# Using Taxi GPS to Gather High-Quality Traffic Data for Winter Road Management Evaluation in Sapporo, Japan

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Figure 1. Narrowed Street Caused by Snow Pile

How can we increase the quality of traffic data to provide effective and efficient winter road management in the City of Sapporo? In Sapporo, not only residents' daily activities but also business and industrial activities depend heavily on automobile mobility. The not-enough winter road management is, however, the critical problem: it leads to worsen traffic movement through the City. The problem is not simply that travel speed is remarkably reduced as a result of icy roads and street width narrowed by snow pile. The problem is that slowing traffic speed down leads ever-worsened traffic congestion as shown in Figure 1; consequently, it results in economic losses and air pollution.

A primary goal of our study is to identify the effective and efficient traffic data gathering technique in order to develop winter road management measurement that might be implemented in the context of Sapporo. Throughout the course of this study, we have attempted to demonstrate how the cutting-edge technology has the potential to help solve the problems with existing traffic analysis methods and increase the quality of data to determine the unique traffic feature in winter.

The cutting-edge technology we are interested in is "floating-car data" collected through putting Global Positioning System (GPS) on "taxis" running through the City. Because of its advantage covering the great Sapporo area and running throughout the day, this would enable up-to-date traffic data to be supplied over a wide area. Besides, "partnership" with taxi-companies provides cost-effective data collection solutions.

## BACKGROUND

The City of Sapporo is the prefectural capital of Hokkaido, the northernmost island of Japan, and is Japan's fifth largest city with a population of approximately 1.8 million in 2003. The City is located on latitude 43 north and longitude 141 east, and cities at roughly the same latitude include Vladivostok (Russia), Chang Chun (China), Rome (Italy), Marseille (France), Boston and Chicago (U.S.). The City is one of the few metropolitan cities with severe, snow-covered winter in the world; indeed, the City has the annual cumulative snowfall reaching five meters and the maximum depth of snowfall reaching one meter (see figure 2).

This is the City's most distinguishing feature.

In Sapporo, residents' daily activities depend heavily on automobile mobility. The auto-usage also provides important means of transportation in business and industrial activities. Road traffic conditions in winter, nevertheless, have get worse because of heavy snow cover and snowfall, and declining temperatures. Although studded tires had been widely used in Japan, its use was regulated in early 1990's to eliminate deterioration of the living environment caused by dust from studded tires. As a result of this regulation, air quality has been significantly improved, though, on the other hand, it causes several traffic issues specified in winter [(1)]. Especially, as shown in Figure 3, an increasing number of car accidents typically in winter such as one slipped on icy path, the worsening traffic movement and safety caused by "extraordinary slippery-roads (see Figure 4)", and an increasing amount of anti-freezing agents and abrasives are the critical problems.

