# DEVELOPMENT OF A SYSTEM FOR THE FLEXIBLE SHIFTING OF SNOW REMOVAL SECTIONS USING REAL-TIME POSITIONING INFORMATION ON SNOW REMOVAL MACHINERY

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## ABSTRACT

Snow removal machinery plays an important role in securing the smooth flow of road traffic. However, there was previously no way to obtain a detailed overview of the progress of local snow removal operations in real time. Accordingly, in FY 2005, the Hokkaido Regional Development Bureau introduced the Information Management System for Snow Removal Machinery (referred to below as the core system). With the introduction of this system, the real-time progress of snow removal operations can be checked on a map, and past operation records can be reviewed.

The goal of this development is to achieve a more efficient and upgraded road maintenance and management service by establishing a management system for snow removal machinery that enables the flexible shifting of snow removal sections by connecting a variety of types of snow-removal-related information based on the core system. In FY 2008, the setup was developed and field-tested for its dynamic section shift support system, which enables flexible shifting of snow removal sections, and for its support system providing daily reports on de-icer application to enable the organization of spreader vehicle operations to verify its effectiveness.

## KEYWORDS

SNOW REMOVAL MACHINERY / MANAGEMENT SYSTEM / GPS / OPERATIONAL SUPPORT

## 1. INTRODUCTION

With an area of 83,500 km$^2$, Hokkaido is the largest of Japan's prefectures and accounts for approximately 22% of the nation's total land area [1]. It is a widely dispersed, cold snowy region with an average intercity distance of 140 km, and is situated between the latitudes of 41 and 45 degrees north.

Figure 1 shows the population and annual total snowfall of major northern cities around the world. Among these, Sapporo in Hokkaido is the only one with a population of over a million to be located in an area with an annual snowfall total of nearly 5 m.

Most cities in Hokkaido have 100 or more days of snow cover each year. Snow accumulation is especially large on the Sea of Japan side and in central Hokkaido. The maximum snow accumulation in Sapporo is approximately 100 cm.

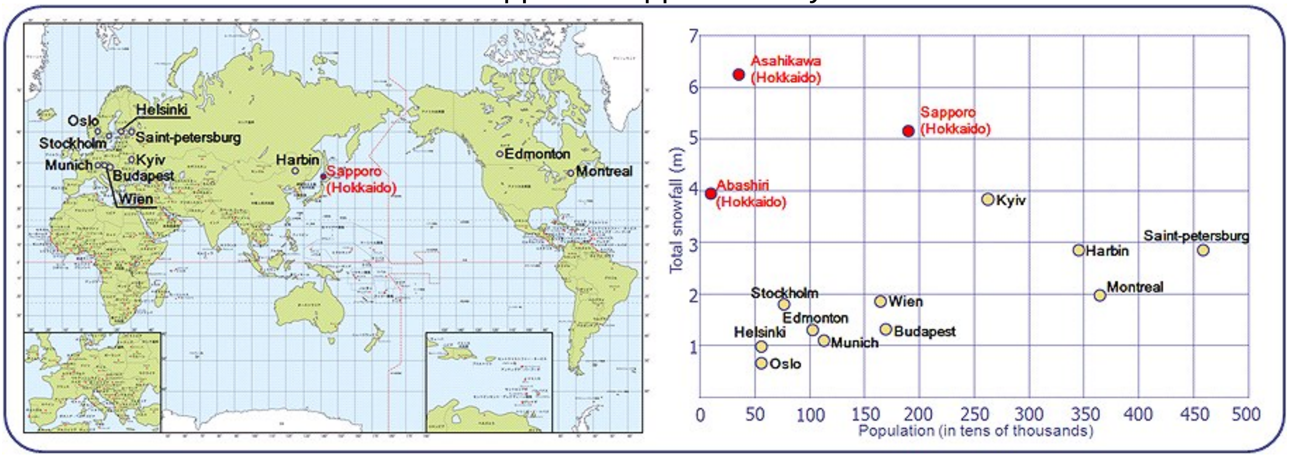


Figure 1 - Population and snowfall of major northern cities [2], [3]

The Hokkaido Regional Development Bureau that manages national highways conducted snow removal on 6,550 km of national highways using 1,023 snow removal machines in FY 2008. While the snow removal length on these highways has been increasing yearly in Hokkaido, removal costs have seen a decreasing trend due to reduced operating expenses in road maintenance/management. A system to monitor changes in snow accumulation and snow removal operation conditions in real time and support for flexible snow removal operations is therefore necessary to meet the needs of winter road users, including guaranteed travel speeds and prompt snow removal operations during abnormal weather.

Accordingly, the Bureau introduced a core system to monitor snow removal machinery behavior using the GPS in FY 2005. Under this system, the real-time progress of snow removal operations can be checked on a map, and past operation records can be reviewed. The setup is also expected to contribute to upgraded and more efficient road maintenance and management, including the implementation of efficient snow removal and the confirmation of daily operation results.

The goal of this development is to achieve a more efficient and upgraded road maintenance and management service by establishing a management system for snow removal machinery that enables the flexible shifting of snow removal sections by connecting a variety of road management data (e.g., weather observation, traffic regulations and roadside camera images) based on the core system.

In FY 2008, the setup was developed and field-tested for its dynamic section shift support system, which enables flexible shifting of snow removal sections, and for its support system providing daily reports on de-icer application to enable the organization of spreader vehicle operations.

