Development and Operation of the Winter Maintenance Support System

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ABSTRACT

In northern communities, keeping the safe, effective and efficient travel during the wintertime is an important theme. Road authorities conduct various snow and ice control operations to provide as good roadway condition as possible. With the limitation of the budgets and the high expectation of the public for keeping good roadway condition, it is necessary to conduct winter maintenance operations more efficiently.

Accurate forecasting of road surface icing is essential to achieve the adequate and appropriate winter maintenance. Especially, it needs developing the approach to predict road icing scientifically. Besides, in order to start operational work on appropriate timing, it requires providing forecasting information to road authorities as soon as possible. Such system providing road weather information and forecasting information of road surface condition is known as Road Weather Information System or Maintenance Decision Support System. For several years, our institution has undertaken developing forecasting method and the "Winter Maintenance Support System" suitable for Japan's geographical feature, weather and existing snow and ice control activities in cooperation with other relevant organizations.

The project began observing the weather and road surface temperature and developing the prediction model in 2004, and in 2005 the prototype started providing the information to road authorities and contractors through the Internet. Then, the system has been practically used while improving the model and interface as the need arises. This paper describes the conceptual framework of the prediction model and of the system, and details of the practical/operational situation.

Keywords: Winter maintenance, Winter maintenance support system, Icing forecast, Heat balance model

1. INTRODUCTION

In cold, snowy region, icy, slippery roadways appear and snowfall and snow accumulation lead to narrowing roads during wintertime. These winter conditions result in negatively affecting traffic performance on roadways. Road authorities have developed and implemented a variety of practices and techniques for better snow and ice control to minimize winter hazards and make travel safer and more reliable. However, while the snow and ice control budget has limitation, it is required to implement more effective and efficient snow and ice control operation and its treatment activities.

In order to contribute to more efficient winter maintenance operation, the Civil Engineering Research Institute for Cold Region (CERI), Japan, has engaged in developing the "Winter Maintenance Support System," also well known as the maintenance decision support system that provides information on road weather and road icing to road authorities since 2004. Then, since the winter of 2005-2006, its test operation has been started for the national highways in Sapporo, and the system has been practically used while improving the interface as the need arises.

The rest of this paper is organized as follows. Next section presents the summary of the system development, and third section describes the system's composition and function. Forth section discusses the state of the system, and the final section summarizes the study result and suggests subjects for future inquiry.

2. SUMMARY OF WINTER MAINTENANCE SUPPORT SYSTEM

2.1 Background of System Development

Accurate forecasting of road surface icing is essential to the adequate and appropriate application of winter road surface management programs. For instance, anti-icing operation is a proactive preventive approach being

desirable to apply early enough to ice from forming [1]; otherwise, it requires forecasting accurately road-surface conditions for winter maintenance decision.

In order to operate such effective operation, it needs developing the approach to predict road icing scientifically as road surface condition changes suddenly with rapidly changing of climate conditions, such as radiation cooling phenomenon. Besides, in order to form operational party by prior decision or to start operational work on appropriate timing, it requires providing forecasting information to road authorities as soon as possible. This might lead to more appropriate and more efficient winter maintenance.

Such system providing road weather information and forecasting information of road surface condition to road authorities is known as Road Weather Information System (RWIS) or Maintenance Decision Support System (MDSS) [2], [3]. In order to support road authority's decision with providing accurate forecasting information based on a scientific approach, our institution has undertaken developing the winter maintenance support system suitable for Japan's geographical feature, weather and existing snow and ice control activities.

2.2 Organization of System Development

The winter maintenance support system has been developed in cooperation with not only the road authority but also with academic and weather institutions. Fig. 1. shows the cooperation status with the agencies/institutions concerned.

