ANALYSIS OF WINTER TRAVEL SPEED IN PASS SECTIONS IN HOKKAIDO

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1.Abstract

This research does an analysis based on the travel speed investigation done targeting the pass of the national route 31 places of Hokkaido. Therefore a road condition in winter is put in the conditions that the deterioration of the road surface, or the decreases of the sight distance or road width are severe. As for the pass section whose condition such as horizontal and vertical alignment is bad, much severer driving technique is forced. It is a part of an important trunk road to make contact in the pass part between the cities. The deterioration of the running environment of the pass section in winter exerts a big influence on the exchanges among municipalities and the convenience for road users.

The data on the travel speed investigation done in 31 pass sections at the national route of Hokkaido are used. The influence of the various factors such as weather, road surface, or alignment on the winter travel speed in pass section is analyzed. The difference of the travel speed between the upgrade and downgrade subsection is also analyzed. The downgrade of the pass section in winter is the section where braking and handling technique are difficult and careful driving technique is forced from the traffic safety as well.

2.Introduction

The traffic conditions on winter roads in cold snowy regions are very severe due to the restricted visibility, the deterioration of surface conditions and the narrowed road width, all of which are caused by heavy snowfall and snow accumulation. On pass sections where horizontal and vertical alignments and other conditions are unfavorable, drivers are forced to travel under particularly severe weather conditions. Safety and reliability of road traffic on pass sections are greatly impaired, and the traffic volume in winter is much less than in summer on some routes that include pass sections. Pass sections are parts of arterial roads that connect municipalities; thus, deterioration of travel conditions there in winter significantly affects exchanges among municipalities and the convenience for road users. For the purpose of improving city infrastructure based on area-wide cooperation, and of creating a comfortable living environment in winter and a road environment that is resistant to winter difficulties, it is necessary to secure safe and smooth traffic on pass sections in winter.

In this paper, various analyses were carried out on the basis of data from winter travel speed investigations conducted on pass sections where travel conditions are especially severe. The data were collected at 31 pass sections on major national roads in Hokkaido, and they were analyzed with respect to the factors (weather, road surface, road alignment, etc.) affecting the travel speed on the pass sections in winter. In addition, on downgrade lanes, braking and steering is very difficult, and drivers must drive with extreme caution. Therefore, travel speed analyses were carried out for each travel direction to clarify how the upgrade and the downgrade affect the travel speed.

Section 2 details the investigations and passes. Section 3 explains the factors that affect the travel speed in winter (conditions such as weather, surface, road width, etc.) and the results of analyses. The factors affecting the travel speed on the pass sections in winter are examined in Section 4 by means of quantification theory, Type I. Section 5 deals with the application of the quantification theory, Type I, and other analyses of the factors that cause differences in the travel speed between upgrade and downgrade.

3. Investigations on travel speed in winter

In this study, the travel speed data collected by the Hokkaido Regional Development Bureau are analyzed with regard to the 31 pass sections on the major national roads in Hokkaido (Table 1). In investigating the travel speed, a passenger car or a van was used to check the actual travel time in units of minutes and seconds. The weather and surface conditions when travel time was recorded were observed by eye or by video camera. The traffic volume, the weather and the surface conditions were taken into consideration in choosing six weekdays in February 1995 for the investigations, and three round trips were done each day on each pass section. For investigations, the pass section was divided into subsections (180 in total) because the travel speed changes at some places as a result of various horizontal and vertical alignments and structures of roads, and the data were collected for each of the subsections. When snow removal operations affected the travel speed, the data were re-collected. The travel speed is calculated by dividing the distance of a subsection by the travel time. In this paper, the calculated travel speed is regarded as the running speed because travel vehicles were not interrupted by traffic signals. As part of the investigations on the road conditions affected by snowfall, the effective road width and the height of snowbank were measured on both the upgrade and the downgrade side of each subsection.