## 2. OVERVIEW OF THE CORE SYSTEM

Snow removal machines are equipped with GPS antennas and operation sensors to enable the collection of location and operation data on them in real time. While the core system collects and manages this data to allow the monitoring of snow removal progress in real time, it also has a function to confirm snow removal operation results from accumulated data.

A variety of data are transmitted using a mobile communications service. Figure 2 shows the equipment configuration of the core system. Figure 3 shows the screens used to monitor the location of snow removal machines and operation records, which is the basic function of the core system.

Snow removal machines in the Sapporo and Abashiri areas are equipped with in-vehicle units for data collection/transmission. Snow removal operation conditions for 256 machines (of which 112 have in-vehicle units to gather operation information) were being monitored as of the end of FY 2008. Provision of the system to contractors undertaking snow removal in the Sapporo and Abashiri areas also started in FY 2008.

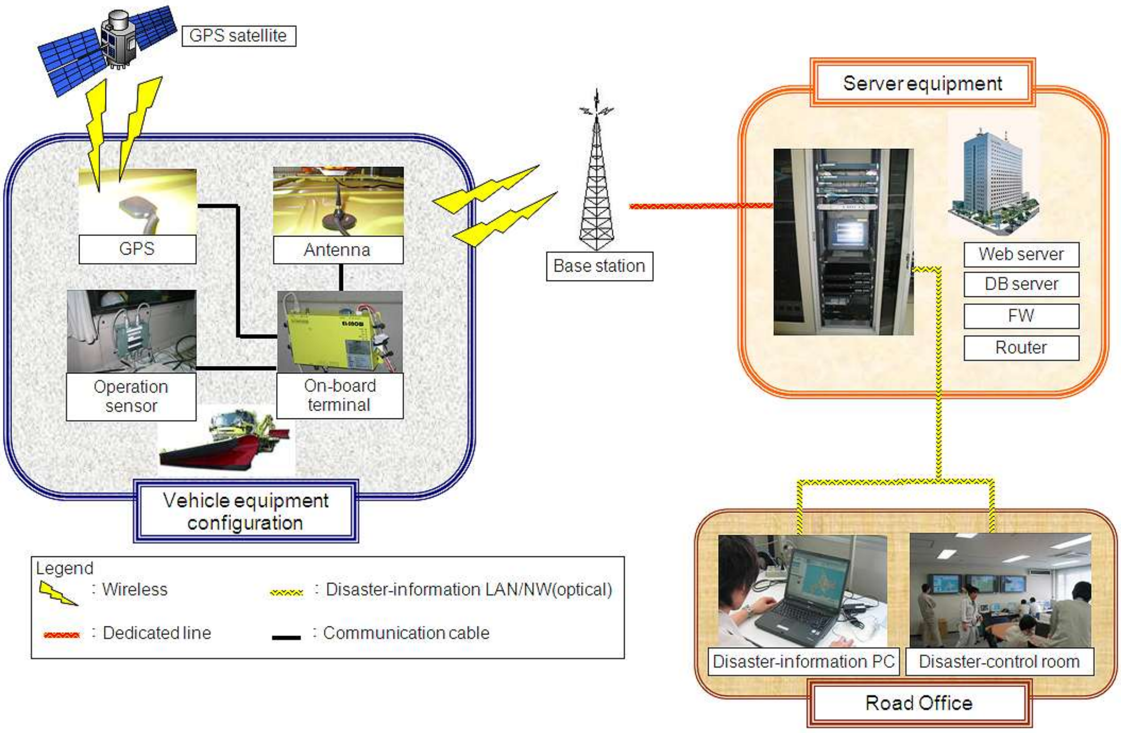


Figure 2 - Equipment configuration of the core system

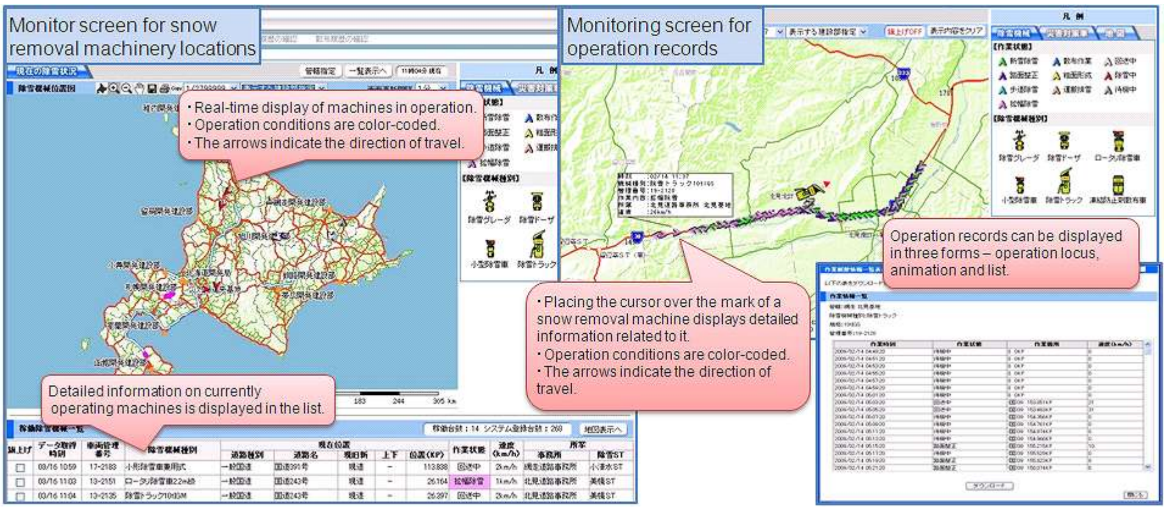


Figure 3 - Monitoring of snow removal machine locations and operation records

## 3. BASIC CONCEPT OF THE MANAGEMENT SYSTEM FOR SNOW REMOVAL MACHINERY

By connecting the location/operation information on snow removal machinery obtained by the core system with road management data (e.g., weather observation, traffic regulations and roadside camera images), the design, development and introduction of functions to enable snow removal management in road maintenance were considered. The aim of snow removal management is to improve the efficiency and service level of road maintenance/management by realizing a PDCA (plan, do, check and action) cycle. This consists of developing a snow removal plan, implementing it, checking the outcome and taking action as appropriate. In this section, the five support functions that form the basis of the management system for snow removal machinery are described [4], [5], [6].

### 3.1. Snow removal planning support

Reviewing snow removal sections and considering the appropriate placement of snow removal machinery is very time-consuming because of the need to organize enormous amounts of past operation and weather data. Accumulating location/operation and weather data and compiling a database will facilitate the retrieval of the necessary data and enable the preparation of snow removal plans in a more efficient manner.

### 3.2. Dispatch judgment support

The aim is to finish snow removal operations before the main commuting time, and judgment regarding the dispatch of snow removal machinery is made based on the experience of those in charge. Offering guidance on dispatch timing based on current weather information using accumulated operation records for snow removal machinery and a weather database will help even supervisors and snow removal contractors with little experience to make efficient judgments on whether to wait or dispatch.

