# DRIVING BEHAVIOR ON THE WINTER ROAD SURFACE IN SAPPORO CITY

Roberto Abraham Tokunaga*, Toru Hagiwara**, Yuki Onodera**,
Akira Takahashi***, Toshiyuki Matsunaga****

*Civil Engineering Research Institute of Hokkaido
1-34, 1-jo 3-chome, Hiragishi, Toyohira-ku, Sapporo 062-8602 JAPAN
Tel: +81-11-841-1738, Fax: +81-11-841-9747, E-mail: roberto@ceri.go.jp

**Graduate School of Engineering, Hokkaido University
Kita 13-jo Nishi 8-chome, Kita-ku, Sapporo 060-0813 JAPAN
Tel: +81-11-706-6214, Fax: +81-11-706-6211, E-mail: hagiwara@eng.hokudai.ac.jp

***General Affairs Section, Management Department, Construction Bureau, City of Sapporo
Kita 1-jo Nishi 2-chome, Chuo-ku, Sapporo 060-8611 JAPAN
Tel: +81-11-211-2444, Fax: +81-11-218-5134, E-mail: akira.takahashi@city.sapporo.jp

****Planning and Research Department, Nippon Data Service Co., Ltd.
1-14, Kita 16-jo Higashi 19-chome, Higashi-ku, Sapporo 065-0016 JAPAN
Tel: +81-11-780-1120, Fax: +81-11-780-1130, E-mail: matu@ndsinc.co.jp

## 1. Introduction

In Hokkaido, a series of problems on traffic safety and smoothness are caused by the slippery road surface during winter. The level of road surface management is an important factor in the smoothness and safety of winter traffic. To estimate this level for icy winter roads, the skid number is used as one of the methods. The objective of this study was to analyze how different winter road surface management levels affect skid number and driving behavior. Furthermore in this study was examined the relationship between the skid number and driving behavior.

The experimental study was performed on the Sapporo City streets twice a week from January 4 to February 1, 2000. To measure the skid number of road surface a Hokkaido University skid-testing vehicle was used. Meanwhile to measure the driving behavior (velocity and acceleration) an experimental vehicle equipped with a series of measuring instrument was used.

## 2. Experimental Method

### 2.1 Measurement vehicles

In this study, two experimental vehicles were used to measure the skid number, velocity and acceleration. Acceleration in this paper can take a positive or negative value. Therefore, "acceleration" may refer to acceleration or deceleration, depending on the sign of the value.

a) Vehicle A: A Skid-testing vehicle developed by Hokkaido University (Isuzu Bus) was used to measure the skid number of road surface (Figure 1).

