

## Development of a Maintenance Decision Support System and Usefulness of Snowstorm Information in That System

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### ABSTRACT

The Civil Engineering Research Institute of Hokkaido (CERI) has developed a prototype MDSS system that provides information on the Sapporo area via website. The system has been in trial operation since the winter of 2002/03, providing snow removal contractors of national highways with road icing and snowfall information (current and forecast information) and with operation guidance on winter road management based on that information. The trial MDSS provided current and forecast weather information and operation support information, and incorporated an emergency reporting system. In the winter of 2004/05, a new system that provides 1-km-mesh snowstorm information was developed and added to the menu. A survey was given to snow removal contractors on the potential uses of snowstorm information in the MDSS. Survey showed high potential for visibility information in winter road management. They also showed that the accuracy of the visibility information that is currently provided needs further improvement, and that this could bring increase the user satisfaction.

**Keywords:** winter road management, MDSS, snowstorm information

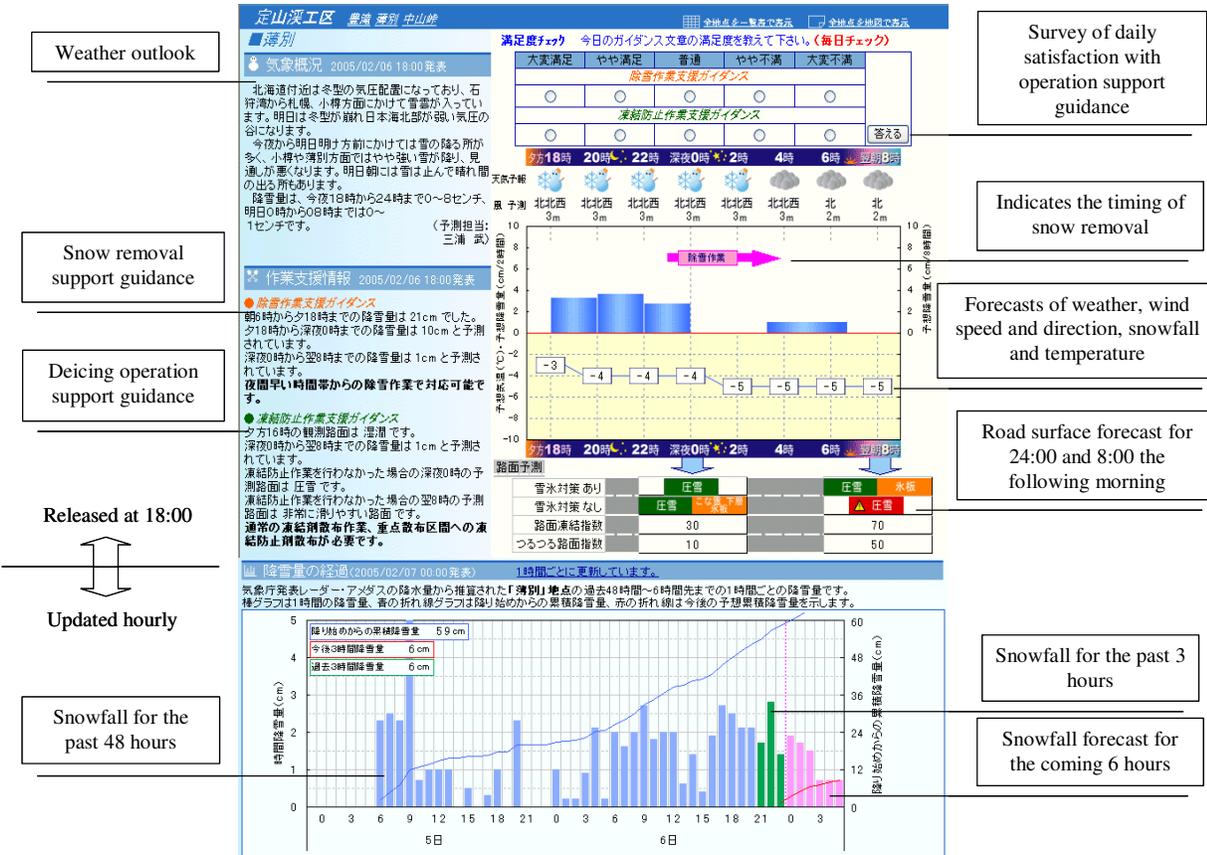
### 1. INTRODUCTION

The Maintenance Decision Support System (MDSS) makes effective use of road weather and road surface information primarily to support decision-making in winter road management, such as deciding the timing and amount of deicing agent to be applied and the mobilization of snow removal vehicles. By allowing effective winter road management operations, MDSS aims at reducing the cost of winter road management. The main operations in winter road management are snow removal and deicing agent application. Snowfall information allows effective snow removal operations and reduces personnel waiting time. Road icing information also affords cost reduction, by reducing the unnecessary application of deicing agents as well as improving road safety by preventing road icing.