4. Analysis of factors affecting travel speed in winter

4.1 Factors affecting travel speed in winter

The travel speed in winter is influenced by various factors, and this paper examines these six: weather conditions, surface conditions, bendiness (i.e., horizontal alignment), hilliness (i.e., vertical alignment), effective road width and height of snowbank. Each of these factors is classified or calculated as follows:

(1) Weather: The five types of fair, cloudy, snow flurries, snowfall, blizzard

Table 1 Lists of investigated pass

Zone	Route No.	Pass	Length (Km)	Subsection	Bendiness	Hilliness
Central Hokkaido	230	Nakayama	51.3	7	31.3	13.99
	276	Bifue	23.9	6	74.66	11.67
	5	Kutchan	13.7	3	6.67	13.75
	5	Inaho	12.8	3	42.28	17.73
	293	Kenashi	31.2	4	162.47	21
Southern Hokkaido	227	Nakayama	12.6	3	15.01	14.18
	228	Fukushima	12.6	3	1.81	12.02
	277	Unseki	18	5	244.11	12.3
Central Hokkaido	37	Shizukari	25.4	6	35.61	15.84
	237	Hidaka	10.1	2	46.39	19.32
	274	Nissho	37.6	9	109.78	16.93
Northern Hokkaido	38	Karikachi	18.8	5	26.9	15.14
	237	Kanayama	10.9	4	31.89	13.88
	273	Ukishima	26.9	4	33.6	11.16
	275	Bifuka	15.9	3	25.36	12.48
	333	Kitami	14.6	4	114.98	18.66
	239	Kiritachi	41.2	2	99.08	9.08
	239	Kiritachi	14	2	36.45	11.33
	275	Tenpoku	26	14	36.94	8.85
Okhotsk	39	Sekihoku	32.8	23	81.6	12.06
	239	Tenpoku	6.4	4	6.58	15.41
	240	Senpoku	16.2	11	24.06	16.84
	244	Konpoku	22.1	7	37.45	21.66
	333	Rukushi	14	4	37.91	16.9
Tokachi	241	Ashoro	12.3	3	0.64	16.82
	242	Chihoku	11.4	6	0	8.71
	273	Mikuni	34.2	7	21.6	11.17
Konsen	241	Oudan	24.7	7	202.03	18
	243	Bihoro	19.5	6	70.64	17.7
	274	Senshou	13.4	8	72.14	14.74
	391	Nogami	13.8	5	86.52	17.32

(2) Surface: The ten types of dry, wet, blowing snow (stirred up by travel vehicles), granular snow (not stirred up by travel vehicles), compacted snow, frozen, icy and smooth (slippery), bumpy compacted snow, black ice (water frozen to form a thin film of ice), and melting snow.

(3) Bendiness (deg/km): As shown in Figure 1, the bendiness is obtained by the sum of all changes (the intersection angles) divided by the road subsection length (between A and B). It is calculated by the following equation (1):

$$\text{Bendiness} = \frac{\theta_1 + \theta_2 + \cdots\cdots + \theta_n (\text{deg})}{\text{Distance AB(Km)}} \quad (1)$$

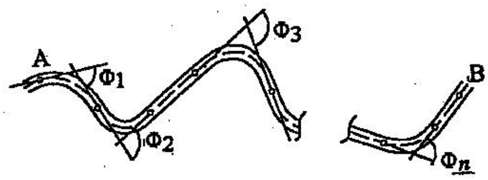

Figure 1. Concept of bendiness calculation

(4) Hilliness (m/km): As shown in Figure 2, the hilliness is expressed by the sum of H_R and H_F. H_R is obtained by the sum of all positive changes in height (hi) (the upgrade portions) divided by the road subsection length and HF is also obtained by the sum of all negative in height (hi + 1) (the downgrade portions) divided by the road subsection length. To indicate the differences in the road alignment, Table 1 includes the values of the bendiness and the hilliness that are calculated for each pass section. It is calculated by equation (2):

$$H_R = \frac{h_1 + h_3 + \cdots\cdots + h_n \text{(deg)}}{\text{Distance AB(Km)}}$$

$$H_F = \frac{h_2 + h_4 + \cdots\cdots + h_{n+1} \text{(deg)}}{\text{Distance AB(Km)}}$$

$$\text{Hilliness} = H_R + H_F \qquad (2)$$

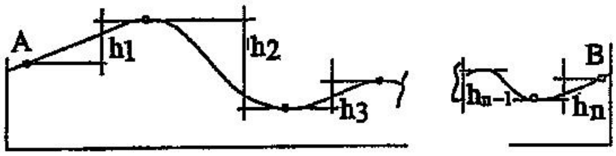

Figure 2. Concept of hilliness calculation

(5) Effective width and snowbank height: Measured by the unit of 0.1 m on both the upgrade and downgrade sides of each subsection.