**Figure 1 Skid-testing Vehicle Developed by Hokkaido Univ.**

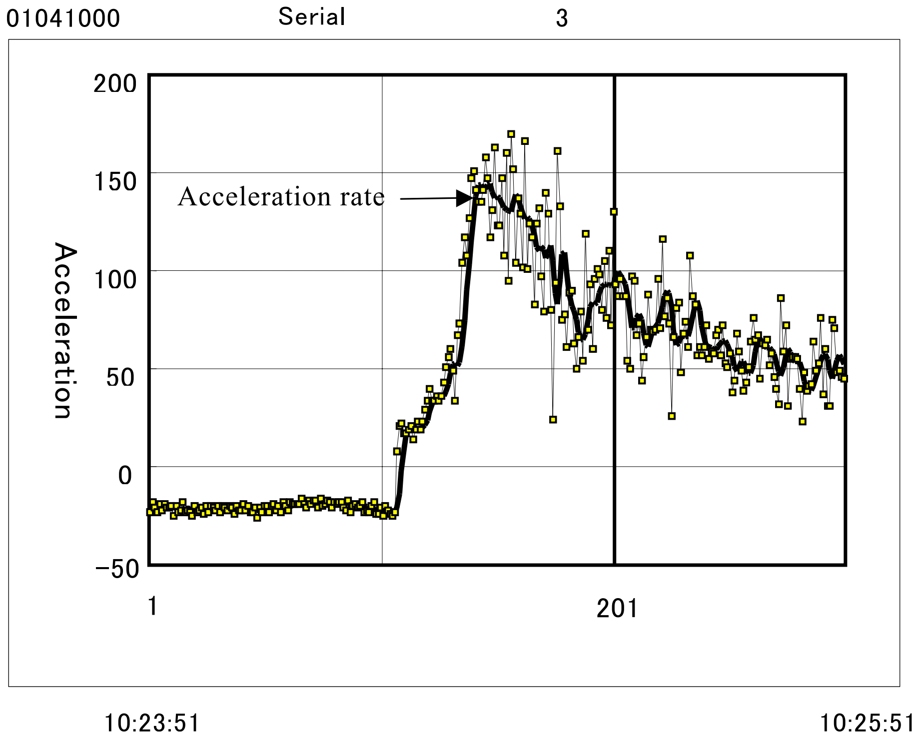


**Figure 2 Sample of Acceleration Waveform**

b) Vehicle B: A 2WD sedan (Toyota Vista 1985) was used to measure the velocity and acceleration on the test section.

**2.2 Measurement of skid number**

Sliding friction is the force of resistance to skidding between the road surface and the vehicle tire. It is roughly divided into two kinds: that acting on vehicles in the direction of the traveling axis (longitudinal skid resistance), and that acting in the direction perpendicular to the traveling axis (latitudinal skid resistance). The skid resistance coefficient is obtained by dividing the latitudinal or longitudinal force exerted on the tire of the measurement vehicle by the load on that tire. This study addressed longitudinal sliding resistance.

This study defines skid number as the longitudinal skid resistance value when a tire is completely locked. The skid number was measured using a skid-testing vehicle developed by Hokkaido University. The skid-testing vehicle, which measures the skid number between the tire and the road surface, can measure longitudinal and latitudinal skid resistance. The resistance force exerted on the experimental tire is measured directly by a torque meter, and together with the load on the tire, the skid number is calculated. The skid number was measured locking completely the tire.

**2.3 Measurement of acceleration and velocity**

To obtain acceleration and velocity, a series of recording devices were settled on the experimental vehicle. Acceleration was measured as a positive value (acceleration) or negative value (deceleration) by an accelerometer installed in the console box (center of gravity) of the experimental vehicle. The measurement was in the direction of the traveling axis. When the vehicle starts, acceleration is detected in the direction opposite the advance. In this study, acceleration at the time of a start was defined as positive, and at the time of stop as negative. When the vehicle stops, acceleration is detected in the direction of the advance. The detected acceleration is that generated by the motion of the vehicle in the direction of the traveling axis plus that due to pitching of the chassis in the direction of the traveling axis. Knowing that the acceleration of a start or stop is around 0.2 G in normal traveling, in this study we employed an accelerometer that can measure up to 2 G. Acceleration is detected by a strain gauge built into the accelerometer. The output of the accelerometer was recorded with other data, after being passed through a board of the onboard computer. Sampling rate was 1/20 seconds.

Figure 2 shows an example of measurement of acceleration. The waveform in this figure shows the data of acceleration caused by pitching of chassis and that caused by forward motion of the vehicle. The high frequency component generated by chassis vibration was removed by waveform processing. Here, IIR (LPF) 2Hz low-pass filter processing was performed for all the measurement data. The bold line in Figure 2 shows the data after waveform processing. The maximum points of acceleration at start and stop are shown in Figure 2. Furthermore, the effects of road gradient were removed. Figure 3 shows the condition when the vehicle stops and then starts at a signalized intersection. Here, positive acceleration occurs even though the vehicle is at rest, because the vehicle is on an upward slope. In this study, the difference between the maximum acceleration at start and the acceleration at rest (Figure 2) was defined as acceleration at start. Similarly, the difference between the maximum acceleration during stopping and the acceleration at rest was defined as acceleration during stopping. However, the experimental vehicle sometimes was affected by surrounding traffic when it starts or stops. Therefore, the video images were used to determine when traffic congestion or emergency influenced starting or stopping for then to exclude the data acquired under these conditions.