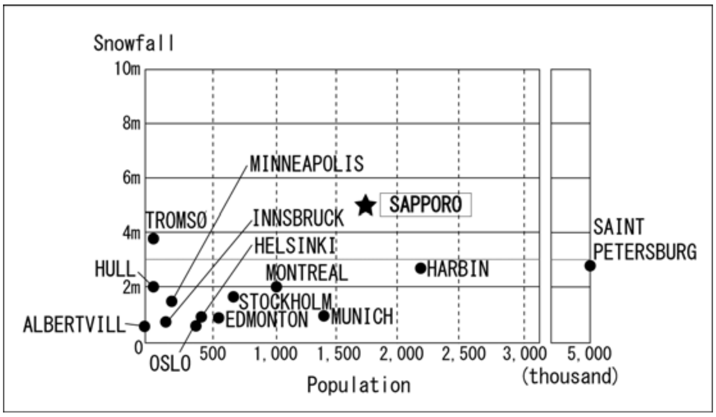



Figure 2. Snowfall and Population

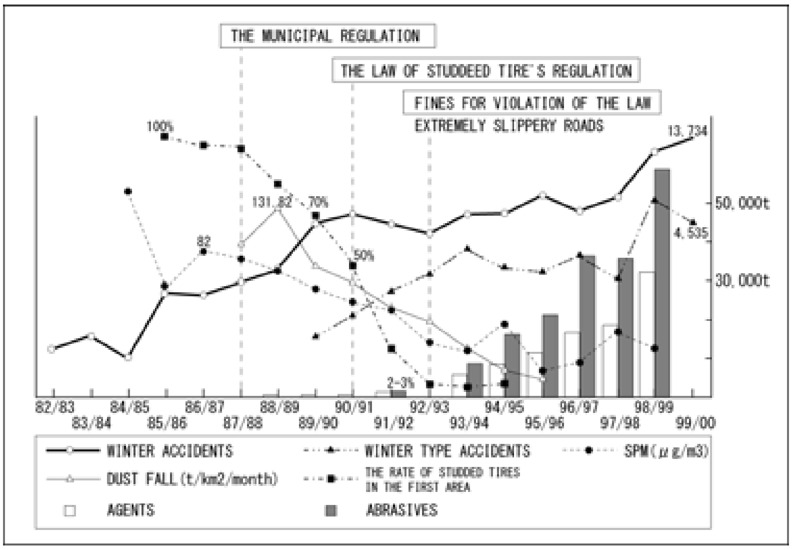
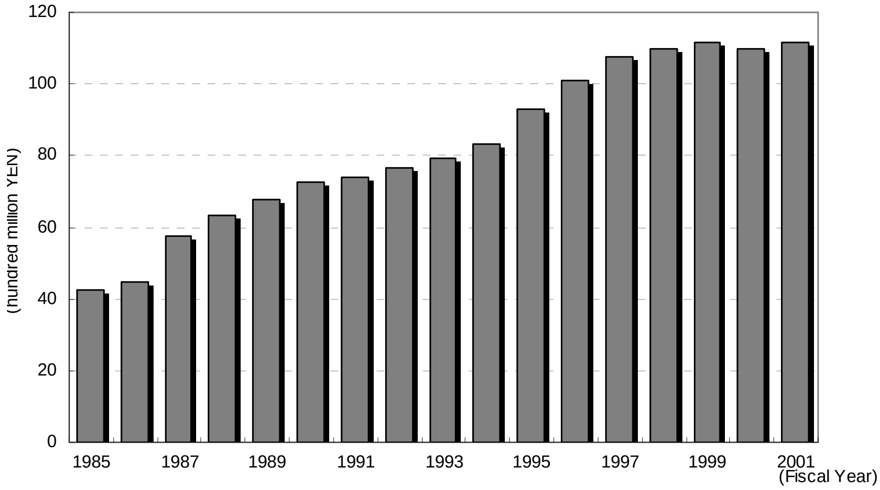



Figure 3. The Several Indices Related to the Rate of Studded Tires

Figure 4. "Extraordinary Slippery-Road"

Road administrations have taken some measures, including snow removal operation, to ensure urban traffic functions in winter. On the other hand, the total amount of winter road management cost has significantly increased for the last 15 years, as shown in Figure 5. This is mainly due to the ban on the use of studded tires from the late 1980's and the road users' growing demand for maintenance quality over the years. Indeed, The City Government's FY2002 budget provided for carrying out the snow and ice control measures of more than 16.5 billion yen while delivering almost 70 % of the budget for snow plowing and removal from streets and sidewalks.

It is also interesting to note huge economic losses caused by heavy snowfall and snow cover for Sapporo. Asano et al. (2001) calculated the direct and indirect economic losses before and after the ban on studded tires [2]. The estimated annual economic losses were more than 18.5 billon yen in the great Sapporo area caused by the increasing of driving time and costs, road accidents, and costs for maintenance and management. Considering that the lessening traffic function was observed in summer even while the use of studded tires was permitted, it might be larger losses than before.



($1 = 110 yen)

Figure 5. Expense Growth of Road Snow Removal
Source: City of Sapporo

## STUDY METHODS:

In order to study the traffic issue in winter, it is significantly important to understand the winter traffic feature in quantitative manner. The traffic feature in weekdays notably differs from that in weekends and holidays. Especially, the traffic feature in winter seems to vary greatly from specific weather condition to the other such as snow cover and snowfall, and declining temperatures; consequently, it is almost impossible to understand the varied traffic features by using the conventional study methods in which days and number of times for surveys are fixed. We therefore attempt to apply taxi floating-car data (Taxi GPS Data) to analyze traffic situations on urban roadways as an advanced survey method. Before moving on to the description of our findings, we would like to briefly discuss characteristics of the survey with taxi GPS and the existing approaches, and Table 1 shows a comparison of these traffic data gathering techniques.