### 3.3. Dynamic section shift support

Since snow removal operations are usually conducted only in designated sections, it is impossible to monitor operation conditions in other areas. This may cause significant differences in snow removal finishing times between adjoining sections during localized heavy snowfall or other abnormal weather conditions, and may lead to delays in snow removal over the entire route.

Support for snow removal in adjoining sections in such cases will enable a reduction in the snow removal time for the entire route by shifting section borders (i.e., the turning points of snow removal machinery).

### 3.4. Support for measures against disaster conditions caused by heavy snow

As wireless and mobile phone communications are used to monitor the locations and progress of snow removal machine operations during periods of heavy snowfall, it takes time to confirm conditions and issue instructions.

Monitoring supportable machines and the progress of operations in real time and automatically preparing dispatch instructions and time-series data using this system enable the implementation of prompt measures against disasters and confirmation/organization of the results of such measures through information sharing.

### 3.5. Support for daily reports on de-icer application

Appropriate application amounts and types of de-icer must be determined based on weather and road surface conditions. As the preparation of daily reports to manage these variables must be performed manually using a fixed form, the process represents a great burden for contractors.

Automatically collecting information on operation panel settings and the locations of de-icer spreaders and indicating such data for each spreader on a map using this system will make it possible to obtain detailed application information and prepare application reports more efficiently.

## 4. DEVELOPMENT / TESTING OF THE MANAGEMENT SYSTEM FOR SNOW REMOVAL MACHINERY

Based on the essential concept of the management system for snow removal machinery, the setup was developed and field-tested in terms of its dynamic section shift support system and its support system for daily reports on de-icer application in FY 2008.

### 4.1. Dynamic section shift support system

#### 4.1.1. Development of the dynamic section shift support system

Figure 4 shows the functions of the dynamic section shift support system. Ordinary turning points (section boundaries) and other possible turning points are registered on the map in advance. When the supervisor designates a turning point for a snow removal machine on the map, the system presents the time (i.e., the expected finishing time) at which snow removal machines on both sides of the section border will return to the starting points (i.e., the snow removal stations). The supervisor judges the shifting of the section border based on this expected finishing time.

Two types of expected finishing time are provided. One is the time for snow removal operations in normal conditions, which is estimated from past average operation speeds. The other is the time for operations during heavy snow conditions or abnormal weather in specific locations, which is estimated from current average operation speeds [4], [5], [6].