4.2 Relationship between travels speed and influence factors

First, the influences given by each factor upon the travel speed are analyzed. Table 2 shows the relationship between the five weather types and the average travel speed. There were 6026 data on travel speed calculated for each subsection of all the pass sections. As indicated by the difference of 7.4 km/h in the average travel speed between the fair condition (47.9 km/h) and blizzard (40.5 km/h), the travel speed decreases as the weather worsens. Figure 3 shows the speed distributions under the conditions of fair, snowfall and blizzard. Additionally, a significant difference in the average travel speeds of two different weather types was statistically examined using a level of significance of 5%. Significant differences were recognized in many relationships between two different types of weather.

Table 2 Weather type and average travel speed

Weather	Number of data samples	Average travel speed (km/h)	Standard deviation (km/h)
Fair	2347	47.9	8.6
Cloudy	1505	46.6	8.9
Snow Flurries	1065	44.8	9.4
Snowfall	884	44.8	7.6
Blizzard	225	40.5	6.8

Table 3 Surface condition and average travel speed

Surface condition	Number of data samples	Ave travel speed (km/h)	Standard devi (km/h)
Dry	699	52.2	9.2
Wet	1433	49.3	8.2
Melting snow	281	46.8	8.8
Compacted snow	1157	46.4	8.4
Ice and smooth	320	44.8	7.9
Frozen	1862	43.3	8.5

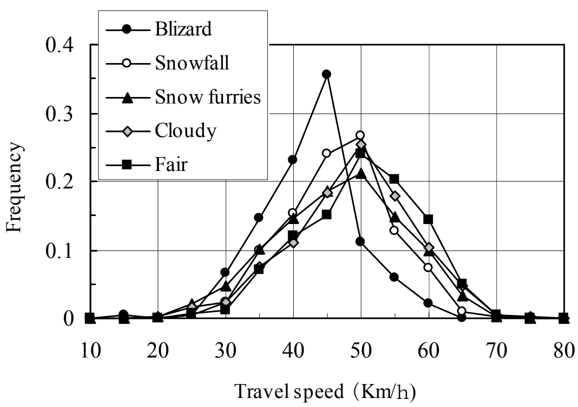

Figure 3 Distributions of travel speed for each weather type

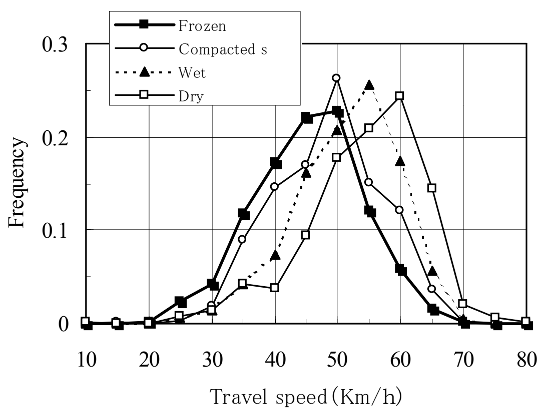

Figure 4 Distributions of travel speed for each surface condition

The correlation between the travel speed and the surface conditions are shown in Table 3 and Figure 4. Surface condition affected the travel speed, as did the weather. There is a difference of 10 (km/h) in the average travel speed between the dry surface (52.5 km/h) and the powdery snow (42.5 km/h), that indicates that the travel speed decreases when the surface conditions deteriorate. In many cases of relationship between two different surface types, significant differences exist in the difference of average travel speed. Thus, it is clear that deterioration of the surface conditions caused by snowfall greatly influences the travel speed.

Figure 5 shows the relationship between the average travel speed and the bendiness. The average travel speed on each subsection (180 subsections in total) correlates with the bendiness. Although the correlation coefficient (0.5146) is not high, it is clear that the travel speed decreases as the curvature becomes sharper (i.e., the intersection angle becomes greater), and as the bendiness value increases. Despite similar analyses of other factors (hilliness, effective road width, height of snowbank), no clear correlations with travel speed were recognized.