### Winter Road Traffic Census

In Japan the road traffic information survey, known as “Road Traffic Census,” has been conducted all over the county in once a few years in order to recognize the existing traffic conditions in summer. In Hokkaido “Road Traffic Census” has been conducted not only in summer but also in winter to collect baseline traffic data in winter.

### Aerial Photograph Analysis

Conducted by our research institution experimentally, this data-gathering method takes aerial photographs the certain areas with lapping at intervals of few seconds (see Figure 6). The collected information of two-dimensional image helps to analyze traffic condition in and around the City of Sapporo in quantitative manner and regional level.

**Satellite Photograph Analysis**

Traffic information obtained through satellite photographs, as shown in Figure 7, fills the same analytical role with aerial photograph analysis, but covering wider area.

Figure 6. Aerial Photograph for Traffic Analysis

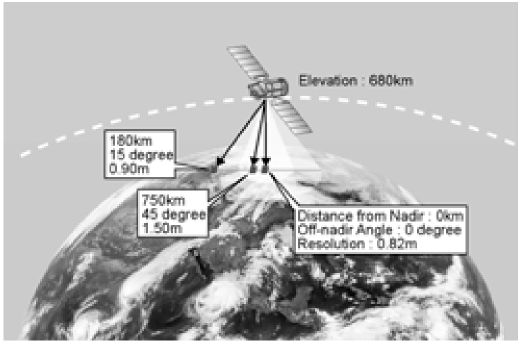


Figure 7. Satellite Photograph Analysis (image)

**Taxi GPS Data**

Building partnership with the taxi-company which has accumulated detailed information on taxi traveling throughout Sapporo by means of putting GPS on taxis, we attempt to apply data of their time instants and locations as "floating-car data." Figure 8 shows the system configuration of taxi GPS data. Locational data are recorded to memory cards after those data are confirmed with maps of car navigation systems operated by GPS installed inside the taxi. The GPS-based data are then compiled and analyzed after reconfirming processes of location and elimination of unusual values.

