47.

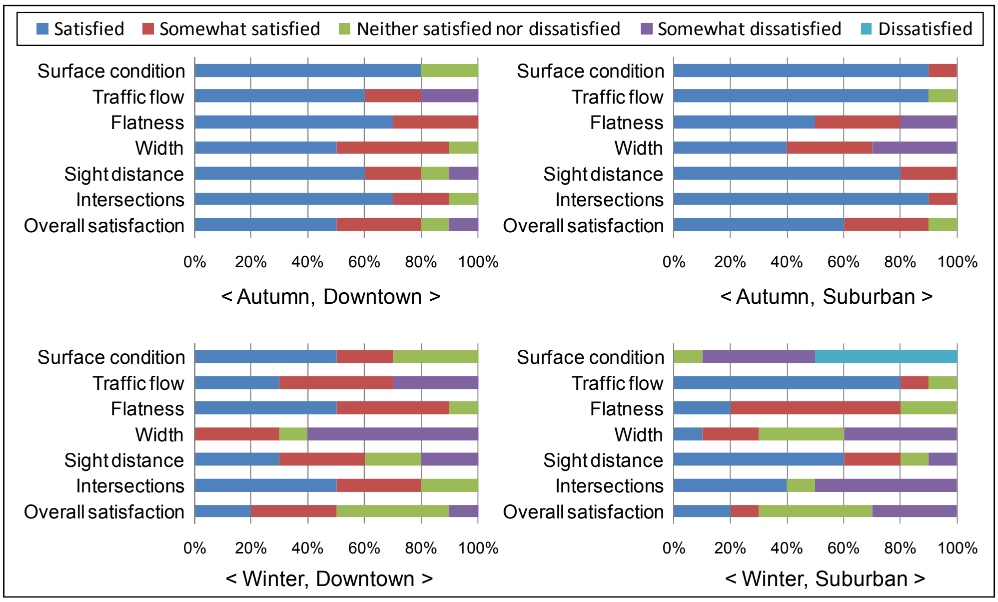

Figure 10. Satisfaction survey results

The CS satisfaction analysis results and calculated improvement necessity factor (IMF) values for the downtown area are shown in Figure 11 and Table 2, and those for the suburban area are shown in Figure 12 and Table 3, respectively. The levels of satisfaction and expectation were normalized and plotted in graph form.

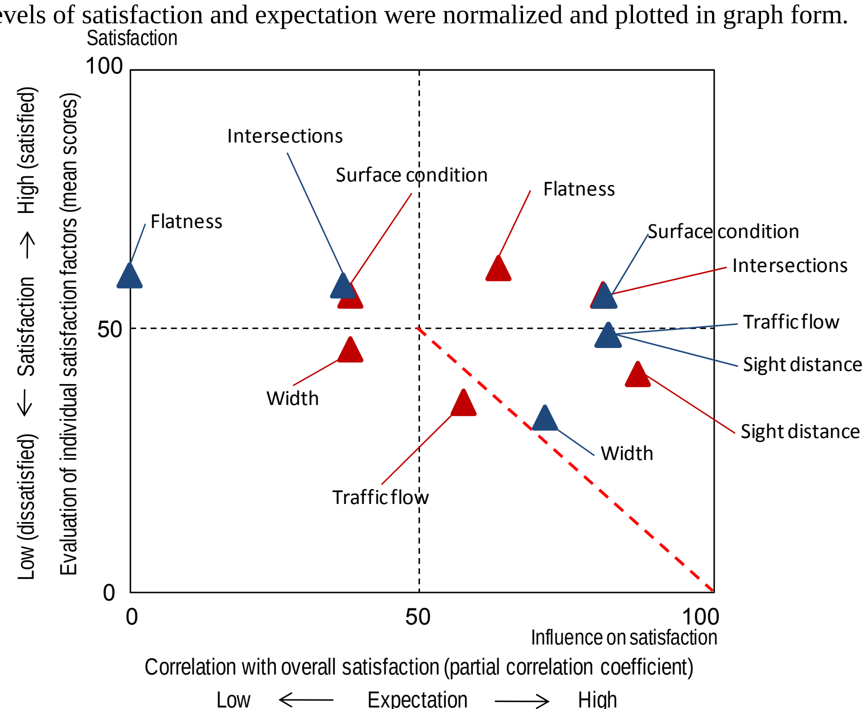

Figure 11. CS portfolio analysis results (downtown)