The velocity of experimental vehicle was obtained from the running time over the velocity measurement section and the traveling distance over that section. Signalized crosswalks and the tunnel entrances were determined as landmarks in the sections where velocity was measured.


**Figure 3 Sample of Video Frame from Interior of Experimental Vehicle**

The traveling distance was measured by a sensor that counts wheel rotations. This sensor outputs pulse voltage five times per rotation of a tire at uniform intervals. The pulse voltage is sent to a counter board built into the onboard computer. The counter board counts the number of pulses. This experiment cumulatively recorded the count in the computer and simultaneously displayed this on a counter display in the vehicle. In addition, an on-board video camera was installed on the back seat of the experimental vehicle. This video camera was set to simultaneously record the driver's driving condition, the counter display and the activation of an LED. The driver activated the LED by pushing pushed a switch on the steering wheel when passing the predetermined landmarks. Figure 3 shows an image taken by video camera when the LED was activated. The distance when the LED was activated was read from the counter. The time was measured from the time recorded in the video image. However, to extract the influence of road surface on velocity, the velocity data was limited to that gained in the condition without the influence of a temporary stop due to a traffic signal or reduced velocity due traffic congestion.

### 2.4 Experimental Design

The examination sections were outbound and inbound (6.6 km total) on Oiwake Av. (overpass above JR Hakodate Line-Route 5) and Miyanosawa Av. (Route 5-Nishino Tonden Av.) in Nishi Ward of Sapporo. Oiwake Av. is a straight main road with two lanes in each direction, with no grade and with a bypass. Miyanosawa Av. is a main road with three lanes in each direction and a grade of more than 4% on most of its length. Surface management level on the latter section is high, and management is done by the spreading of anti-freezing agent instead of road heating. Differences between the section of standard road surface management level (Oiwake Av.) and that of high road surface management level (Miyanosawa Av.) were compared. Figure 4 shows the alignment of the test sections and the road management levels in winter.