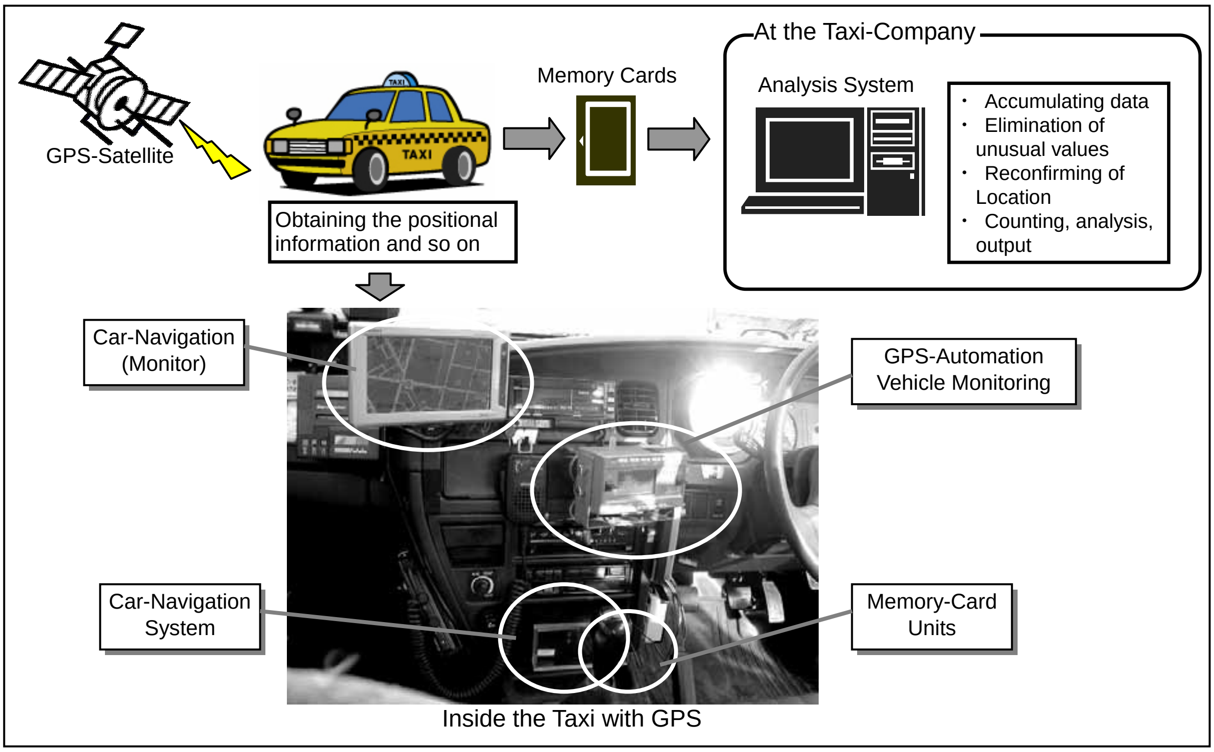


Figure 8. System Configurations of Taxi GPS Data

"Partnership" with the taxi-company provides cost-effective data collection solutions. The partnership company has essentially obtained and accumulated data for supervising and effective running management. Therefore, we can obtain high quality and enormous amount of data at low cost by using secondary data collected through the taxi-company for traffic analysis.

| TYPES | SUMMARY | SURVEY ITEMS | METHODS AND ANALYSIS | ADVANTAGES | DISADVANTAGES | COST (yen)* |
|---|---|---|---|---|---|---|
| Winter Road Traffic Census | • Apply nationwide survey done in summer only to winter | • Traffic volume<br>• (12- and 24-hours)<br>• Average travel speeds during rush hours (on weekdays) | • Travel volume (manually observed from road side)<br>• Travel speeds (observed by a probe car) | • Commonly used across the county | • Conducted in once a few year<br>• Few survey points<br>• Surveyed at arterials only<br>• Not exact data because of only one probe car observing | 5 million |
| Aerial Photograph Analysis | • Recognize the traffic features quantitatively with 2-D image | • The number of vehicles (Travel volume and travel density can be calculated)<br>• Travel speeds | • Counting the number of vehicles on the photographs manually | • Possible to recognize traffic condition in quantitative manner and regional level at the same time period | • Can know only the instantaneous traffic condition<br>• Can't be conducted in bad weather (especially in winter it is impossible to conduct surveys when it is snowing) | 4 million |
| Satellite Photograph Analysis | • Recognize the traffic features quantitatively with 2-D image | • The number of vehicles.(Travel volume and travel density can be calculated)<br>• Travel speeds | • Processing of data of photographs semi-automaticaly | • Possible to know traffic conditions in much wider area than aerial photographs | • Conducted only when satellite passing through the areas<br>• Survey time and days are fixed<br>• Can know only the instantaneous traffic condition<br>• Can't be conducted in bad weather.(Not work when the amount of cloud is more than 20 percent) | 4 million |
| Taxi GPS Data | • Using Traveling data of taxis (GPS) secondary | • Travel speeds | • Recording Data on memory cards then being processed by analysis systems | • Enormous amount of data (60,000 km per day)<br>• Possible to obtain data by day and night<br>• Possible to obtain data of any road<br>• As new equipments and workforce don't be needed, cost will be low | • Not sure the traffic volume<br>• Traveling routes and frequency are not even<br>• Do not know where traveling on multi-stories roads<br>• Different traveling characteristic between empty taxis and carrying passengers | 7,000 |

($1 = 110 yen)

*It is the estimated costs in the case a survey is conducted in and around the city of Sapporo per day (the costs of data analysis don't be included.)

Table 1. Comparison between Taxi-GPS Data and Existing Approaches

## EMPIRICAL FINDINGS

This section describes winter road traffic conditions in the entire Sapporo area based on travel speed data in all of the road sections where traveling

| | |
|---|---|
| # of Taxi with GPS | 115 cars |
| Data items | Date, Time (second unit) |
| | Locations (latitude, longitude) |
| | Speed, Traveling Directions (16 directions) |

Table 2. Summary of Taxi GPS Data in this Study

information of taxies were obtained (see Table 2). The time range we calculated average travel speeds is between 7 a.m. and 7 p.m. which is the same as the range used for the Road Traffic Census. In the City of Sapporo, the snow removal and plowing has been operated in the nighttime when traffic densities are low to avoid influences on road traffic. Therefore, we selects the best possible time range in which the study result might not be influenced by external factors such as traffic regulation for snow removal and plowing.