Fig. 1. Cooperation with the Agencies Concerned

2.3 Summary of System

Fig. 2. shows the conceptual diagram of the "Winter Maintenance Support System" developed in this study and the process of how to provide forecast information is described as follows along the diagram.
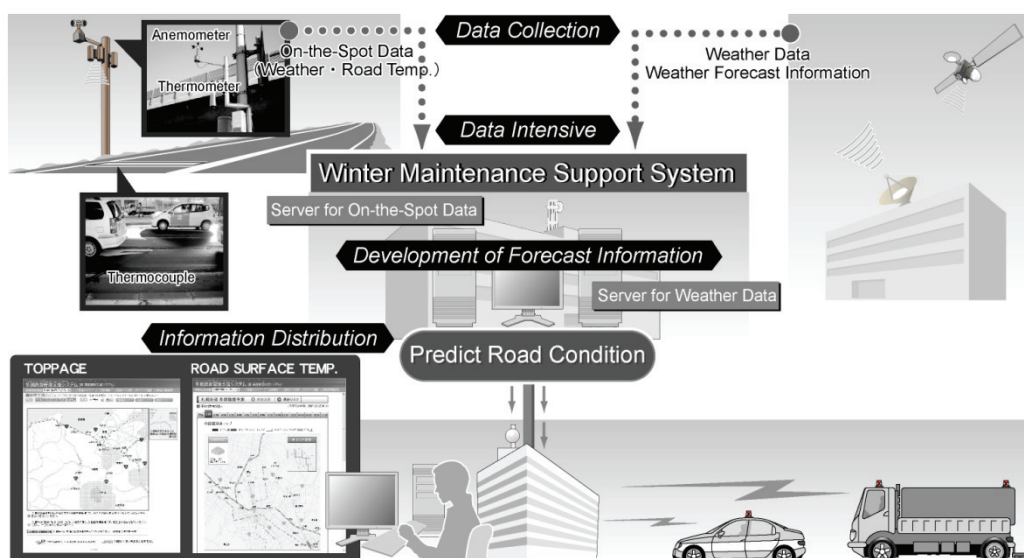

Fig. 2. Conceptual Diagram of Winter Maintenance Support System

2.3.1 Data Collection
Measurement devices are placed at the study point to observe weather and road surface temperature. The study also obtains on-the-spot weather data and prediction data, such as amount of solar radiation, cloud, and humidity, from the meteorological agency.

2.3.2 Data Intensive
The meteorological data and road surface temperature data obtained at the study point are recorded on a data logger. Those data are concentrated at the server of the maintenance support system through the phone line. On the other hand, the area's weather-related data from the meteorological agency is sent to the system server through the private line.

2.3.3 Development of Forecast Information
Based on the collected data, the system develops prediction information on road surface temperature and condition by joint research with an academic institution.

At first, the study developed road surface temperature prediction model based on the heat balance method. This method derives surface temperature through analysis of the heat transferred to and from the road surface. The distinguish feature of the model is that takes into account the effect of running vehicles and surrounding environment [4], [5] (see Fig. 3. and Equation 1 to 3). By solving these equations, road surface temperature can be determined. And Table 1 shows the parameters necessary to calculate them.

During the winter of 2007-2008, the study conducted to verify the accuracy of the model, and it shows that the accuracy of the calculation through the model is improved to approximately 1.2 degree Celsius (see Fig. 4.).
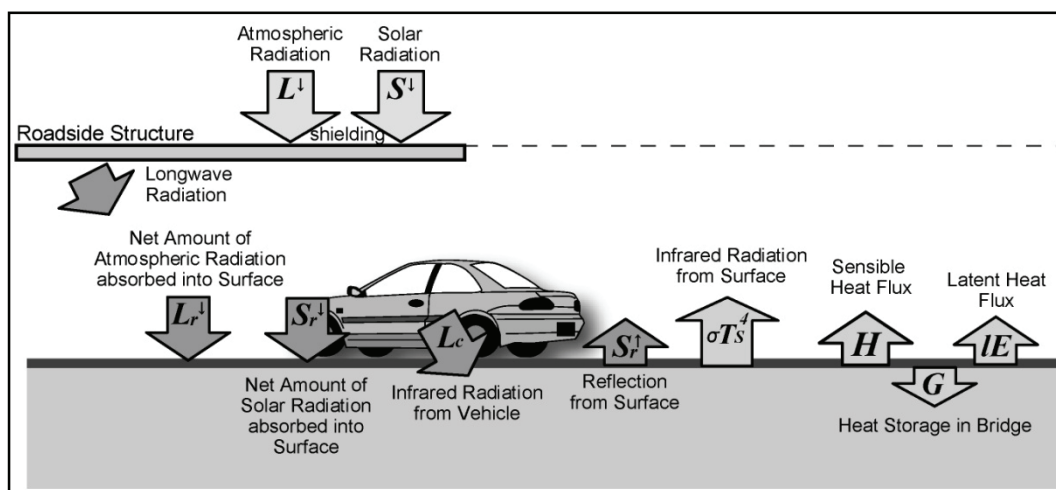