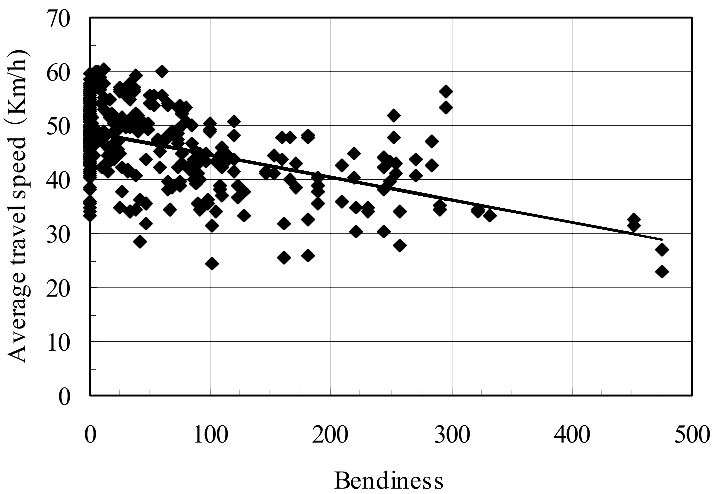

Figure 5 Relationship between bendiness and average travel speed

5. Analyses of travel speed in winter by Quantification Theory, Type I

As described above, the travel speed in winter is greatly influenced by the changes in the surface and by snowfall. In this respect, reductive analyses based on quantification theory, Type I were done on 6026 data for all subsections, while defining the travel speed on each subsection as an criterion variable and the six factors in Section 3 as explanatory variables. Among all the explanatory variables, the weather and the road surface are divided into five and ten types, respectively, as mentioned above. As shown in Table 4, the bendiness, the hilliness, the effective width and the snowbank height were classified into 5, 6, 5 and 4 types, respectively, based on the frequency distributions of each factor. The average travel speed is 46.3 km/h, the standard deviation is 8.8 km/h, and the multiple correlation coefficient is 0.5748. Thus, about 33 % of the change in travel speed is attributable to factors of surface and traffic conditions. Although the multiple correlation coefficient is not high, the results in Table 4 help clarify the factors affecting the travel speed on the pass sections in winter.

The factor that exerts the greatest influence on the travel speed in winter is the bendiness, showing a great value both in the partial correlation coefficient (0.4271) and in the range (9.9860).

Table 4 Results of Quantification Theory. Type Ⅰ

Explanatory variable	Category	Samples	Category score	Range	Partial correlation
Weather	Fair	2359	1.1858	8.8920 (2)	0.1801 (3)
	Cloudy	1498	-0.1204		
	Snow flurry	1039	-0.4689		
	Snowfall	895	-1.1108		
	Blizzard	235	-5.0198		
Surface	Dry	643	3.4388	5.6902 (4)	0.2698 (2)
	Wet	1365	2.0797		
	Powdery snow	268	-1.6102		
	Granular snow	36	3.3126		
	Compacted snow	1160	0.1663		
	Frozen	1822	-2.2514		
	Icy and smooth	329	-1.7863		
	Bumpy compacted	34	-1.61		
	Black ice	86	-0.8143		
	Melting snow	283	-0.4057		
Bendiness	0	2153	1.7193	9.986 (1)	0.4271 (1)
	0～30	1086	3.8493		
	30～40	722	0.6994		
	60～90	706	-0.5092		
	90～120	392	-5.0991		
	Over 120	967	-6.1366		
Hilliness	0	35	4.5006	5.5715 (5)	0.1228 (6)
	0～10	288	0.1384		
	10～20	1693	0.8262		
	20～30	1346	0.6274		
	30～40	1166	-0.7321		
	Over 40	1498	-1.0709		
Effective width	3.0m or less	252	-4.2571	5.9053 (3)	0.1386 (4)
	3.0～4.0	2272	0.0735		
	4.0～5.0	2917	0.2688		
	5.0～6.0	315	1.6481		
	6.0m or more	270	-1.4479		
Snowbank height	0.5m or less	593	2.5681	3.2832 (6)	0.1323 (5)
	0.5～1.0	2135	0.3155		
	1.0～1.5	1948	-0.6264		
	1.5m or more	1350	-0.7151		

The second most influential factors are the deterioration of the surface conditions (0.2698) and the weather (0.1801) in terms of partial correlation coefficients. The effective road width and the snowbank height, which are affected by snowfall, and the hilliness (i.e., vertical alignment) have less influence than other factors. These results suggest that on the curved subsections of the pass sections where drivers are required to drive very carefully, deterioration of the surface conditions caused by snowfall results in additional effects on the travel speed.