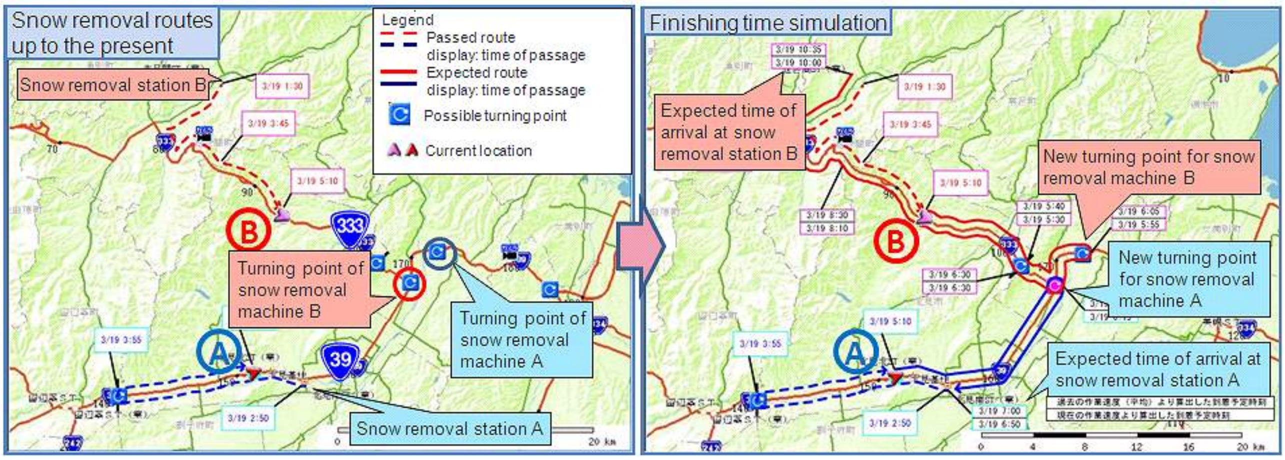


Figure 4 - Dynamic section shift screen

#### 4.1.2. Field test for dynamic section shift

(1) Selection of the target sections and implementation date for the field test

The Abashiri Development and Construction Department of the Hokkaido Regional Development Bureau conducted section shift to equalize the time of snow removal operations between adjoining sections and reduce traffic disruption. Simulation using this system was conducted concurrently with section shift by the Department to verify the validity of the dynamic section shift functions.

Figure 5 shows the target sections of the field test. Sections with large differences in operation times with adjoining sections (i.e., those where operation times can be equalized by support from adjoining sections) and with large traffic volumes were selected. The field test was implemented on a day when snow removal was conducted in all sections to evaluate the effect of the support.

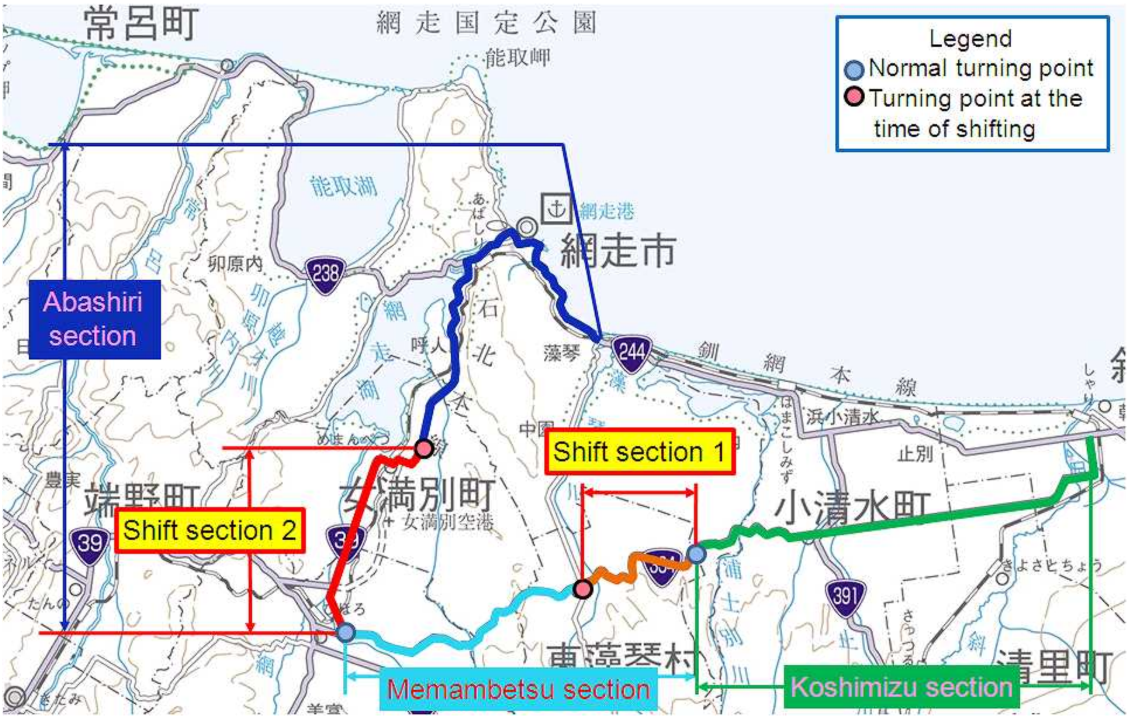


Figure 5 - Section shift map of the area under management of the Abashiri Development and Construction Department

(2) Section shift method

The field test was conducted for two section shifts simultaneously. The target sections were those of Abashiri, Memambetsu and Koshimizu (Figure 5). Of these, the Abashiri section (which had a large traffic volume and a long snow removal operation time) was supported by the adjoining Memambetsu section (shift section 2: 13.8 km). As the operation time in the Memambetsu section therefore increased, support from the adjoining Koshimizu section was provided (shift section 1: 8.2 km).

(3) Section shift simulation

Figure 6 shows the results of simulating cases with and without the Koshimizu section snow removal truck shifting to the Memambetsu section in the above field test. The operation route between dispatch from the snow removal station at 4:00 a.m. and the time of simulation is indicated with a broken line, while the scheduled route after designating the turning point is indicated with a solid line. The figure at the top is the expected time of arrival at each point estimated from the average operation time over the past year, and the figure at the bottom is the expected time of arrival estimated from the current operation speed. The expected time of arrival in the simulation at 4:53 a.m. (Figure 6, with shifting) and the actual time of arrival at the station were compared. The expected time estimated from the past operation speed was 6:43 a.m., while that estimated from the current operation speed was 7:21 a.m. The actual time of arrival was 6:22 a.m. Since ordinary snow removal operations were conducted on the day without local heavy snow, the simulation result for the time estimated from the past operation speed was considered basically valid.