Fig. 3. Conceptual Diagram of Heat Transfer of a Road Surface

$$R^{\downarrow} = \sigma T_s^4 + H + lE + G \tag{1}$$

where
$R^{\downarrow}$ = net thermal energy into the road surface,
σ = Stefan-Boltzman constant,
T_s = road surface temperature,
H = sensible heat flux,
lE = latent heat flux, and
G = ground heat flux.

$$R^{\downarrow} = S_r^{\downarrow} - S_r^{\uparrow} + L_r^{\downarrow} + L_c \tag{2}$$

where
$S_r^{\downarrow}$ = net solar radiation into the road surface,
$S_r^{\uparrow}$ = net radiation reflected from the road surface,
$L_r^{\downarrow}$ = net atmospheric radiation into the road surface, and
L_c = net infrared radiation into the road surface from vehicular traffic.

$$L_r^{\downarrow} = (1 - \varphi)L_r^{\downarrow} + \varphi L_{strc}^{\downarrow} \tag{3}$$

Where
φ = rate of radiation shielding, and
L_{strc} = net outgoing longwave radiation from structures.

Table 1 Parameters Needed for Calculation

| Heat Balance Composition	Parameter	Unit	Value	
Radiation Amount $R^{\downarrow}$	Ave. Length of Vehicles d	m	5	
	Ave. Speed of Vehicles v	km/h	Intersection: 5	Non-Intersection: 30