### Weather Conditions in the Winter of 2001

Table3 shows a variety of winter climatic conditions between October in 2001 and April in 2002. Even though 200-cm snowfall was observed in December, which was nearly double average year (the average of the 30 years between 1971 and 2000), it had light snowfall after January. The total amount of snowfall in the winter of 2001 was 415 cm: it was about 80 cm less than average year (496 cm on the average). The date of first snow was in November 4th, 2001, and this was about a week later than average year (in October 27th on the average). The average and the highest temperature of each month was higher than average year, even if the lowest temperature of each month in the winter of 2001 was lower than average year. Beside, snow cover and snowfall are usually observed on April, but not in 2002. Therefore, it could be said that the winter of 2001 was light snowfall and a mild winter.

| | Ave. Temp. (℃) | | Highest Temp. (℃) | | Lowest Temp. (℃) | | Snowfall (cm) | | Max. Snow Depth (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | 12.1 | 11.3 | 19.8 | 15.8 | 2.5 | 6.9 | 0 | 1 | 0 | 1 |
| Nov. | 5 | 4.6 | 16.4 | 8.1 | -5.1 | 0.9 | 34 | 25 | 21 | 12 |
| Dec. | -3.4 | -1 | 5.3 | 2.1 | -10.8 | -4.4 | 200 | 109 | 81 | 44 |
| Jan. | -2.5 | -4.1 | 6.9 | -0.9 | -11.7 | -7.7 | 71 | 158 | 76 | 73 |
| Feb. | -0.6 | -3.5 | 9.8 | -0.3 | -10 | -7.2 | 73 | 132 | 83 | 98 |
| Mar. | 2.5 | 0.1 | 12.8 | 3.5 | -8.7 | -3.5 | 37 | 67 | 66 | 81 |
| Apr. | 9.6 | 6.7 | 20.3 | 11.1 | 1 | 2.7 | 0 | 8 | 0 | 22 |

Average Year

Table 3. Winter Climatic Condition from Oct. in 2001 to Apr. in 2002

### Average Travel Speeds on a Daily and Monthly Basis [(3)]

Figure9 shows the monthly- and daily-based average travel speeds based on traveling information from taxies with GPS. The average travel speed in April was just under the speed of 30 km/h and it slightly rose and fell at the speed of 30 km/h between in May and October. It started dropping in late November, and December had the lowest with the speed of 22.1 km/h. It rose slowly in January through February, and it almost recovered its April level in mid-March. It is interesting to note that the average travel speeds have risen periodically; those are in Sunday and in national holidays.

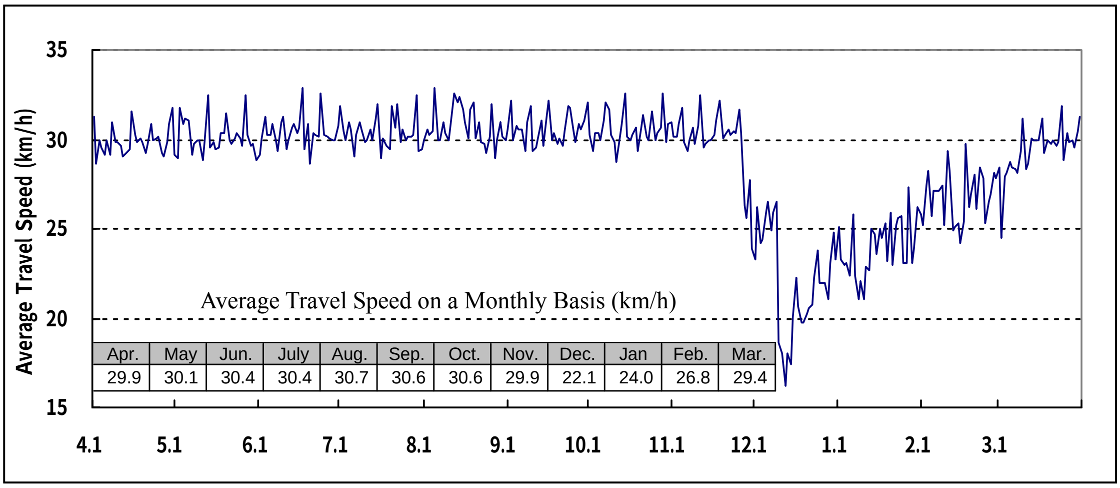


Figure 9. Average Travel Speed on a Daily Basis (2001)

**Relations between Average Travel Speeds and Snow Cover & Temperatures**

Figure10 shows the relationship between average travel speed and snow depth (the maximum snow depth) on a daily basis, and figure11 shows the relationship between daily average travel speed and temperature on a daily basis.