Regression analyses based on quantification theory Type I were done for each pass section. Of the 31 passes, 26 passes have a multiple correlation coefficient of 0.50 or over. Good models of the travel speed are obtained on the pass sections of Fukushima, Bihoro, Oudan, Nissho, Kitami, Tenpoku, Nogami and Sekihoku, all of which have a multiple correlation coefficient of over 0.75. At Kitami Pass, which has the greatest multiple correlation coefficient (0.8871), the partial correlation coefficients of the bendiness (the greatest) and of the surface conditions (the second greatest) are 0.6987 and 0.4245, respectively. Thus, the bendiness and the surface conditions most significantly affect the travel speed on this pass section. The relationship between the greatest and the second-greatest partial correlation coefficients for other pass sections indicates that the bendiness and the surface conditions exert significant influence on the travel speed on many pass sections, which agrees with the above analyses of all pass sections.

6. Analysis of factors affecting travel speed in the upgrade and downgrade subsection

6.1 Travel speed in the upgrade and downgrade subsection

The pass sections are divided into 180 subsections in total. Differences in the average travel speed (in terms of absolute values) in both the upgrade and the downgrade subsection on the 180 subsections are summarized in Table 6. While the difference in the average travel speed is 5 km/h or less on many subsections, it is more than 5 km/h on 27 subsections. For the purpose of seeing whether the difference in speed is clearly affected by slopes, the upgrade (or downgrade) subsections that have no flat portions were sampled. In total, 100 upgrade (or downgrade) subsections were sampled, of which 22 subsections have a difference in average travel speed of 5 km/h or more. Figure 7 shows the relationship between the average travel speed on the upgrade lane and that on the downgrade lane on the same subsection. In 31 subsections out of 100, the average travel speed was greater in the downgrade subsection than in the upgrade subsection by 2.0 km/h or less on most subsections, although the maximum difference was 4.1 km/h. On the other 69 subsections, the average travel speed on the downgrade was smaller than that on the upgrade, which suggests that the travel speed is generally reduced on downgrade slopes on the pass sections in winter. The broken line in Figure 7 represents 5 km/h of difference in travel speed. The maximum difference of 12.7 km/h was observed at Senpoku Pass.

Table 7 and Figure 8 include the analysis results 1734 data each on the upgrade and the downgrade subsection on 100 subsections. These results also help in clarifying that the travel speed is generally reduced in the downgrade subsection on the pass sections in winter.

Table 6 Frequency of average travel speed on each subsection

Difference in travel speed (Km/h)	Total of all subsections	Upgrade (downgrade) subsection
0～5	153	78
5～10	22	17
Over 10	5	5
Mean	2.56 (Km/h)	3.14 (Km/h)

Table 7 Travel speed in upgrade and downgrade subsection

Subsection	Upgrade	Downgrade
Minimum	13 (Km/h)	14(Km/h)
Maximum	69.0	74.0
Mean	47.1	44.8
Standard deviation	8.1	9.3

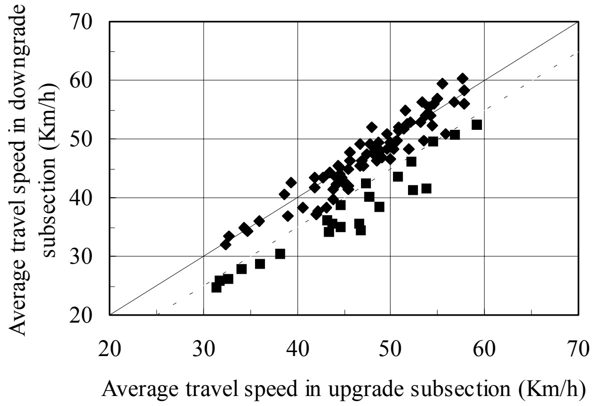

Figure 6 Relationship between average travel speed of upgrade and downgrade subsection