The Civil Engineering Research Institute of Hokkaido (CERI) has developed a prototype MDSS system that provides information on the Sapporo area via website. The system has been in trial operation since the winter of 2002/03, providing snow removal contractors of national highways with road icing and snowfall information (current and forecast information) and with operation guidance on winter road management based on that information [1]. In the winter of 2004/05, a new system that provides snowstorm information was added. This paper outlines the MDSS and the usefulness of snowstorm information.

### 2. OUTLINE OF THE MAINTENANCE DECISION SUPPORT SYSTEM (MDSS)

The trial MDSS provided current and forecast weather information and operation support information, and incorporated an emergency reporting system. Current and forecast weather information is shown in 1-km-mesh format and is updated hourly. The information includes that on snowfall, snowstorm visibility, temperature and precipitation for current conditions, forecasts up to 6 hours in advance, and records up to 48 hours in the past. The operation support information provides support for decision-making on snow removal and deicing operation that are performed from late at night to early in the morning. Every day at 18:00, the system provides weather summaries, snowfall and temperature charts, road surface forecasts, and snow removal and deicing operation support guidance for 16 locations along national highways (Figure 1).



Survey of daily satisfaction with operation support guidance

Indicates the timing of snow removal

Forecasts of weather, wind speed and direction, snowfall and temperature

Road surface forecast for 24:00 and 8:00 the following morning

Snowfall for the past 3 hours

Snowfall forecast for the coming 6 hours

Weather outlook

Snow removal support guidance

Deicing operation support guidance

Released at 18:00



Updated hourly

Snowfall for the past 48 hours

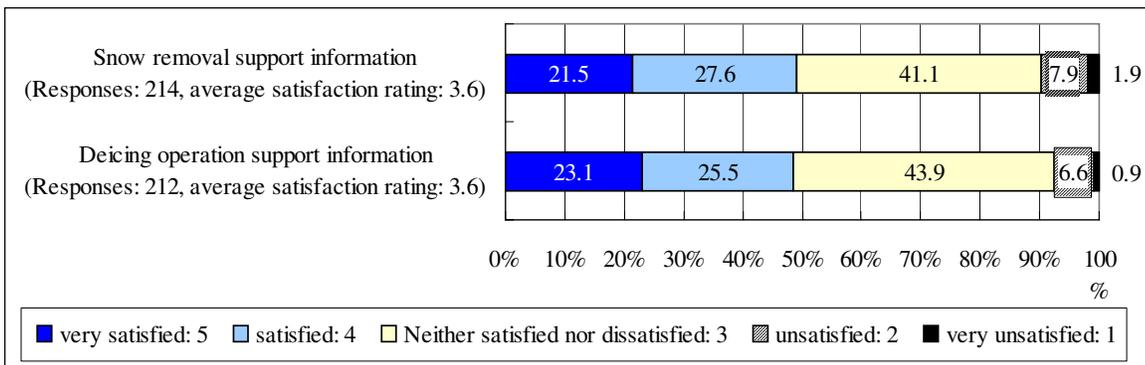
Road surface forecasts are based on visually observed road surface conditions as of 16:00, obtained through road patrols. The road surface forecast provides road conditions expected for 24:00 and 8:00 the following morning, according to whether snow removal and deicing operations are performed. The road surface forecast also provides a road icing index, which is an index of the likelihood of road icing, as well as a slippery road index, which is an index of the likelihood of very slippery road surfaces emerging. The road surface forecasts are made according to the 13 visual classifications of road surface conditions (Table 1) in the *Draft Manual for Winter Road Management* (November 1997, Hokkaido Regional Development Bureau).