	Autumn			Winter		
	Modified exponent	Distance from coordinates	IMF	Modified exponent	Distance from coordinates	IMF
Surface condition	-0.82	14.00	-11.51	0.38	31.83	12.20
Traffic flow	0.82	15.50	12.73	0.54	31.97	17.33
Flatness	0.04	17.97	0.74	-0.61	50.80	-31.14
Width	-0.32	12.47	-4.05	0.95	27.78	26.31
Sight distance	0.64	38.25	24.57	0.54	32.27	17.48
Intersections	0.36	31.93	11.61	-0.83	15.08	-12.46

Table 2. Determination of improvement necessity factors (downtown)

As shown in Figure 10, for autumn road conditions in the downtown area, traffic flow and sight distance are located in the Priority Improvement quadrant. Low travel speed in the downtown area is considered to have resulted in low satisfaction with traffic flow. In winter, however, width, traffic flow and sight distance appear in the Priority Improvement quadrant. It can be inferred from the evaluation of road conditions that satisfaction with traffic flow decreased due to lower sight distance and a driving speed equivalent to just 78% of that in autumn as a result of the effective road width being reduced by snow piles on road shoulders.

For autumn road conditions in the suburban area, width was in the Priority Improvement quadrant. Low satisfaction with width is considered to result from reduced road width in tunnels and on bridges, which is a problem with road configuration in suburban areas. In winter, surface condition and intersections were in the Priority Improvement quadrant. It can be inferred from the evaluation of road conditions that reduced satisfaction with these considerations was caused by low friction number. In contrast to the results for the downtown area, traffic flow was not included in this quadrant. This is considered to be because the decrease in driving speed was not as great as that in the downtown area.

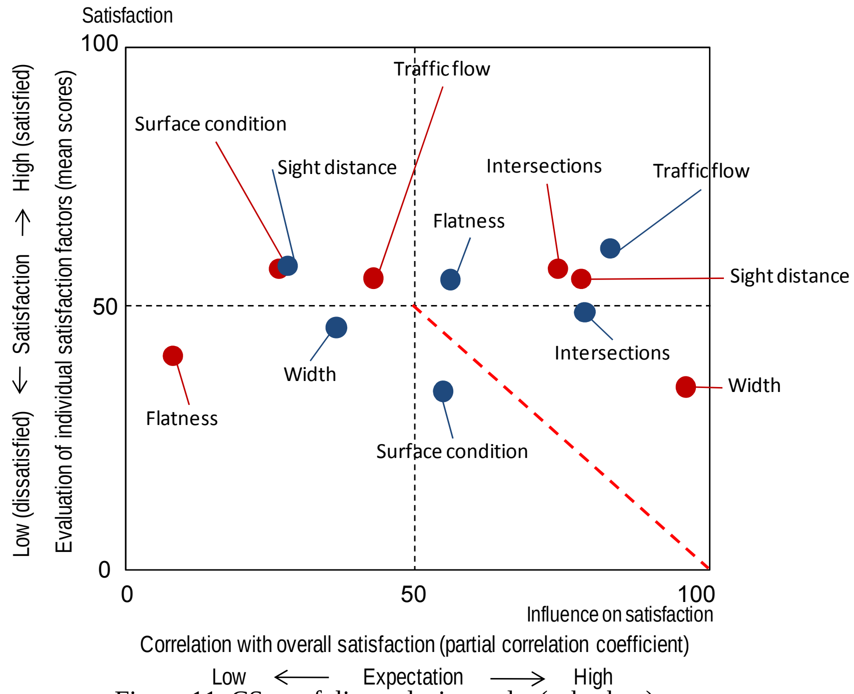

Figure 11. CS portfolio analysis results (suburban)