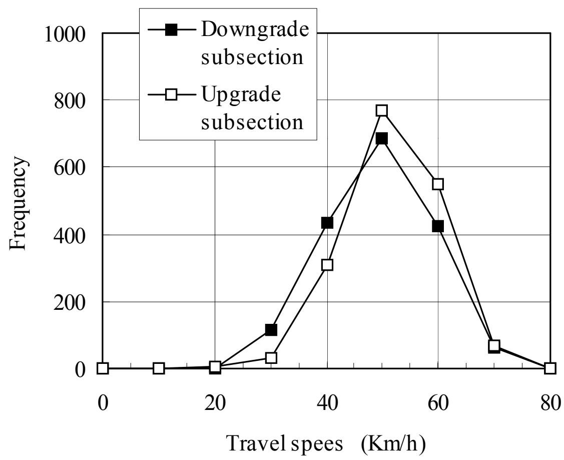

Figure 7 Distributions of travel speed on upgrade and downgrade subsection

6.2 Difference of average travel speed between upgrade and downgrade subsection

Of the six influence factors, four (weather, surface, bendiness, hilliness) are used here to analyze the effects of each on the travel speed in the upgrade and the downgrade subsection. Table 8 and Figure 8 show the relations between five weather types and the average travel speed. The travel speed is more greatly reduced as the weather worsens on both the upgrade and the downgrade, and the difference in the average travel speed between the upgrade and downgrade subsection is about 2 km/h. However, the worst weather condition, blizzard, affects the travel speed almost equally on the upgrade and the downgrade. Table 9 and Figure 9 show the relationship between the surface types and the average travel speed. As the surface conditions worsen, the travel speed is reduced in both the upgrade and the downgrade subsection. At the same time, it is clearly indicated that the difference in the average travel speed between the upgrade and the downgrade becomes larger the worse is the deterioration of surface conditions.

The relationship between the average travel speed and the bendiness (i.e., horizontal alignment) is shown in Table 10 and Figure 10. Both on the upgrade and the downgrade, the travel speed is reduced, as the bendiness becomes larger. The travel speed is greatly reduced particularly on the subsections with bendiness of 90 deg/km or greater, a correlation that means that changes in the intersection angle have a significant influence on the travel speed. Table 11 and Figure 11 show the relationship between the average travel speed and the hilliness. In the upgrade subsection, the travel speed increases slightly as the hilliness becomes larger. In the downgrade subsection, the average travel speed becomes smaller by 5.5 km/h when the hilliness increases from less than 10 to more than 40, and the travel speed is generally reduced as the hilliness grows. Thus, it is concluded that while deterioration of the surface conditions caused by snowfall affects the travel speed both on the upgrade and the downgrade, the effects are much greater on the downgrade.

Table 8 Weather type and average travel speed

Weather	Fair	Cloudy	Snow flurries	Snowfall	Blizzard
Upgrade	49.4	47.0	45.9	45.9	39.8
Downgrade	46.9	44.8	43.5	43.6	40.1
Difference	2.5	2.2	2.5	2.3	-0.3

Table 9 Surface condition and average travel

Surface	Dry	Wet	Compacted snow	Frozen	Blizzard
Upgrade	50.9	49.5	47.5	44.6	39.8
Downgrade	50.5	47.9	44.0	41.6	40.1
Difference	0.4	1.6	3.5	3.0	-0.3