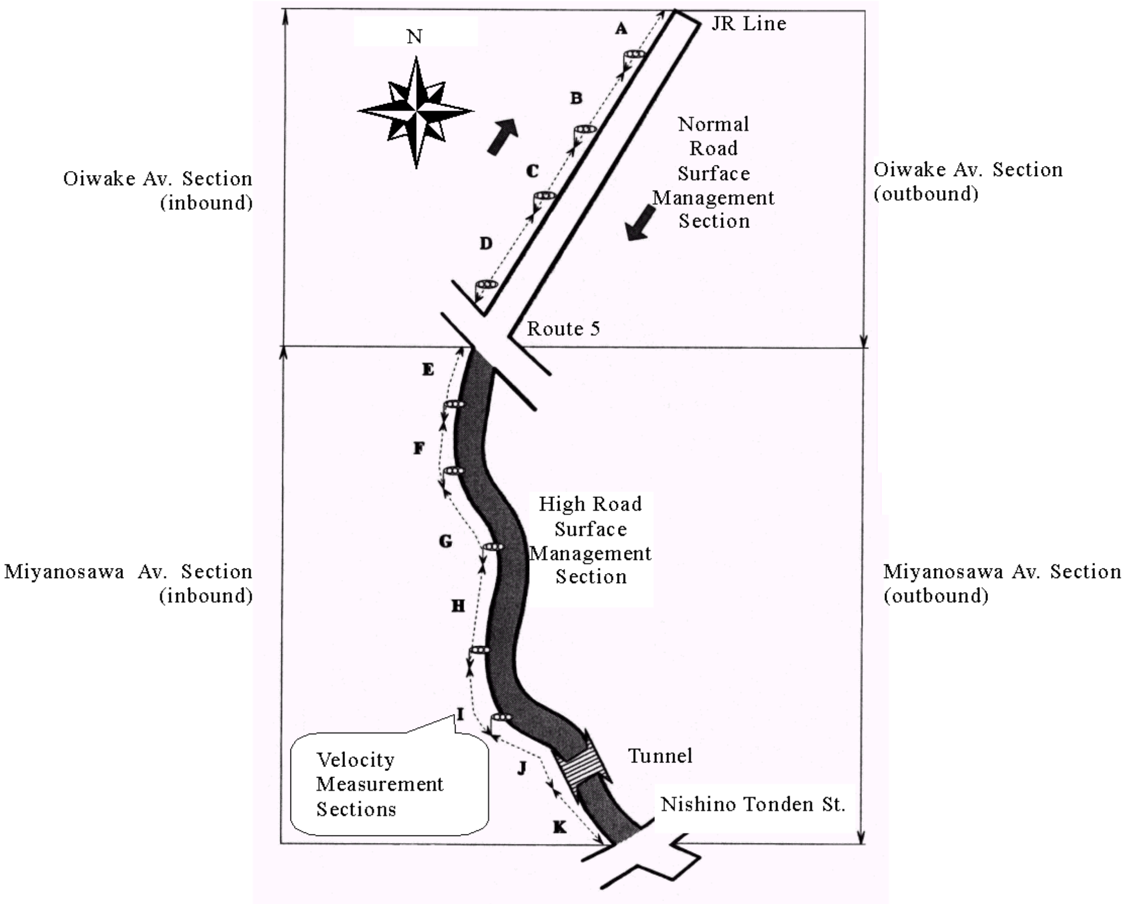


**Figure 4 Test Sections on the Sapporo City (6.6 km total)**

**Table 1 Road Surface Classification by Visual Observation and Coefficient of Friction**

| | Classification of road surface | Coefficient of Friction |
|---|---|---|
| 1 | Extremely Slippery Thin Ice<br>Extremely Slippery Thick Ice | ～0.15 |
| | Extremely Slippery Compacted Snow | ～0.20 |
| 2 | Thick Ice<br>Powder Snow on Ice Crust | 0.15～0.20 |
| | Thin Ice | 0.15～0.30 |
| 3 | Granular Snow on Ice Crust<br>Compacted Snow | 0.20～0.30 |
| 4 | Powder Snow<br>Granular Snow<br>Slush | 0.25～0.35 |
| 5 | Wet<br>Dry | 0.45～ |

*Measuremaent conditions
Tire used : standard tires for winter road surface research
Tire size : 165 80 R13
Tire pressure : 1.9 kgf/cm$^2$
Ground contact load : 400 kg

*Coefficient of Friction roughly represents up to 50% the accumulation values of actual measurement by each visual classification of road surface.

The experimental vehicle that measured the velocity and acceleration ran the outbound and inbound of test section of ordinary road surface management level and that of high road surface management level four times a day from Tuesday to Friday for eight consecutive weeks from December 1999 to early February 2000. Measurement was made at 10:00, 13:00, 16:00 and 19:00.

The vehicle for measurement of skid resistance ran nine times on Tuesdays and Fridays between January 4 and February 1, 2000. Due the time to measure the skid number was from 10:00 to 11:00, the analysis was made using the skid number, velocity and acceleration based on the date and hour when the skid-testing vehicle ran. Additionally, the road surface condition and temperature at the time of measurement was measured. For road surface condition, the image at the time of skid number measurement was recorded and judged the condition afterwards. For temperature, a thermometer was attached to the skid-testing vehicle. Road surface conditions were classified according to Road Surface Classification by Visual Observation of the Hokkaido Development Bureau's Winter Road Surface Management Manual (proposed). Table 1 shows the classifications.

## 3. Experimental Results

### 3.1 Road surface conditions and skid number

The temperature was below zero for five days and above zero for four days at the time when the skid number and the vehicle behavior were measured on Oiwake Av. and Miyanosawa Av.. Table 2 shows the temperature at the time the skid resistance value was measured. We did not limit examination to times when the road surface was slippery, because we focused on determining whether different road surface management levels resulted in different road use conditions. There were roughly as many examination days with an above-zero temperature as those with a below-zero temperature. The condition of roads thickly covered with snow or ice did not appear. The road surface condition was mainly thin snow or ice, slushy or wet.