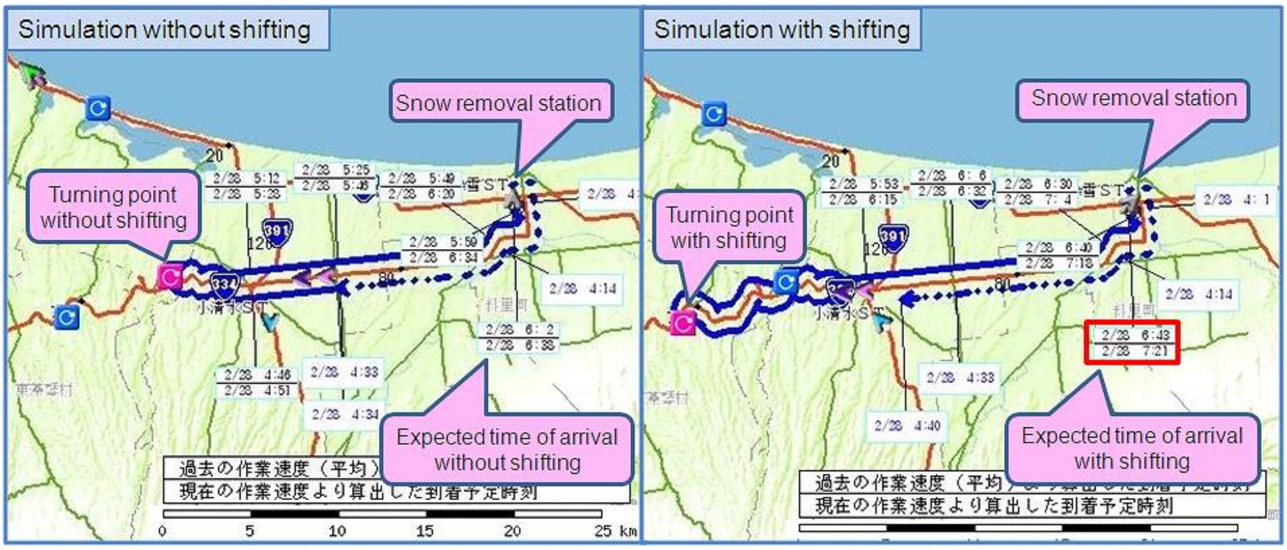


Figure 6 - Dynamic section shift simulation

The results of the field test revealed the following problems:

- Errors occurred when snow removal machines deviated from their pre-registered scheduled operation routes.
- It took too long to display estimation results.
- The finish time could not be estimated unless the machines supporting and being supported were designated in pairs.

The above problems will be addressed taking user needs into account.

### 4.1.3. Effect of dynamic section shift

The effects of the field test were confirmed by comparing the influence of snow removal operations on traffic congestion (reduction in speed) in cases with and without section shift support.

For the field test, snow removal operation speed data obtained from the management system for snow removal machinery and section traffic volume/travel time data based on the latest traffic census (FY 2005) were used. From these data, the amounts of congestion loss caused by snow removal were estimated using the calculation formula in Figure 7.

Table 1 shows a comparison of the amounts of congestion loss. In the case of support from the Koshimizu to the Memambetsu sections (shift section 1), the figure for the Koshimizu section increased by 29,000 yen, and that for the Memambetsu section decreased by 58,000 yen, resulting in an overall decrease of 29,000 yen. In the case of support from the Memambetsu to the Abashiri sections (shift section 2), the figure for the Memambetsu section increased by 104,000 yen, and that for the Abashiri section decreased by 1,043,000 yen, resulting in an overall decrease of 939,000 yen. The total amount of congestion loss for both shift sections decreased by 968,000 yen.

Congestion loss=(time required for snow removal-standard required time)×traffic volume in the section×basic time value unit by type of vehicle

$$=\left\{\left(\frac{\text{Section length}}{\text{Average speed of snow removal trucks}}\right)-\left(\frac{\text{Section length}}{\text{Standard speed}}\right)\right\}\times\text{Traffic volume in the section}\times\text{Basic time value unit by type of vehicle}$$

•Congestion loss (yen/min.)
•Average speed of snow removal trucks (km/h)
Speed data from the management system for snow removal machinery were used.
•Standard speed (km/h) / traffic volume in the section (no. of vehicles/h)
Data from the latest road traffic census were used.
•Basic time value unit by type of vehicle (yen/min.・no. of vehicles)
The Cost Benefit Analysis Manual (August 2003, Road Bureau/ City and Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism) was used[7].

Basic time value unit by type of vehicle (yen/min.・no. of vehicles)

| Type of vehicle | Basic time value unit |
|---|---|
| Passenger car | 62.86 |
| Bus | 519.74 |
| Small freight vehicle | 56.81 |
| Large freight vehicle | 87.44 |