	Autumn			Winter		
	Modified exponent	Distance from coordinates	IMF	Modified exponent	Distance from coordinates	IMF
Surface condition	-0.70	24.34	-16.92	0.68	17.54	11.87
Traffic flow	-0.91	8.71	-7.94	0.30	34.80	10.34
Flatness	-0.36	42.41	-15.14	0.08	7.54	0.60
Width	0.71	48.86	34.63	-0.30	13.80	-4.09
Sight distance	0.39	29.22	11.25	-0.71	23.09	-16.29
Intersections	0.31	25.63	8.07	0.54	29.15	15.62

Table 3. Determination of improvement necessity factors (suburban)

Table 4 shows changes in the effects of varying winter driving environments on driving behavior and satisfaction, and also presents decrease rates (DR) for road conditions and driving behavior. To determine which improvement items need to be prioritized in relation to winter driving environment, differences in the improvement necessity factor (IMF) between winter and autumn were established. The difference in IMF value shows the priority of improvement in each factor. For the downtown area, the IMF difference was the greatest for width at 30.4, followed by the value for surface condition at 23.7. Although the DR for the HFN was greater than that for width, the IMF difference for width was the greatest from the viewpoint of driver satisfaction. For the suburban area, the HFN showed a decrease of 53%, and the IMF difference for surface condition was the greatest.

	Road condition DR		Driving behavior DR		Difference in IMF					
	Width	HFN	Driving speed	Acceleration	Surface condition	Traffic flow	Flatness	Width	Sight distance	Intersections
Downtown	21%	31%	22%	60%	23.7	4.6	-31.9	30.4	-7.1	-24.1
Suburban	0%	53%	14%	70%	28.8	18.3	15.7	-38.7	-27.5	7.5

Table 4. Changes in road condition, driving behavior and IMF in autumn and winter

4 CONCLUSIONS

In this study, road conditions were evaluated and driving tests were conducted with the participation of subjects in autumn and winter to clarify how changes in winter driving environments affect driving behavior and road user satisfaction. For road condition evaluation, road surface slipperiness was determined by using CFT, and the dimensions of snow piles on road shoulders were measured to assess the changes in winter road conditions quantitatively. In the driving tests, winter driving environments were assessed based on changes in driving behavior and driver satisfaction. To examine changes in driving behavior, impacts on driving speed and acceleration in winter were clarified. However, the extent to which changes in winter driving environment affect driving behavior has not yet been elucidated by the driving tests.

In regard to changes in levels of driver satisfaction, CS portfolio analysis was performed to identify driving environments that required improvement in autumn and winter to enhance road user satisfaction. Calculation of the IMF value for individual variables in autumn and winter to clarify inter-seasonal differences allowed quantitative assessment enabling the identification of winter driving environment that should be prioritized for improvement. Compared with the road condition evaluation results, the IMF value was high for width in the downtown area, where there was a remarkable reduction in the effective road width, and was also high for surface condition in the suburban area, where there was a notable decrease in the road surface friction number. In this regard, subjective evaluation can be considered as an effective tool for the assessment of driving environment and the identification of factors for improvement.

Road user satisfaction with driving environment is considered to be affected by drivers' experience and their level of familiarity with the road in question. In this study, driving tests were conducted using subjects with similar characteristics in terms of age, driving experience, driving frequency and annual mileage. In this regard, there is a need to evaluate road conditions and driving behavior and conduct CS surveys involving subjects with a wider range of driving backgrounds in a variety of road environments. It is expected that this will provide a clearer understanding of how the changes in driving environment affect driving behavior and user satisfaction.

In light of recent severe financial constraints, there is a need to further improve the effectiveness, efficiency and transparency of winter road maintenance. To realize this goal, it is essential to place importance on the perspectives of road users to allocate the budget, to evaluate the effectiveness of countermeasures, and to deliberate on the priority of countermeasures. The quantitative evaluation of user satisfaction would enhance the appropriateness of winter road maintenance and contribute to provide safe, smooth and user-oriented driving environment.

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