The average travel speed dropped after November 27th in which the temperatures also dropped and snowfall was observed. November 27th was the first day on which the temperature dropped below 0 degrees Celsius in the winter of 2001 and heavy snowfall was observed. (Table 4 shows the meteorological data and the average travel speeds between November 24th and 30th.)

Around December 10th, the travel speed dropped again. This might be due to heavy snow for four straight days from December 9th. It snowed 56 cm in December 10th only, and it was the second-heaviest snowfall on record [(4)]. Because of this heavy snow, the average travel speeds dropped to the level of the speed of 10 km/h between December 10th and 14th, and the average travel speed in December 12th was the lowest of the speed of 16.2 km/h, though the average travel speeds slightly rose and fell at the speed of around 25 km/h in early December. (Table5 shows the meteorological data and the average travel speed between December 8th and 14th.)

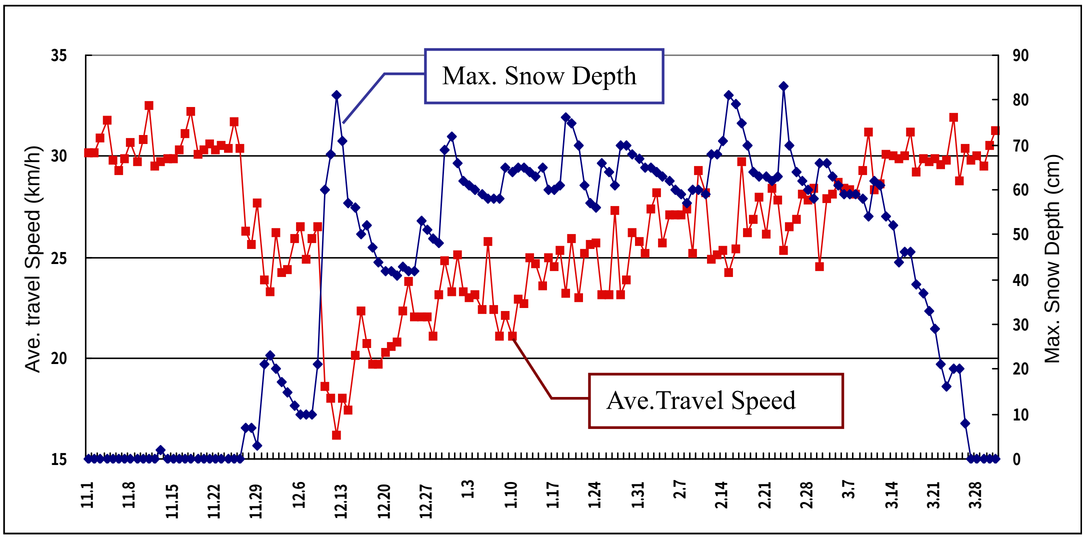


Figure 10. Average Travel Speed & Max. Snow Depth

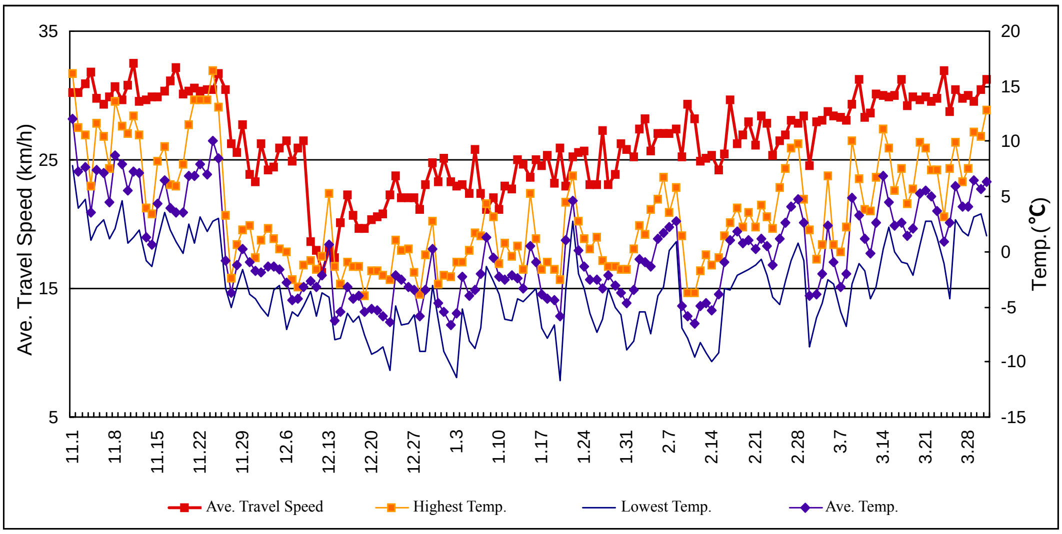



Figure 11. Average Travel Speed & Temperature

| | Ave. Trave Speed (km/h) | Ave. Temp. (℃) | Highest Temp. (℃) | Lowest Temp. (℃) | Snowfall (cm) | Max. Snow Depth (cm) |
|---|---|---|---|---|---|---|
| 11.14 | 30.4 | 10.1 | 16.4 | 2.8 | 0 | 0 |
| 11.25 | 31.7 | 8.5 | 13.1 | 3 | 0 | 0 |
| 11.26 | 30.4 | -0.8 | 3.3 | -3.3 | 0 | 0 |
| 11.27 | 26.3 | -3.7 | -2.4 | -5.1 | 5 | 7 |
| 11.28 | 25.6 | -1.2 | 0.7 | -3.2 | 8 | 7 |
| 11.29 | 27.7 | 0.3 | 2 | -1.6 | 0 | 3 |
| 11.30 | 23.9 | -0.9 | 2.4 | -3.8 | 18 | 21 |

Table 4. Ave. Travel Speed & Winter Climatic Condition (Nov. 14-30)

| | Ave. Trave Speed (km/h) | Ave. Temp. (℃) | Highest Temp. (℃) | Lowest Temp. (℃) | Snowfall (cm) | Max. Snow Depth (cm) |