	Strength of Scattered-Radiating Light S_s	W/m²	$Ss = 0.1S^{\downarrow}$ ($S^{\downarrow}$ shows all incoming light)	
	Temp. of Vehicle Tv	°C	$T_v = T_a + 20$ (T_a shows temp.)	
	Albedo α	−	0.1	
Sensible Heat Flux H	Bulk Coefficient C_h	−	0.003	
Latent Heat Flux IE	Bulk Coefficient C_e	−	0.003	
	Relative Humanity rh_r	−	0.5	
	Atmospheric Pressure P	hPa	1000	
Ground Flux G	Heat Conductivity k	W/mK	2.1	
	Depth Δz	m	0.05	
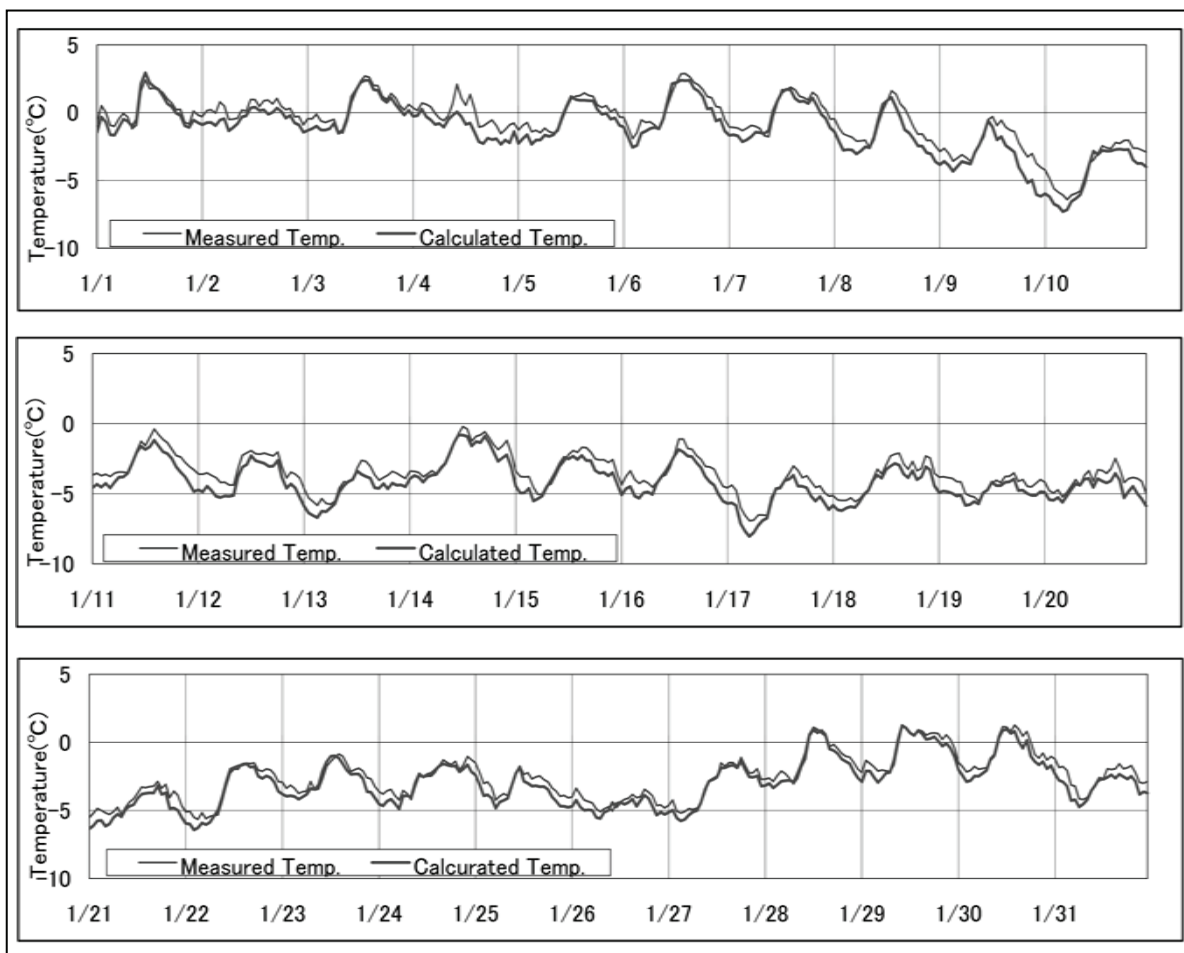
Fig. 4. Comparison of Measured and Calculated Values (from 2008.1.1 to 2008.1.31)

Also, the study developed the model to predict road surface condition based on water balance on road surface as shown in Fig. 5. and Equation 4 to 6,. The study defines "Road Icing Risk" to indicate road surface conditions. To be concrete, the study defines "High Risk" as icy roadway, "Moderate Risk" as compacted snow or slush, and "Low Risk" as wet or dry. The prediction accuracy during the 2007-2008 winter was about 70% .
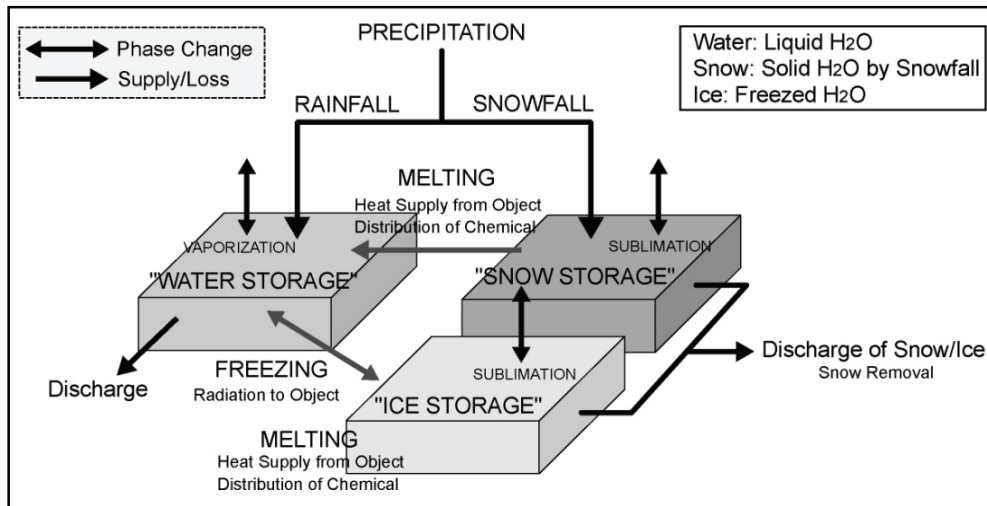
Fig. 5. Conceptual Diagram of Road Surface Condition Prediction