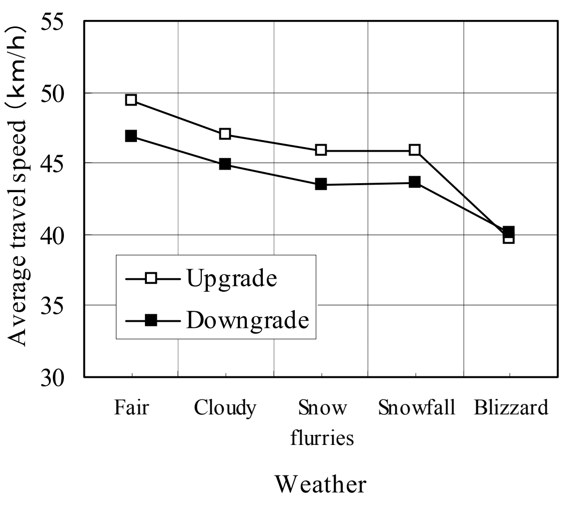

Figure 8 Weather type and average travel speed

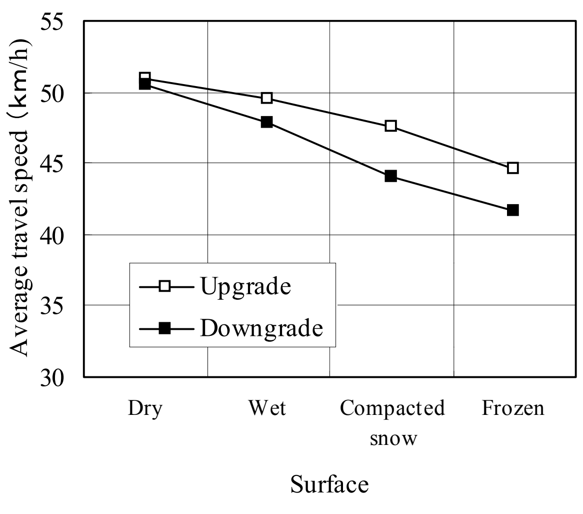

Figure 9 Surface condition and average travel speed

Table 10 Bendiness and average travel speed

Bendiness	0	～30	～60	～90	～120	Over 120
Upgrade	49.0	49.9	48.4	47.4	41.9	39.8
Downgrade	47.7	48.4	44.9	45.2	37.5	36.2
Difference	1.3	1.5	3.5	2.2	4.4	3.5

Table 11 Hilliness and average travel speed

Hilliness	Less than 10	10～20	20～30	30～40	More than 40
Upgrade	45.6	47.6	49.0	48.0	44.6
Downgrade	46.6	46.7	45.9	45.5	41.8
Difference	-0.9	0.9	3.1	2.5	2.8

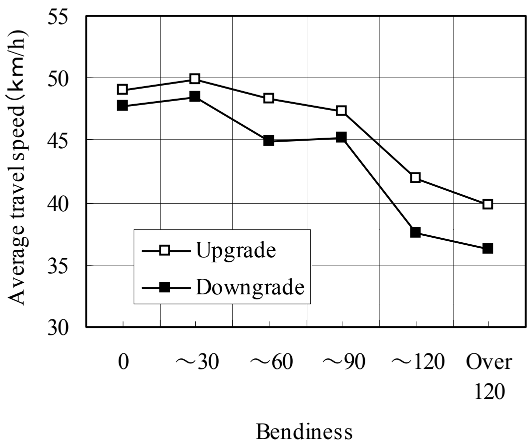

Figure 10 Bendiness and average travel speed

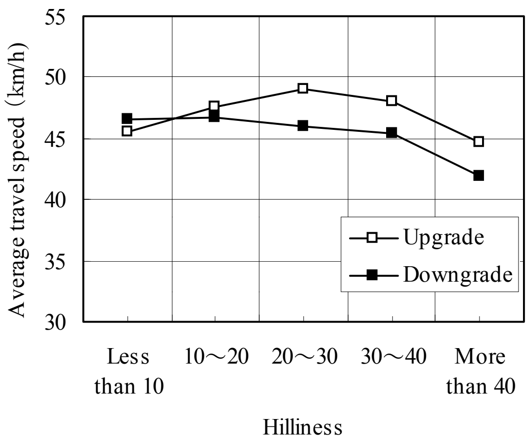

Figure 11 Hilliness and average travel speed

6.3 Analyses by Quantification Theory Type I

The travel speed on upgrade and downgrade pass sections in winter is greatly influenced by the changes in the surface and traffic conditions caused by snowfall. In the same way as in Section 5, regression analyses based on quantification theory Type I were done, while defining the travel speed in each subsection as an criterion variable. The results show that the average travel speed is 47.1 km/h on upgrade subsection and 44.8 km/h on downgrade subsection, and that the multiple correlation coefficient for the criterion variables is 0.5915 and 0.6408 for upgrade and downgrade, respectively. Table 12 shows the results of analyses for both the upgrade and the downgrade, and summarizes the degree of influence given by each explanatory variable on the travel speed.