The snow removal operation support guidance provides information on snowfall from 6:00 in the morning to 18:00, snowfall forecast for 18:00 to 24:00, and snowfall forecast for 24:00 to 8:00 the following morning, together with guidance on the timing and workload of snow removal. The deicing operation support guidance system provides information on road surface condition at 16:00, snowfall forecast for 24:00 to 8:00 the following morning, forecast of road conditions at 24:00 and 8:00 the following morning according to whether or not deicing is performed, and with guidance on the timing and workload of deicing operation.

The emergency reporting system aims to support initial response and monitoring during sudden changes of weather, by enabling users (road management contractors) to select and preset thresholds for receipt of weather forecasts, data from road weather telemeters, and road icing forecasts. As soon as the preset thresholds are exceeded, reports are e-mailed to PCs or mobile phones of the users.

In the winter of 2004/05, six snow removal contractors were asked to perform trial of the MDSS, and surveys of daily satisfaction ratings were performed to study whether the operation support information was useful. There were 214 responses to the questionnaires, in which the respondents rated the system according to five levels (very satisfied, 5; satisfied, 4; neither satisfied nor dissatisfied, 3; unsatisfied, 2; very unsatisfied, 1) as shown in Figure 2. Approximately half of the respondents were either "very satisfied" or "satisfied" for both snow removal and deicing operation support information, and the average satisfaction rating was 3.6. The snowfall forecast information was the most highly regarded support information. Great dissatisfaction resulted from those snowfall forecasts that turned out to be inaccurate. In the first year of the trial, the winter of 2002/03, the average satisfaction rating was 2.4 [1]. By improving user-friendliness, such as by presenting a graphic visualization of weather data and guidance, the satisfaction ratings increased.

1	Very slippery compacted snow
2	Very slippery ice sheet
3	Very slippery ice film
4	Ice sheet
5	Ice film
6	Powdery snow over ice sheet
7	Granular snow over ice film
8	Compacted snow
9	Powdery snow
10	Granular snow
11	Slush
12	Wet
13	Dry



### 3. SNOWSTORM INFORMATION IN MDSS

Snowstorm is the leading cause of road closure for national highways in Hokkaido, accounting for about 40% of closures. It is thought that adding snowstorm information to the MDSS would be useful in supporting decision-making regarding road closures at times of snowfall. In the winter of 2004/05, a new system that provides 1-km-mesh snowstorm information was developed and added to the menu. A survey was given to snow removal contractors on the potential uses of snowstorm information in the MDSS. Conventional snowfall intensity information and the new (current and forecast) visibility information in snowstorm were provided as snowstorm information for this study.

#### 3.1 Visibility estimation method

Local visibility data typically are obtained by visibility meter or from CCTV images, but this does not allow gathering of area-wide information such as snowfall intensity. Visibility in snowstorms is closely linked to weather conditions such as wind velocity and snowfall intensity, and by drawing equations from this relationship it is possible to estimate the visibility in snowstorms. Therefore, this was estimated by using a visibility estimation method developed by Matsuzawa et al [2]. To obtain visibility, this method uses the two following equations. Equation (1) is the vertical distribution equation for spatial density of snow particles (the total mass of blown snow particles per unit space);  $N$  [ $g/m^3$ ]. Equation (2) is the relationship between visibility,  $Vis$  [m]; spatial density of snow particles,  $N$  [ $g/m^3$ ]; and wind velocity;  $V$  [m/s].

$$N = \frac{P}{w_f} + \left( N_t - \frac{P}{w_f} \right) \left( \frac{Z}{Z_t} \right)^{-\frac{w_b}{kU_*}} \quad (1)$$

$$Vis = 10^{-0.77 \cdot \log(N \cdot V) + 2.85} \quad (2)$$

Where,  $P$  [ $g/(m^2s)$ ] is snowfall intensity;  $N_t$  [ $g/m^3$ ] is spatial density of snow particles at reference height  $Z_t$  [m];  $w_b$  [m/s] is falling velocity of blown snow particles;  $w_f$  [m/s] is falling velocity of snowfall particles;  $U_*$  [m/s] is friction velocity; and  $k$  is Karman's constant ( $= 0.4$ ).

The variables in Equation (1) that are difficult to measure were decided by referring to previous research.  $N_t = 30$  [ $g/m^3$ ];  $Z_t = 0.15$  [m];  $w_b = 0.35$  [m/s];  $w_f = 1.2$  [m/s];  $U_* = 0.036 V_{10}$  [m/s]. ( $V_{10}$  is the wind velocity at a height of 10 m. Roughness was assumed as  $1.5 \cdot 10^{-4}$  [m].) Using the standard hourly precipitation of  $Pr$  [mm/h],  $P$  could be calculated as  $P = 0.028 Pr$ .