The distribution of skid number by condition of road surface is shown in Table 3. For it, values obtained from outbound and inbound sections of Oiwake St. and Miyanosawa St. were used. Whereas the skid number of wet roads was around 70, the averages of skid numbers of roads covered with snow or ice were between 25 and 45. Roads covered with compacted snow or ice tended to have a lower skid number.

### 3.2 Velocity and acceleration

The velocity and acceleration obtained on the outbound and inbound sections of ordinary management level and those of high management level are shown in Table 4. These velocities were measured excluding stop and low velocity due to traffic signal or congestion. The average of the velocities in the sections remained in the range 45-47 km/h, regardless of management level. The variance of one-way allocation with four kinds of road surface management sections as independent variables and velocities as dependent variables was analyzed. Although a significant difference was not found, the velocity of inbound exceeded that outbound on Miyanosawa Av., a section of high management level.

**Table 2　Temperature at the Time When the Skid Number was Measured**

| DATE | TIME | | TEMPERERATURE (Celsius) | |
|---|---|---|---|---|
| | START | END | START | END |
| 4-Jan | 10:40 AM | 12:24 PM | 0 | -0.1 |
| 7-Jan | 09:15 AM | 10:35 AM | 3.3 | 3.4 |
| 11-Jan | 09:38 AM | 11:26 AM | -3 | -3.5 |
| 14-Jan | 09:26 AM | 10:58 AM | 1.1 | 1.3 |
| 18-Jan | 09:30 AM | 11:03 AM | -1.9 | -2.8 |
| 21-Jan | 09:17 AM | 10:44 AM | -1.5 | -1.7 |
| 25-Jan | 09:27 AM | 11:12 AM | -7.2 | -7.2 |
| 1-Feb | 09:33 AM | 11:05 AM | 0.1 | -0.3 |
| 4-Feb | 09:47 AM | 11:27 AM | -1.8 | -0.9 |

**Table 3　Breakdown of Road Surface Classifications and Their Skid Numbers**

| Skid Number | Wet | Slushy | Granular Snow | Compacted Snow | Granular Snow on Ice Crust | Ice Crust |
|---|---|---|---|---|---|---|
| Average | 71.64 | 42.02 | 38.41 | 36.22 | 28.60 | 25.29 |
| SD | 10.97 | 12.44 | 7.78 | 5.85 | 4.10 | 8.75 |
| AVE + SD | 82.61 | 54.46 | 46.19 | 42.07 | 32.70 | 34.04 |
| AVE - SD | 60.66 | 29.58 | 30.63 | 30.38 | 24.50 | 16.54 |
| Samples | 159 | 98 | 29 | 27 | 5 | 7 |
| Ratio | 49% | 30% | 9% | 8% | 2% | 2% |

**Table 4　Velocity, Deceleration and Acceleration on the Test Sections**

| Velocity | Outbound | | Inbound | |
|---|---|---|---|---|
| | Oiwake Av. | Miyanosawa Av. | Miyanosawa Av. | Oiwake Av. |
| Average | 46.56 | 45.35 | 47.12 | 45.86 |
| SD | 5.49 | 7.05 | 5.04 | 4.98 |
| AVE+SD | 52.06 | 52.39 | 52.15 | 50.84 |
| AVE-SD | 41.07 | 38.30 | 42.08 | 40.88 |
| Samples | 23 | 72 | 72 | 39 |

| Deceleration | Outbound | | Inbound | |
|---|---|---|---|---|
| | Oiwake Av. | Miyanosawa Av. | Miyanosawa Av. | Oiwake Av. |
| Average | 16.17 | 18.63 | 22.27 | 23.35 |
| SD | 4.45 | 4.20 | 8.08 | 5.88 |
| AVE+SD | 20.62 | 22.83 | 30.35 | 29.22 |
| AVE-SD | 11.72 | 14.43 | 14.20 | 17.47 |
| Samples | 37 | 33 | 45 | 24 |

| Aceleration | Outbound | | Inbound | |
|---|---|---|---|---|
| | Oiwake Av. | Miyanosawa Av. | Miyanosawa Av. | Oiwake Av. |
| Average | 22.85 | 26.26 | 17.32 | 16.70 |
| SD | 5.78 | 7.91 | 3.48 | 4.95 |
| AVE+SD | 28.63 | 34.18 | 20.80 | 21.66 |
| AVE-SD | 17.06 | 18.35 | 13.84 | 11.75 |
| Samples | 25 | 45 | 30 | 39 |