|---|---|---|---|---|---|---|
| 12.8 | 25.9 | -4.3 | -3.2 | -5.8 | 0 | 10 |
| 12.9 | 26.5 | -3.2 | -1.2 | -4.9 | 15 | 21 |
| 12.10 | 18.6 | -2.7 | -0.8 | -3.6 | 56 | 60 |
| 12.11 | 18 | -3.2 | -1.6 | -5.8 | 22 | 68 |
| 12.12 | 16.2 | -2.2 | -0.4 | -3.7 | 23 | 81 |
| 12.13 | 18 | 0.6 | 5.3 | -4.1 | 0 | 71 |
| 12.14 | 17.4 | -6.2 | -1.4 | -8 | 12 | 57 |

Table 5. Ave. Travel Speed & Winter Climatic Condition (Dec. 8-14)

## FACTOR ANALYSIS

The previous section provides that winter weather conditions have a profound effect on declining average travel speeds in winter. In order to explore the effect of each weather factor in declining travel speeds in winter, a multiple linear regression (MLR) analysis [5][6][7] has been conducted.

### Average Travel Speed in Summer

In order to analyze the declining travel speeds in winter, we first define and investigate average travel speed in summer. We define the time period from April 8 through November 3 in 2001 in which temperature is over 0 degrees Celsius, and snowfall and snow cover are not observed as “summer” in this study.

Figure12 shows average travel speeds in summer according to day of the week. Meanwhile, national holidays are included in Sundays, as travel speeds are high. From Mondays to Fridays (weekdays), the average travel speed can be said approximately 30km/h even if there is a slight fluctuation depending on day of the week. In Saturdays are slightly high, and those in Sunday are

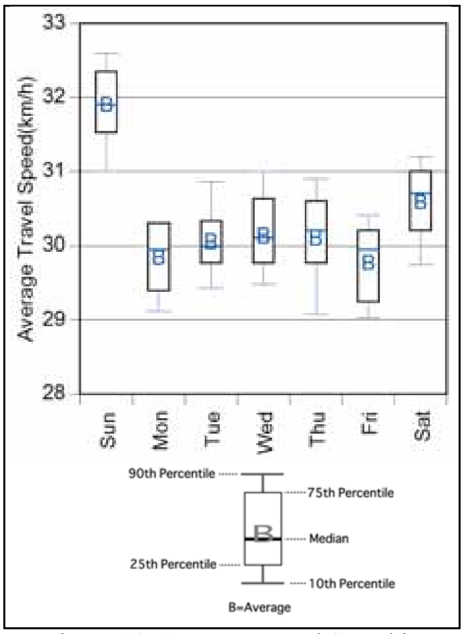



Figure 12. Average Travel Speed in Summer (Day of the Week)

about the speed of 2 km/h higher than those of weekdays'. As a result, in this study we define the weekdays' average travel speed of 30 km/h as average travel speed in summer.