This visibility estimation method allows estimation of blown snow accompanied by snowfall, using easily acquired weather data such as snowfall intensity and wind velocity. The method also allows area-wide visibility forecast using estimated values as input weather data. Furthermore, it allows the calculation of visibility at various altitudes.

Matsuzawa et al. have assessed the accuracy of this visibility estimation method by comparing the estimated visibility, based on ground-level weather observation data, with visibility measured by visibility meter at the same location [2]. The estimated visibility levels were assessed by applying the five visibility classifications in Table 2. The hit rate of the estimated visibility was 79%, when a hit is defined as when the estimated visibility falls within the same classification as the measured visibility, or when the estimated visibility is on the safe side, i.e. one class lower than the measured visibility.

This visibility estimation method assumes that visibility levels are obtained at flat open areas without snow fences or snowbreak woods, i.e., it examines the potential risk of poor visibility in the area. For monitoring local obstructions to visibility on certain roads, it is necessary to use visibility meters or CCTV cameras according to the location.

Snowfall intensity		Visibility	
Text expression	Definition	Text expression	Definition
None		Good	1000 m or more
Light	0.1 - 1 cm/h	Fair	500 - 1000 m
Moderate	1 - 3 cm/h	Bad	200 - 500 m
Heavy	3 - 6 cm/h	Very bad	100 - 200 m
Very heavy	6 cm/h or more	Extremely bad	less than 100 m

### 3.2 Flow of snowstorm information data

In the snowstorm information, there are two types of information: snowfall intensity, and visibility. Visibility hindrance can occur from blowing snow under low temperatures and strong winds even where there is no snowfall. Therefore, the MDSS snowstorm information provides snowfall intensity and visibility information. Figure 3 shows the data flow in the system.

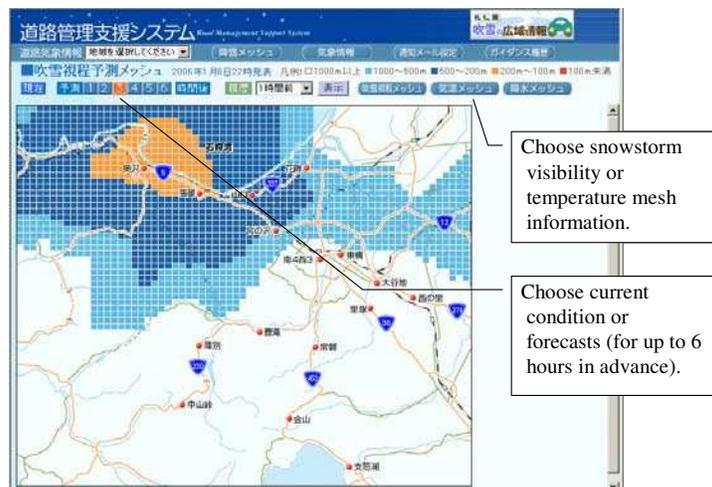
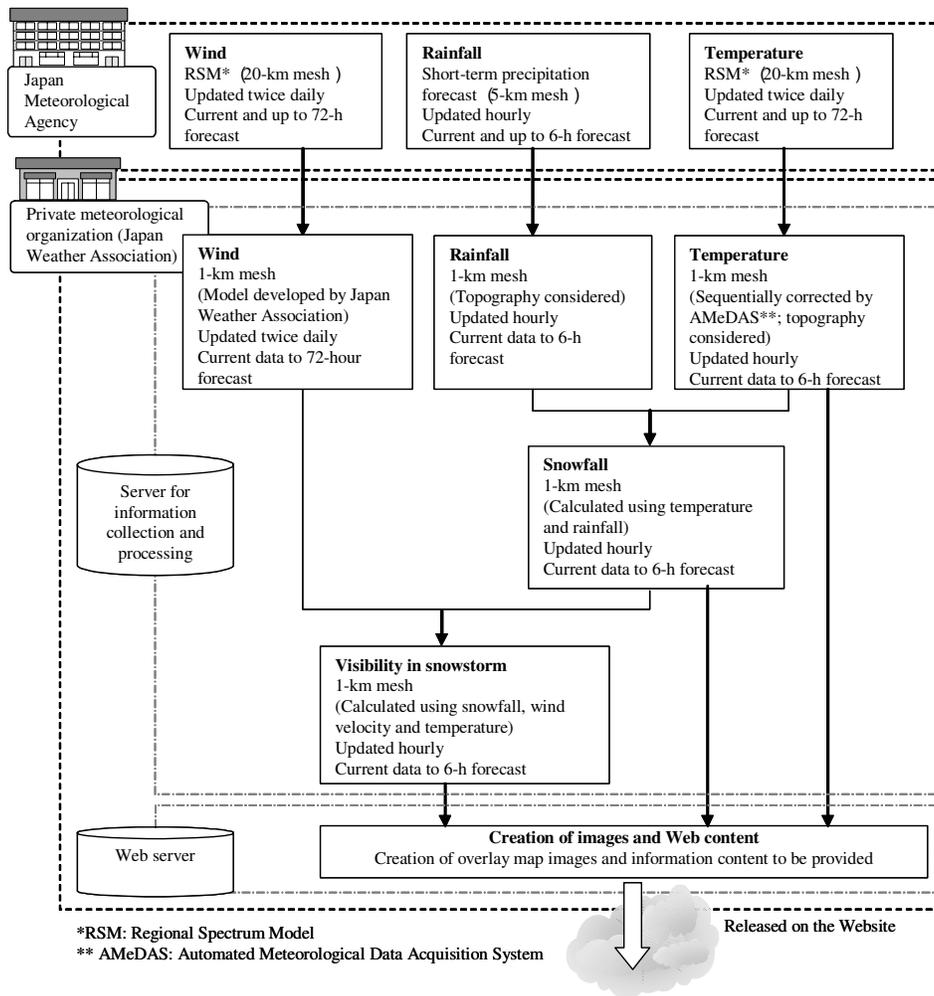
The snowfall intensity (hourly snowfall) data that were used are the precipitation and short-term precipitation forecasts in 5-km-mesh format released every hour by the Japan Metrological Agency and then processed by the Japan Weather Association (JWA). This fee-based service of JWA provides information in 1-km- x 1-km-mesh format on the current conditions and hourly forecasts up to 6 hours in advance.