Figure 7 - Calculation formula for congestion loss

Table 1 - Comparison of congestion loss figures

| | | Shift section 1 | | Shift section 2 | |
|---|---|---|---|---|---|
| | | Koshimizu section (supporting side) | Memambetsu section (supported side) | Memambetsu section (supporting side) | Abashiri section (supported side) |
| Normal time | Return road length(km) | 47.5 | 57.4 | 41.0 | 82.9 |
| | Snow removal speed(km/h) | 32.0 | 33.0 | 33.0 | 23.2 |
| | Operation time(h)* | **1.5** | **1.7** | 1.2 | **3.6** |
| | Amount of loss (tens of thousands of yen) | 8.6 | 19.6 | 13.8 | 312.8 |
| Time of shifting (support) | Return road length(km) | 63.9 | 41.0 | 68.6 | 55.3 |
| | Snow removal speed(km/h) | 32.0 | 33.0 | 33.0 | 23.2 |
| | Operation time(h)* | **2.0** | 1.2 | **2.1** | **2.4** |
| | Amount of loss (tens of thousands of yen) | 11.4 | 13.8 | 24.2 | 208.6 |
| Comparison of loss times between normal time and time of shifting(h)* | | 0.5 | -0.5 | 0.9 | -1.2 |
| Comparison of amounts of loss between normal time and time of shifting (tens of thousands of yen) | | **2.9** | **-5.8** | **10.4** | **-104.3** |
| Total | | **-96.8** | | | |

* The operation time in the table was calculated using speed data from the management system for snow removal machinery.

The normal operation time is approximately 1.5 hours in Koshimizu, 1.7 hours in Memambetsu and 3.6 hours in Abashiri (excluding waiting time). The operation times after section shift were 2, 2.1 and 2.4 hours, respectively, indicating an equalization of the time required for snow removal in these sections.

While section shift in this case was conducted during normal snow removal operations, it was presumed that, even if there is delay in such operations due to abnormal weather or other factors, the amount of congestion loss can be cut by reducing the snow removal time for the entire route through dynamic section shift.

## 4.2. System for daily reports on de-icer application

### 4.2.1. Detailed application information

When applying de-icer, variables such as turning on and off spreaders, types of de-icer (i.e., sand, salt), the amounts ($g/m^2$), width and direction of application and the mix proportions of the solution are determined each time through the control panel in the driver's cabin of the spreader vehicle. Collecting application settings and location information when any of these operations is conducted and displaying them on a map makes it possible to ascertain the time, place and amount of application. It also enables monitoring and accumulation of detailed application information for use as basic data to set guidelines for appropriate application locations and amounts.

Figure 8 shows screens with application data obtained from an actual de-icer spreader.

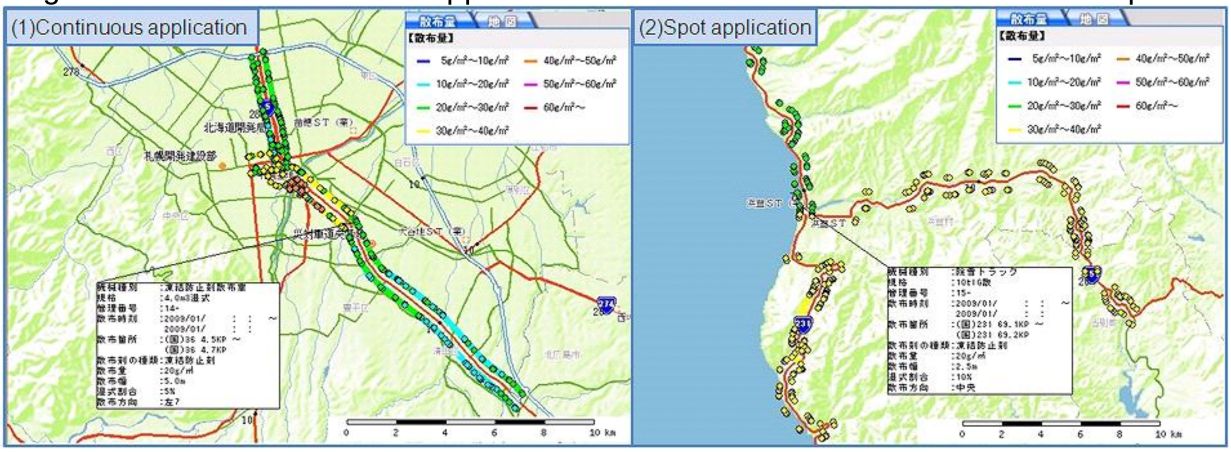


Figure 8 - Examples of application location display

Figure 8 (1) shows continuous application information. The application locations are marked on the left side of the road's direction of travel. The start and end points of application are indicated with circles, and sections with connected lines represent continuous application. The application amounts are color-coded as shown in the legend. By placing the cursor on a circle, the time, location and details of the application settings at that point can be displayed.

Figure 8 (2) shows spot application information. It can be seen from the system screen that spot application was conducted at the necessary points.

Detailed application information can also be obtained in CSV format by downloading the list of application records shown in Figure 9 for use when preparing daily reports on de-icer application.