**Table 5　Multiple Comparison of Skid Numbers for Each Road Surface Management Section**

| Multiple Comparison (probability) | | Outbound | | Inbound | |
|---|---|---|---|---|---|
| | | Oiwake Av. | Miyanosawa Av. | Miyanosawa Av. | Oiwake Av. |
| Outbound | Oiwake Av. | | 0.000 | 0.005 | 0.423 |
| | Miyanosawa Av. | | | 0.147 | 0.000 |
| Inbound | Miyanosawa Av. | | | | 0.331 |
| | Oiwake Av. | | | | |

The mean values of deceleration were larger in inbound than outbound of both management level sections. However, the acceleration values were greater in outbound than inbound for both management levels. Furthermore, the variance of one-way allocation with four kinds of road surface management sections as independent variables and deceleration or acceleration as dependent variables was analyzed. A significant difference was found in acceleration or deceleration between different management sections. In addition, multiple comparison of deceleration indicated that the difference between the outbound route and the inbound route was more significant than between different management levels. A multiple comparison of acceleration showed a similar tendency.

### 3.3 Relationship between skid number and road surface management

Using analysis of variance was performed to determine whether road surface management levels influenced on skid numbers. The variance of one-way allocation with four kinds of road surface management sections as independent variables and skid number as dependent variables was performed. Table 5 shows the results of a multiple comparison of road surface management sections. The compared road surface management sections were two outbound and inbound sections of Oiwake Av. and two outbound and inbound sections of Miyanosawa Av. A significant difference in skid number was found between different road surface management sections. The multiple comparison showed that skid number outbound on Miyanosawa Av. was significantly large except for inbound on Miyanosawa Av. In contrast, there was no significant difference between Miyanosawa Av. inbound and Oiwake Av. inbound. This is thought to be because anti-freezing agent sprinkled on Miyanosawa Av. inbound was carried to Oiwake Av. by the tires of passing vehicles. Except for this case, the two management levels of Oiwake Av. and Miyanosawa Av. showed a clear difference.

### 3.4 Relationships between acceleration and the road surface, and between velocity and the road surface

Based on the measurement results, Figure 5 shows the relationship between the skid number and the acceleration or deceleration of the vehicle as a scatter diagram. Skid number was not measured when road surfaces were obviously wet. In the case of such wet road conditions, data was processed using a skid number of 70.

Velocities were those at the time the measurement vehicle passed without stopping between landmarks set within the examination sections. In outbound sections, there was no tendency for velocity to decrease when the skid number decreased. However, in inbound sections, velocity tended to decrease when the skid resistance coefficient decreased to around 40. Such a difference it could be attributed to that outbound route sloped upward and the inbound route sloped downward. At any rate, the influence of the skid number on velocity was small.

Figure 6 shows the relationship between the skid number and acceleration. Acceleration tended to decrease when the skid number decreased both outbound and inbound. Acceleration was greater and the tendency of decrease was greater outbound than inbound. This seems to be because on the wet road surface the accelerator was often depressed upon start because the outbound route sloped upward and this increased the pitching of the chassis. Contrarily, it is thought that because the inbound route sloped downward, the vehicle accelerated naturally simply by releasing the brake pedal and that this kept the pitching of the chassis small.