The visibility data that were used are mesh data of current and forecast weather information on snowfall, wind velocity and temperature provided by the JWA. Using these data, the current visibility level and the estimated visibility levels of up to 6 hours in advance are obtained in 1-km- x 1-km-mesh format.

By overlaying snowfall and visibility information on the map data to improve user-friendliness, the information was released via website and updated every hour.

Figure 4 shows an example of MDSS information with the visibility forecast mesh information displayed. Each 1-km mesh is color-coded according to the classification in Table 2. Snowfall intensity and temperature information are also displayed on the map in the same manner. Using the button at the top left of the screen, the user can choose to see the current condition or forecasts for up to 6 hours in advance.

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#### 4. RESEARCH ON THE USEFULNESS OF SNOWSTORM INFORMATION

After the trial of MDSS, questionnaire surveys were performed on managers of road maintenance contractors to study the usefulness of the visibility information. There were 19 responses in this survey.

Figure 5 shows the responses to the question on visibility information (snowstorm visibility); “How useful would the visibility information be to your operations such as road maintenance and snow removal?” As shown in the figure, 11 of the 19 respondents reported that the information would be “very useful” or “useful,” and 6 reported that it would be “neither useful nor useless.”

Questionnaire surveys were performed on the level of demand for forecasts of different hours in advance to study the use of snowstorm information.

The question asked was, “For the following lead times, which of these actions do you think would be helped by provision of snowstorm visibility information?” The five lead times (Figure 6) are current information, 1 to 3 h, 6 to 12 h, 24 to 48 h, and 48 to 96 h. The six actions are

- 1 Decision-making on personnel stand-by and deployment
- 2 Planning and decision-making on road patrol dispatch
- 3 Preparation for road closure, re-opening, and prediction of these
- 4 Decision-making on road closure and re-opening
- 5 As reference information for variable message boards
- 6 Information provision to the public upon their inquiry

Figure 7 shows the results of the questionnaire survey. A large number of respondents reported that the information was very useful in cases related to snow and ice removal (e.g., “Decision-making on personnel stand-by and deployment” and “Planning and decision-making on road patrol dispatch”).