散布履歴情報一覧

管轄:札幌開発建設部 札幌道路事務所

除雪機械種別:凍結防止剤散布車

規格:4.0m3湿式

管理番号:14-

散布総量(kg):7509【凍結防止剤】 0【防滑剤】 311【水溶液】

| 散布時刻 | 散布箇所 | 散布剤の種類 | 散布量 (g/m²) | 散布幅 (m) |
|---|---|---|---|---|
| 2009/01/ 05:58:04~2009/01/ 05:58:29 | (国)36 10.481KP ~ (国)36 10.293KP | 凍結防止剤 | 10 | 3.5 |
| 2009/01/ 05:59:14~2009/01/ 06:01:10 | (国)36 10.282KP ~ (国)36 9.178KP | 凍結防止剤 | 10 | 3.5 |
| 2009/01/ 06:01:10~2009/01/ 06:01:26 | (国)36 9.178KP ~ (国)36 9.073KP | 凍結防止剤 | 10 | 3.5 |
| 2009/01/ 06:01:26~2009/01/ 06:01:29 | (国)36 9.073KP ~ (国)36 9.043KP | 凍結防止剤 | 15 | 3.5 |
| 2009/01/ 06:01:29~2009/01/ 06:03:17 | (国)36 9.043KP ~ (国)36 7.829KP | 凍結防止剤 | 20 | 3.5 |
| 2009/01/ 06:03:37~2009/01/ 06:04:45 | (国)36 7.826KP ~ (国)36 7.160KP | 凍結防止剤 | 20 | 3.5 |
| 2009/01/ 06:04:45~2009/01/ 06:06:28 | (国)36 7.160KP ~ (国)36 5.889KP | 凍結防止剤 | 20 | 4.5 |
| 2009/01/ 06:06:28~2009/01/ 06:07:02 | (国)36 5.889KP ~ (国)36 5.555KP | 凍結防止剤 | 20 | 5.0 |
| 2009/01/ 06:07:29~2009/01/ 06:08:23 | (国)36 5.542KP ~ (国)36 5.020KP | 凍結防止剤 | 20 | 5.0 |
| 2009/01/ 06:08:24~2009/01/ 06:08:42 | (国)36 5.009KP ~ (国)36 4.832KP | 凍結防止剤 | 20 | 5.0 |
| 2009/01/ 06:09:16~2009/01/ 06:10:07 | (国)36 4.799KP ~ (国)36 4.297KP | 凍結防止剤 | 20 | 5.0 |
| 2009/01/ 06:10:53~2009/01/ 06:12:21 | (国)36 4.296KP ~ (国)36 3.485KP | 凍結防止剤 | 25 | 5.0 |
| 2009/01/ 06:13:07~2009/01/ 06:14:56 | (国)36 3.481KP ~ (国)36 2.391KP | 凍結防止剤 | 25 | 5.0 |
| 2009/01/ 06:15:43~2009/01/ 06:16:00 | (国)36 2.384KP ~ (国)36 2.279KP | 凍結防止剤 | 25 | 5.0 |
| 2009/01/ 06:16:00~2009/01/ 06:16:21 | (国)36 2.279KP ~ (国)36 2.127KP | 凍結防止剤 | 30 | 5.0 |

Figure 9 - List of application records

### 4.2.2. Calculation of application amounts

Adding travel distance information to application setting data enables the calculation of daily application amounts. It also makes it possible to obtain the data necessary for daily application reports prepared by snow removal contractors.

A comparison with daily reports prepared by contractors was made to examine the accuracy of the calculated daily application amounts. The results indicated that the amounts in daily application reports differed from those calculated by the system. Further studies will be conducted on possible causes for this, such as limited hydraulic pump capacity in spreader vehicles and variations in the specific gravity of different de-icers.

## 5. SYSTEM USE CONDITIONS AND A QUESTIONNAIRE SURVEY

### 5.1. System use conditions

The number of accesses was investigated to ascertain the conditions of use of the management system for snow removal machinery. The targets of the system's provision are the employees of the Hokkaido Regional Development Bureau and snow removal contractors in the Sapporo and Abashiri areas.

Figure 10 shows changes in the number of accesses to the system. Comparing accesses and snowfall amounts in Sapporo and Abashiri shows that the number of accesses was higher on days with large amounts of snowfall. This number was particularly large on December 26, 2008, and on February 21, 2009, when heavy snow fell. Detailed examination of the access log also revealed that the screen for monitoring operation conditions was used the most, followed by the screen for monitoring the locations of snow removal machinery.