The placing of the ranges and the partial correlation coefficients in each explanatory variable clarifies that the bendiness greatly influences the travel speed both in the upgrade and the downgrade subsection. The analyses based on quantification theory also suggest the significance of the influence given by the bendiness. Additionally, the range values tell us that the degree of influence given by the bendiness is larger on the downgrade than on the upgrade. Other factors contributing to the deterioration of driving conditions, such as the surface, the hilliness and the effective road width, show that the travel speed is more significantly affected on the downgrade than on the upgrade.

7. Conclusions

In this study, various analyses were done with regard to some factors that affect the travel speed on pass sections in winter, based on the data on winter travel speed collected at 31 major passes in Hokkaido. The results of the analyses are summarized as follows: 1) It was statistically proven that changes in the surface and weather conditions caused by snowfall affect the travel speed; 2) regarding the road alignment, changes in the intersection angles (i.e., the horizontal alignment) greatly influence the travel speed; 3) analyses based on quantification theory, Type I also indicate that the travel speed

Table 12 Results of Quantification Theoryfor each subsection

Explanatory variable	Category	Upgrade subsection		Range	correlation	Downgrade subsection		Range	correlation
		Samples	Score			Samples	Score		
Weather	Fair	576	1.4709	7.5606 (2)	0.2435 (3)	574	0.7105	3.1349 (6)	0.0975 (6)
	Cloudy	473	-0.1097			467	-0.2383		
	Snow flurry	317	-0.0887			334	0.1648		
	Snowfall	274	-0.8443			273	-0.5950		
	Blizzard	88	-6.0897			78	-2.4244		
Surface	Dry	199	2.4069	4.5425 (4)	0.2597 (2)	178	4.1063	6.9140 (3)	0.3227 (2)
	Wet	401	1.8735			404	2.9239		
	Powdery snow	54	-2.1356			50	-1.6053		
	Granular snow	8	1.8933			3	-0.2311		
	Compacted	297	0.8089			336	-0.6931		
	Frozen	603	-1.8588			600	-2.3624		
	Icy and smooth	40	-1.7239			42	1.2837		
	Bumpy	13	-0.8095			18	-2.4993		
	Black ice	26	0.2814			28	-2.8077		
	Melting snow	87	-2.0375			67	-1.6599		
Bendiness	0	718	1.6759	8.0677 (1)	0.4049 (1)	714	2.1970	11.5902 (1)	0.4524 (1)
	0～30	275	2.4953			275	3.5039		
	30～40	175	1.5616			174	1.3256		
	60～90	185	-0.4662			185	-1.2051		
	90～120	113	-5.4564			113	-8.0863		
	Over 120	262	-5.5724			265	-6.1366		
Hilliness	0～10	36	-0.6342	1.8925 (5)	0.1023 (5)	36	4.1413	5.4987 (4)	0.1588 (5)
	10～20	433	0.2737			436	1.1751		
	20～30	377	1.0683			375	0.8182		
	30～40	372	-0.2099			371	-0.7512		
	Over 40	510	-0.8242			508	-1.3574		
Effective width	4.0m or less	619	-0.1585	4.7490 (3)	0.1886 (4)	621	0.8271	7.0591 (2)	0.2651 (3)
	4.0～5.0	850	0.7399			846	0.5918		
	5.0～6.0	89	1.0677			89	0.5075		
	6.0m or more	170	-3.6813			170	-6.2320		
Snowbank height	0.5m or less	141	1.3371	1.7738 (6)	0.0685 (6)	139	3.0786	4.3216 (5)	0.1787 (4)
	0.5～1.0	689	0.0482			687	0.9502		
	1.0～1.5	631	-0.4368			633	-1.2429		
	1.5m or more	267	0.2017			267	-1.1009		

on curved subsections, where drivers are required to travel carefully, is affected significantly by the deterioration of the surface conditions caused by snowfalls; 4) the analyses for each of the pass sections suggest the importance of surface control, particularly on the curved subsections.

The degree of influence on the travel speed in both the upgrade and the downgrade subsection on the pass sections also was analyzed. Consequently, it was made clear that although deterioration of the surface and traffic conditions due to snowfall affect the travel speed in the both subsection, the travel speed on the downgrade is more greatly affected.

In the future, the authors will continue to examine the required standards of surface management in winter, on the basis of the analyses in this study.

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Reference

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