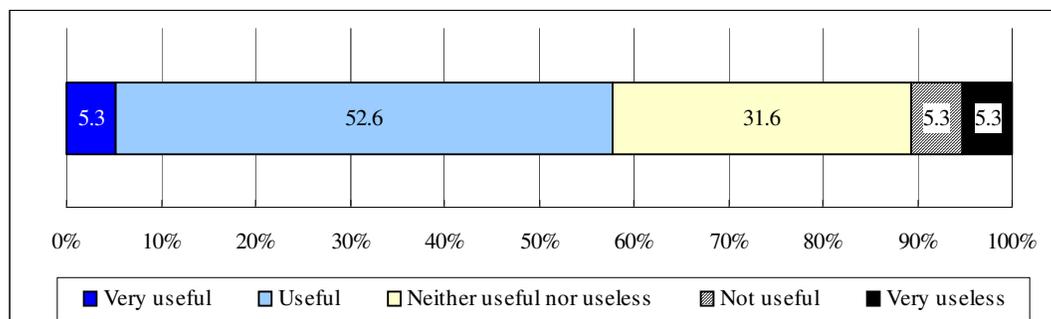
Figure 7 shows the following:

- 1) 16 out of 19 respondents reported that the 6- to 12-hour forecast would be useful for “Decision-making on personnel stand-by and deployment.”
- 2) 15 out of 19 responses reported that 1 to 3-hour forecast would be useful for “Planning and decision-making on road patrol dispatch.”
- 3) 13 out of 19 respondents reported that information on current condition would be useful for both “Decision-making on personnel stand-by and deployment” and “Planning and decision-making on road patrol dispatch.”

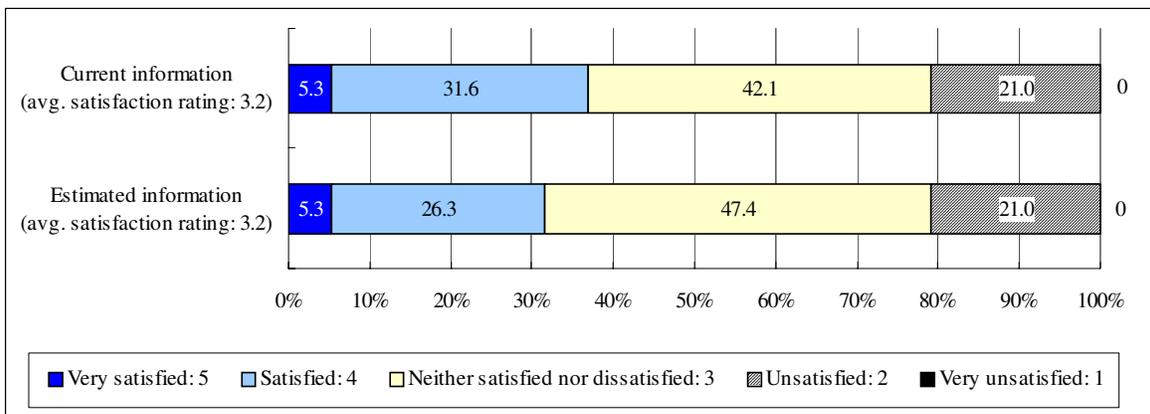
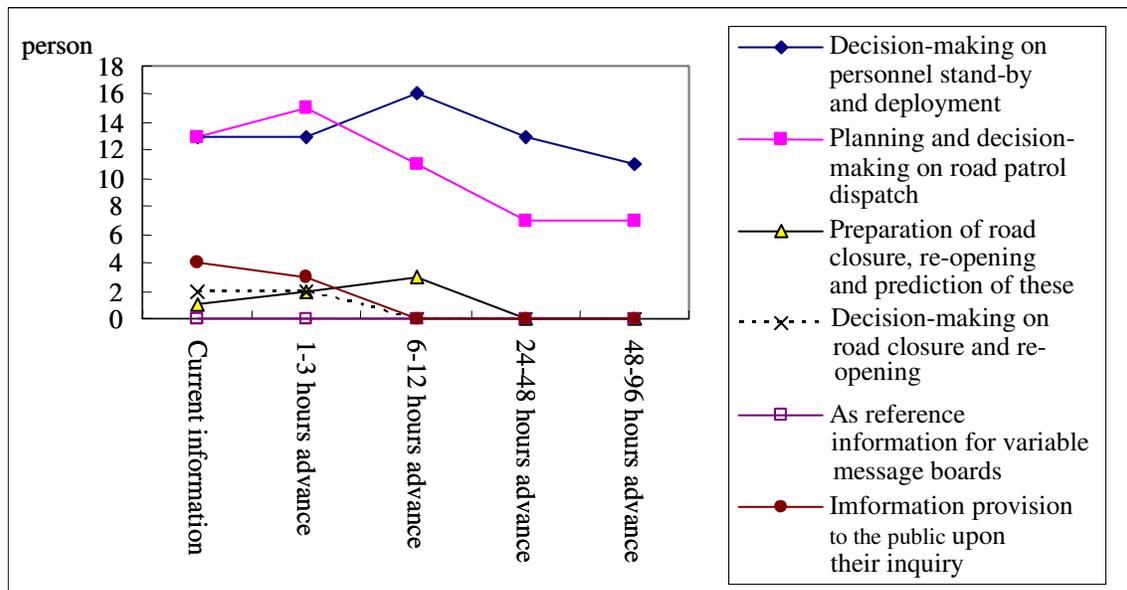
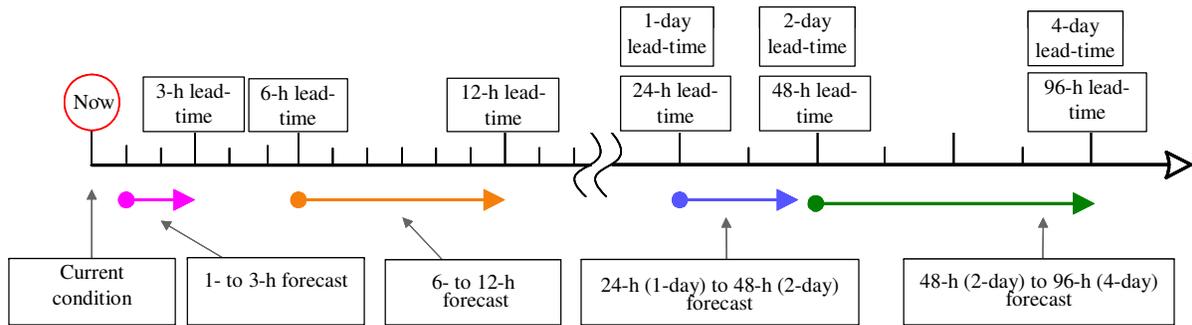
Despite the fact that slightly fewer than 60% of the respondents evaluated the provided visibility information as useful (Figure 5), many managers seem to recognize that visibility information is necessary for road management. This is also suggested from the results where the answer “Neither useful nor useless” was relatively common (Figure 5).