$$\frac{dq_{water}}{dt} = -\tau \cdot q_{water} + \frac{M}{L} - \frac{lE}{L_{evap}} + \Pr ec_{water} \qquad (4)$$

Where q_{water} = accumulated water level,
                    τ = drainage coefficient (0~1),
                    M = melting (if positive value)/freezing (if negative value) heat transfer,
                    L = latent heat,
                    L_{evap} = enthalpy of vaporization, and
                    $\Pr ec_{water}$ = rainfall.

$$\frac{dq_{snow}}{dt} = -A\frac{M}{L} - B\frac{lE}{L_{subl}} - \Gamma \cdot rm \cdot \frac{q_{snow}}{q_{snow} + q_{ice}} + \Pr ec_{snow} \qquad (5)$$

$$\frac{dq_{ice}}{dt} = -(1-A)\frac{M}{L} - (1-B)\frac{lE}{L_{subl}} - \Gamma \cdot rm \cdot \frac{q_{ice}}{q_{snow} + q_{ice}} \qquad (6)$$

where q_{snow} = accumulated level of snow,
                    L_{subl} = latent heat of sublimation,
                    rm = snow removal,
                    $\Pr ec_{snow}$ = snowfall, and
                    A, B, Γ: 0, 1 flags are:

$$A = \begin{cases} 1, & q_{snow} > 0 \quad and \quad M > 0 \\ 0 \end{cases} \qquad B = \begin{cases} 1, & q_{snow} > 0 \\ 0 \end{cases} \qquad \Gamma = \begin{cases} 1, & rm > 0 \\ 0 \end{cases}$$

2.4 Process of System Development and Operation
Table 2 describes the process of system development and its operation.

Table 2 Process of System Development and Operation

DATE	ACTION
2004	- Selected a case study route - Began to observe weather and road surface temp. - Developed the model to predict road surface temperature - Evaluated in model verification
Dec. 2005	- Began to operate the system experimentalily (Provide text-based information: 1 point)
Feb. 2006	- Displayed the predicted result with the graph - Added the points to predict road condition (1 points to 5 points)
Dec. 2006	- Started the experimental operation of the system with the same interface as the 2005/06 version - Added the study route to predict road condition
Feb. 2007	- Integrated with the existing system used by road authority - Began to provide the route information for the case study route
Dec. 2007	- Started the experimental operation of the system with the same interface as the 2006/07 version - Added the study route to predict road condition
Feb. 2008	- Improved the interface of the map (zooming, dragging) - Added the study route to provide the route information

Generally, there are two kinds of approach to develop the winter maintenance support system. One is a "Waterfall Model" which develops the whole system at once with advancing a process as turn. The other is a "Spiral Model" which performs design and mounting about a part of the system first and then repeats a design and mounting through the feedback from customers.