### Defined Variables

The MLR analysis for declining weekday average travel speeds in winter and winter weather factors has been conducted with the following variables (see Table 6).

| | |
|---|---|
| Dependent Variable | Declining Average Travel Speed (ATS) Compared to ATS in summer (30 km/h) |
| Explanatory Variable | Snow Depth, Snowfall Amount, Snowfall Amount on Previous Day, Average Temperature, Sunshine Duration |

Table 6. Defined Variables

### Multiple Linear Regression Analysis

Table7 shows the results of the multiple linear regression analysis using the defined variables in Table 6. Multiple correlation coefficient was the high value of 0.831. As the result of conducting variance analysis, we got the level of significance$^{\alpha}$=0.05 and null hypothesis was dismissed, which means multiple regression equation is useful for predictions.

The MLR analysis shows that the dropping average temperature has the most profound effect on declining average travel speed in winter. It is interesting to note that the amount of snowfall and that on the previous day has little effect on declining travel speed even though a popular idea exists nowadays that snowfall amount has marked effects on travel speed.

**MODEL**

| Model | R | R-Square | Adjusted R-Square |
|---|---|---|---|
| 1 | 0.831 | 0.69 | 0.674 |

**ANOVA**

| Model | | Sum of Squares | df | Mean Sueare | F |
|---|---|---|---|---|---|
| 1 | Regression | 908.883 | 5 | 181.777 | 43.619 |
| | Residual | 408.404 | 98 | 4.167 | |
| | Total | 1317.286 | 103 | | |

**COEFFICIENT**

| Model | | Unstandardlized Coefficients | | Standardlized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3.416 | 0.484 | | 7.059 | 0.000 |
| | Snow Depth | 0.025 | 0.009 | 0.019 | 2.74 | 0.007 |
| | Snowfall Amount | 0.084 | 0.032 | 0.167 | 2.598 | 0.110 |
| | Average Temperature | -0.454 | 0.064 | -0.501 | -7.093 | 0.000 |
| | Sunshine Duration | -0.234 | 0.075 | -0.184 | -3.113 | 0.002 |
| | Snowfall Amount on Previous Day | 0.078 | 0.031 | 0.161 | 2.563 | 0.012 |

Table 7. MLR Analysis Results

## CONCLUSION AND FUTURE STUDY

Throughout the course of this study, we have attempted to demonstrate how the cutting-edge technology has the potential to help solve the problems with existing approaches and increase the quality of data to determine the unique traffic feature in winter. The main positive contribution of this study has been to show that using taxi GPS data is a very useful survey method to understand and analyze Sapporo's unique traffic feature in winter. For instance, we find that it is possible to recognize variances in traveling speed on a daily basis, which is unrecognizable by the existing approaches, throughout year by using floating-car data. Besides, the study finds that snow cover, snowfall and declining temperature give not a little influence to declining travel speed, and unexpected events such as heavy snowfall have a profound effect on its traveling speed.

Furthermore, a multiple linear regression analysis has been conducted to evaluate the effect of weather factors in declining travel speed in winter. The result of analysis shows that the declining temperature has a strongest effect in declining travel speed in winter while the amount of snowfall and that on previous day has less influence in. This might be due to the consequence of little snow in the winter of 2001.

Most importantly, we find that traffic speed declines even after road administrations are conducted various winter road management measures such as snow removal and plowing and anti-freezing agents spread over roadways. This suggests that winter road management activities might not be conducted as effectively as possible. Indeed, measures for winter road surface condition, which is significantly affected by temperature, might be inadequate in comparison with measures for snow removal and plowing.

Even though we do not extend into evaluating effect on measures for winter road management in quantitative manner at this time, in the future we move on to recognizing the traffic characteristics in winter of Sapporo and considering proper balance to conduct measures for winter road management and the standard for the measures while doing accumulations and analyses of data including coefficient of friction on road surface. Furthermore, by applying the method to calculate economic losses against winter road traffic, we hope that it might help evaluating winter road management.

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