Surveys were also performed on satisfaction regarding the accuracy of visibility information. About 40% of respondents reported being “very satisfied” or “relatively satisfied” with the current information, and about 30% of respondents reported being “very satisfied” or “relatively satisfied” with the estimated information. The average satisfaction rating was 3.2. However, the greatest number of responses was “neither satisfied nor dissatisfied.” This seems to indicate a potential for increased satisfaction through further improvements (Figure 8).

Answers to the open-ended question, “Can you suggest any improvements?” included these: “I need pinpoint information as well,” “I need more frequent updating of information (within 30 minutes),” and “You need to increase as much as possible the accuracy of current and forecast information.” There were also many requests for image information of roads. This is thought to be because of the higher user acceptability of image information, which does not require the initial process of reading. Furthermore, it appears that the underlying reason for this is that final decisions for winter road management operations are made according to current information rather than forecast information.



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## 5. CONCLUSION AND FUTURE ISSUES

The trial on MDSS in the Sapporo area started in the winter of 2002/03. Since then, improvements had been made on the system to increase user-friendliness and to provide information useful for supporting the operations decision-making. In the winter of 2004/05, snowstorm information was added to the system. Surveys showed high potential for visibility information in winter road management. They also showed that the accuracy of the visibility information that is currently provided needs further improvement, and that this could bring increase the user satisfaction.

Future issues in the use of MDSS visibility information include the following: 1) increasing the accuracy of visibility information, 2) providing information together with forecasts of about half a day in advance, 3) providing more frequent updating of current information to bring it closer to real time, 4) providing more localized information, such as CCTV road images. Such improvements are expected to raise user satisfaction regarding visibility information.

Further trials on the MDSS are to be continued throughout the winter of 2005/06 to examine its effectiveness in reducing winter road management costs and other areas. Further research and development will be performed for toward implementing the MDSS in Hokkaido.

## 6. REFERENCES

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