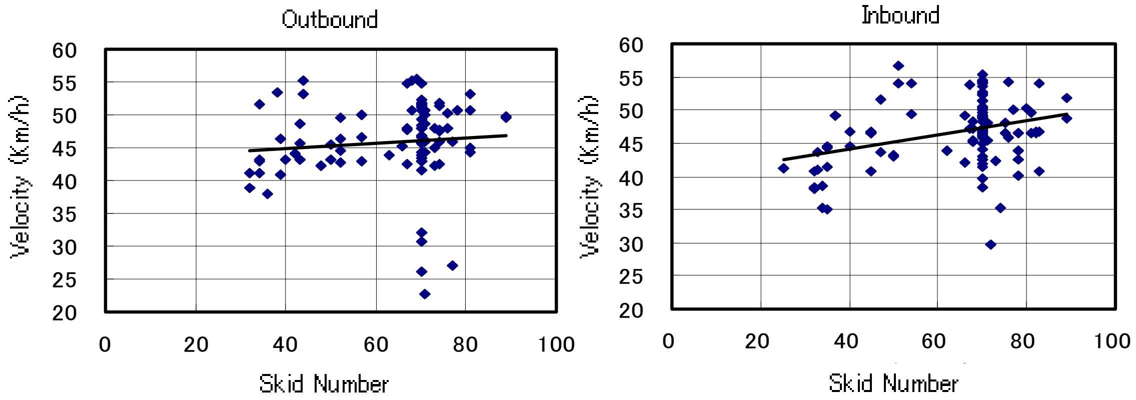


**Figure 5 Relationship Between Skid Number and Velocity**

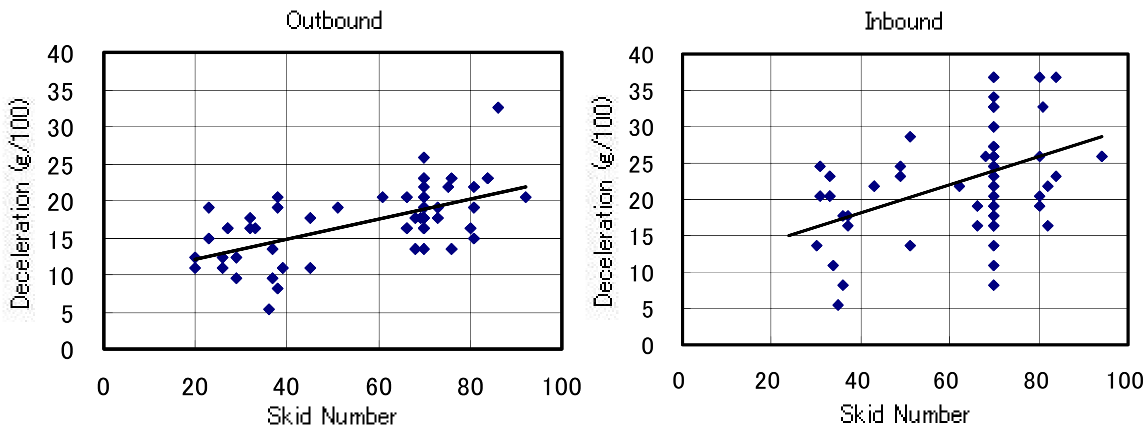


**Figure 6 Relationship Between Skid Number and Deceleration**

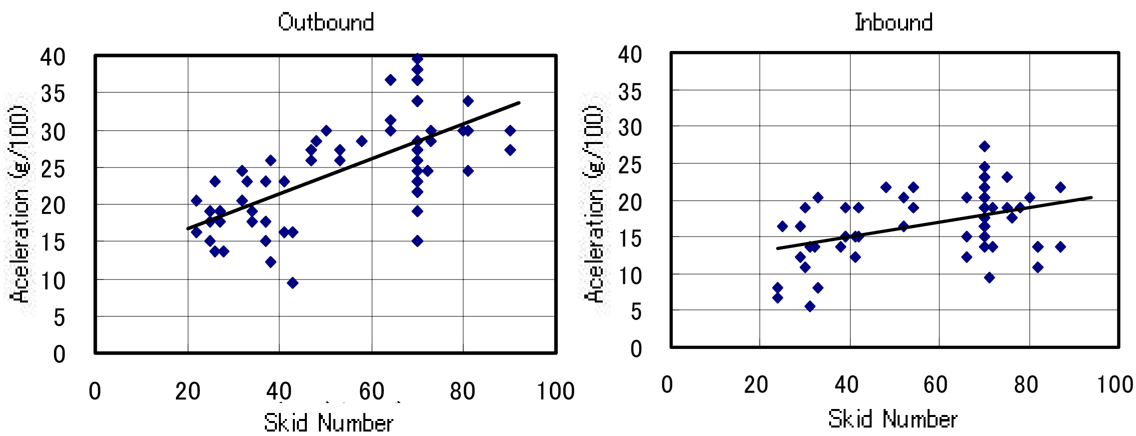


**Figure 7 Relationship Between Skid Number and Acceleration**

**Table 6 Effects of Dependent Variables on Dependent Variables**

| Independent Variables | | Dependent Variables | | | |
|---|---|---|---|---|---|
| | | Skid Number | Velocity | Deceleration | Aceleration |
| Outbound | Section (2 sections) | 0.000 n=180 | 0.450 n=94 | 0.021 n=69 | 0.062 n=62 |
| Inbound | Section (2 sections) | 0.173 n=143 | 0.21 n=110 | 0.57 n=68 | 0.567 n=68 |

*Numerical values in the table are significance probability

Figure 7 shows the relationship between the skid number and deceleration. Like acceleration, deceleration tended to decrease when the skid number decreased. However, in contrast with acceleration, deceleration was larger inbound than outbound. It could have been because the pitching of the chassis was increased by the application of stronger braking due to the downward slope. An analysis of variance was performed to compare whether the difference between high management level and ordinary management level would significantly influence the skid number, velocity and acceleration (Table 6). In case of outbound sections was found a significant difference in the skid number and acceleration but not in velocity. However, in inbound sections was found no significant differences in velocity and acceleration. It could be attributed to the influence of anti-freezing agent carried in by passing vehicles, because the section of ordinary management level comes after that of high management level on the inbound route.

## 4. Discussion and Conclusions

This study was performed to examine how different winter road surface management levels affect skid number and driving behavior. Furthermore in this study was examined the relationship between the skid number and driving behavior. The skid number, velocity and acceleration were measured by a skid-testing vehicle developed by