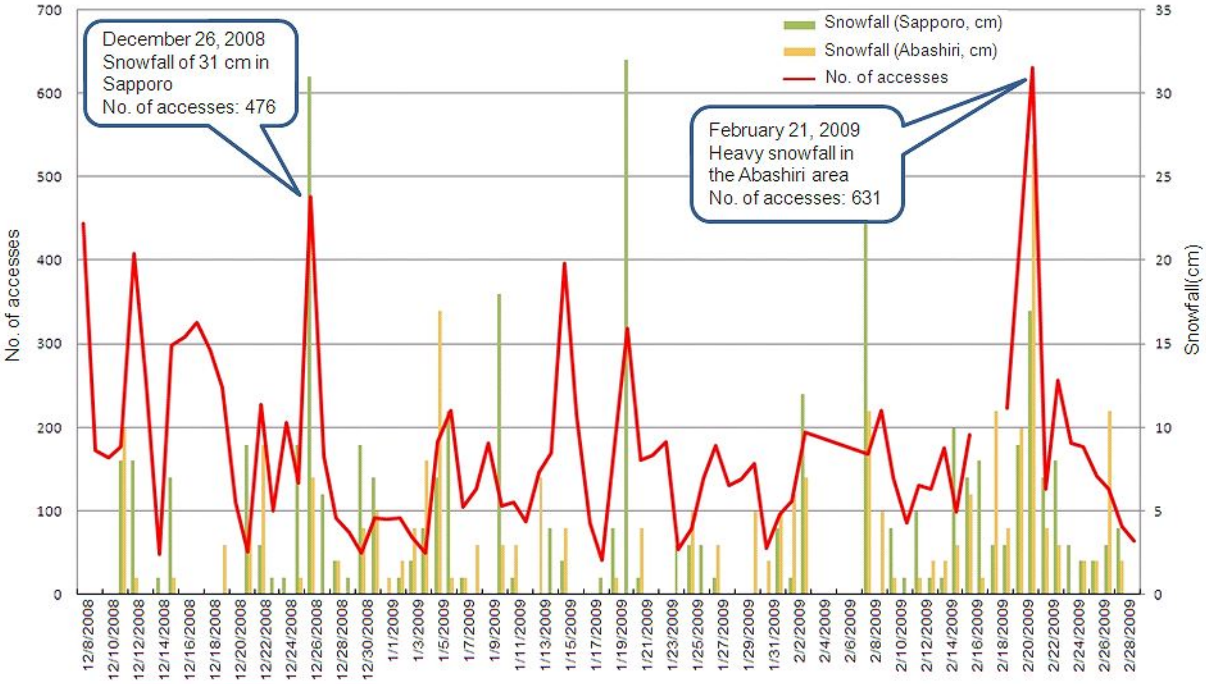


Figure 10 - Changes in the number of accesses to the system

### 5.2. Questionnaire survey on the system

To study the system's status of use and pinpoint areas for improvement, an online questionnaire survey was conducted among employees of the Hokkaido Regional Development Bureau and snow removal contractors in the Sapporo and Abashiri areas, generating responses from 58 people. An interview survey was also conducted among employees of road offices and snow removal contractors in the Abashiri area to ascertain how they used the system and hear any requests they might have in relation to it.

Figure 11 shows the frequency of use for the function to monitor the locations of snow removal machinery. Those who used the system every day to once a week accounted for 52% of the total. Users including those taking advantage of the system only during heavy snowfall accounted for 91%, indicating that location information is actually used in practice. As for the purpose of use, most respondents listed "monitoring of the locations and operation conditions of snow removal machinery in local sections." While a majority of respondents from the Regional Development Bureau listed "dealing with inquiries from road users and the police," those from snow removal contractors listed "monitoring of the locations and operation conditions of snow removal machinery in other sections."

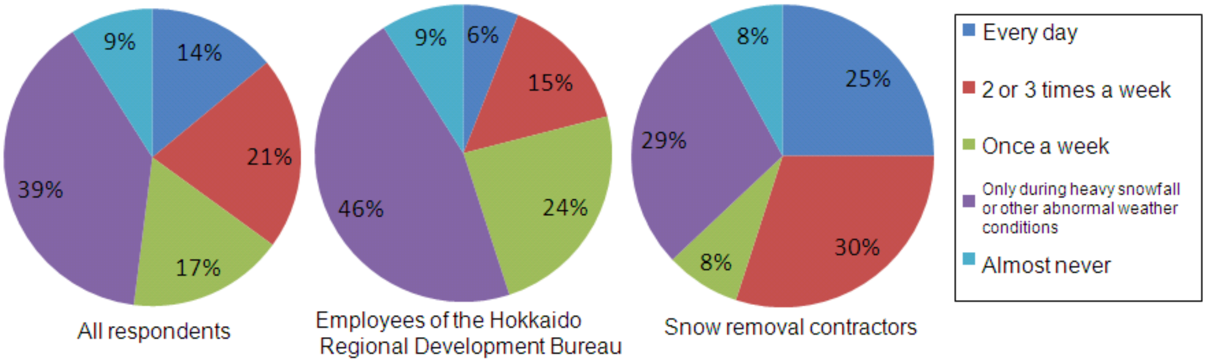


Figure 11 - Frequency of use of the function to monitor snow removal machinery locations

The interview survey on the use of the system revealed that snow removal contractors determined the timing of dispatch for de-icer spreaders while monitoring the progress of snow removal in local sections, or that they used it to confirm that de-icer was spread at the designated points. Road office employees said that they confirmed current operation conditions using the system and explained them in response to inquiries from road users or requests for application from the police, or used it to monitor the progress of snow removal when it was difficult to contact removal contractors during periods of extreme snow. At one time of heavy snowfall on February 21, 2009, some workers looked for a snow removal machine operating nearby to lead ambulances, or directed support as they judged from the system that there was a delay in snow removal in the adjoining section.

There were many requests concerning the general slowness of the system. Although the display speed may depend on communication lines and other user conditions, it needs to be improved to promote its use. There were also many requests for the display of weather observations, traffic regulations and roadside camera image data as an additional function. This makes it very important to monitor site conditions along with the locations and operation of snow removal machinery.

## 6. CONCLUSION

The goal of this development was to establish a system enabling the use of real-time location and operation information regarding snow removal machinery and to support the management and flexible operation of such machinery for the purpose of ensuring travel speeds for winter road users and prompt snow removal during abnormal weather.

In FY 2008, a system was developed and field-tested in terms of its dynamic section shift support and support for daily reports on de-icer application, and the opinions of employees from the Hokkaido Regional Development Bureau and snow removal contractors as users of the system were summarized. The results confirmed that supervising employees and snow removal contractors in adjoining sections can monitor the progress of snow removal in each other's areas. It was also found that the operation efficiency of snow removal in general can be improved by reducing congestion loss caused by snow removal through support for sections with delays by shifting section boundaries as necessary.

Detailed information on de-icer application that can be obtained by the system will also be useful as a basic tool when considering guidelines for appropriate application.

Future plans include the promotion of system development to enable more efficient support for snow removal machinery operations and further facilitate improvements in the efficiency and advancement of road maintenance and management.

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