This study selected the latter model since a scheme and an interface desirable for road authority were unknown in advance. Therefore, it made possible to improve a system, applying experimentally with repeating the discussion about operation cycle, operation time, information service item, interface, and operability with road authority and contractors. Otherwise, the system's continuous improvement has been performed from the early stage of the system development to realize the effective operation (see Fig. 6., Table 3).

Fig. 6. Discussion with Road Authority and Contractor

Table 3 Discussion Theme

① Regarding to State of Snow and Ice Control Operation

- Schedule and cycle of daily operation
- Goal on operational performance
- Point and section where should be noticed as icy roadway
- Important point and section for anti-icing treatment
- Amount of anti-icing materials and their proper use

② Item, Contents, and Interface

- Appropriate forecast time to provide information?
- Necessary items for information service?
- Suitable classifications for winter road conditions?
- Appropriate display and description on top screen
- Amount of Information displayed on one screen
- Size of screen showing predicted condition at specific point
- Permissible frequency of click
- How to display route prediction
- Request for the existing screen and information
- Request for long-term improvement

3. SCHEME AND FUNCTIONAL FORMATION OF SYSTEM

3.1 Scheme of the System

This system's scheme is shown in Fig. 7. The information for providing to road authorities is roughly classified into two categories; mesh weather information and road icing prediction information. Then, it is provided with accompanying general weather information. The outline of the main parts consisting of the system is introduced after the following subsection.
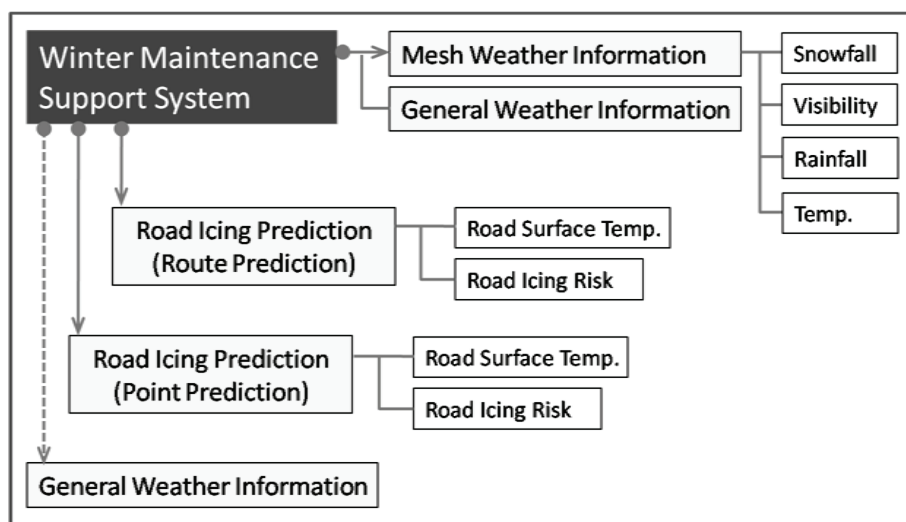

Fig. 7. Scheme of Winter Maintenance Support System

3.2 Top Page and Mesh Weather Information Screen

Fig. 8. shows the top page of the system. The road authorities had traditionally used the "Road Management Support System" which provided snowfall forecast information [6], except for this winter maintenance support system. Although the winter maintenance support system in this study was originally developed as an independent system, it integrated with the road authority's existing system according to the opinion from road authority and contractors. Integration is completed to put information together with utilizing the top page of the road management support system, which is high name recognition as applied for many years. Consequently, the number of accesses has increased significantly.

The top page serves a double purpose for road authorities; one is the mesh forecast information including snowfall, visual range, rain and temperature, and the other is the mesh weather information screen showing the

past data. Only rainfall and temperature information are distributed from the Meteorological Agency, and all the other are provided with developing in this system.

The size of each mesh is 1 square kilometers in area, and the information to provide is classified into 5 steps on the basis of the value referred to when road authority works. Besides, the color pattern displaying information is made into about five colors based on the discussion in which it is difficult to distinguish the specific color when there are many categories.