Hokkaido University and an experimental vehicle equipped with sensors and data recorder. As the skid resistance value of the road surface, we used the skid number, which is the longitudinal skid resistance value when the tire is completely locked. The acceleration and velocity of the vehicle were measured excluding conditions of traffic congestion and emergency, i.e. the measured vehicle behavior did not include the influences of surrounding traffic.

On all the test sections, acceleration tended to decrease as the skid resistance number decreased. Acceleration was greater on an upward slope than on a downward slope. The reason is thought to be that the accelerator was often depressed when starting the vehicle on the upward slope and this increased the pitching of chassis. On the downward slope, the pitching of the chassis was small because the vehicle accelerated only releasing the brake pedal. Although deceleration decreased as the skid number decreased, deceleration on the downward slope exceeded that on the upward slope, in contrast to the case of acceleration. The reason is thought to be that the pitching of the chassis was increased by the application of stronger braking due to the downward slope.

Traveling velocity did not tend to decrease when the skid number decreased. However, velocity tended to decrease on the downward slope when the skid number decreased to 40 or less. At any rate, the influence of the skid number on velocity was small.

Finally, from these results it can be said that the skid number allows the most direct estimation of road surface conditions. It was verified that the influences of driving and road traffic conditions should be considered when driving behavior is used to understand the influence of road management level.

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1) City of Sapporo et al., Traffic Assessment of Minami 19 jo–Miyanosawa Avenue, Surveillance Study Report, Sapporo, March 2000 (in Japanese).
2) Hokkaido Development Bureau et al., Introduction of Winter Road Surface Management Manual (proposal), http://www2.ceri.go.jp/eng/e4a.html, Hokkaido, November 1997.