Fig. 8. Top Page and Mesh Weather Information Screen

3.3 Road Icing Prediction Screen (Route Prediction)

It moves to the top screen of road icing prediction (route prediction) by clicking a map of the top page or the window beside the map. There are two kinds of information on road icing prediction. One is road surface temperature prediction and the other is icing risk-related information (prediction information for road surface condition).

A road authority performs "spot spraying" limited to a crossing and a bridge with many slip accidents or the point being able to icing, rather than distribute anti-icing material to the entire route. Therefore, "information on route prediction" corresponds to such snow and ice control operation.

3.3.1 Road Surface Prediction Screen

As shown in Fig. 9, on the top screen of road icing prediction shows the panorama view of road surface temperature distribution of the targeted route. The road surface temperature is divided into five levels in addition to one with 2 degrees Celsius or more, which do not almost have the possibility of icing. Clicking the tab on a map, the system shows the road surface temperature distribution of 1- and 16-hour forecast. In urban area, snow and ice control operations are usually conducted from the midnight to early morning in order to provide as good winter roadway condition as possible during morning commuter hours. Therefore, by setting to 16-hour forecast, it enables to considering operational plan at daytime.

For the map, zoom operation is possible in three steps. Thereby more detailed road surface temperature distribution can be confirmed. It is also possible to move a point by dragging the map in the window. Moreover, road weather prediction (pictogram) and the weather forecast of temperature and precipitation are displayed on the small window at the upper left of the map.
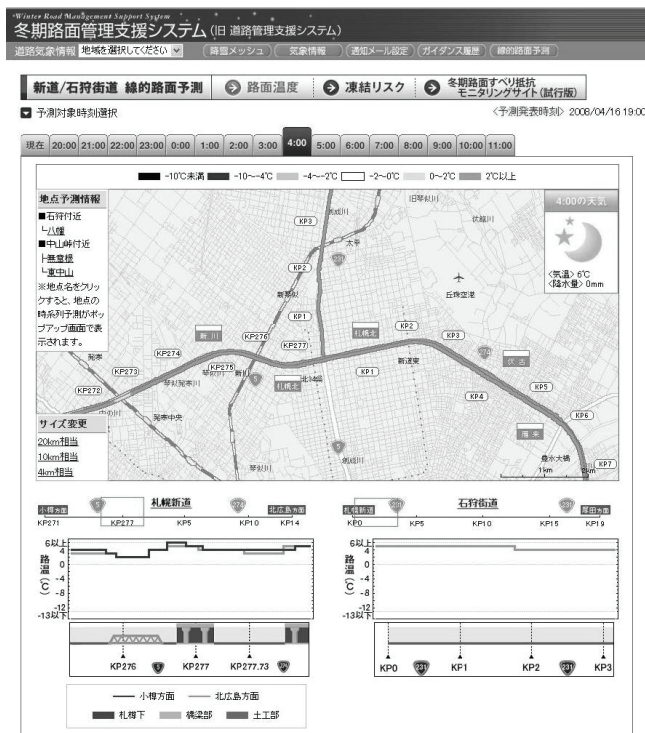
Fig. 9. Rod Surface Temperature Prediction Screen

3.3.2 Road Icing Risk Prediction Screen

When the "Risk of Road Icing" button of the upper part of the screen is clicked, it moves to the top screen of road icing risk prediction, and the spot with road icing risk through the entire route is displayed (see Fig. 10.). At the present stage, "Risk of Road Icing" is displayed into three levels; High Risk (icing), Moderate Risk (compacted snow or slush), and Low Risk (wet or dry). This is due to the road authority's opinion that would like to know whether a road surface would icy more directly than a detailed road surface classification. This page shows the same content as one of the road surface temperature prediction with the 1- and 16-hour forecast.

For the map, zoom operation is possible in three steps. Thereby more detailed road surface condition distribution can be confirmed. It is also possible to move a point by dragging the map in the window. This page also shows the road weather prediction with pictogram at the upper left of the map, as well as arranging the small window of area selection at the upper right of the map.
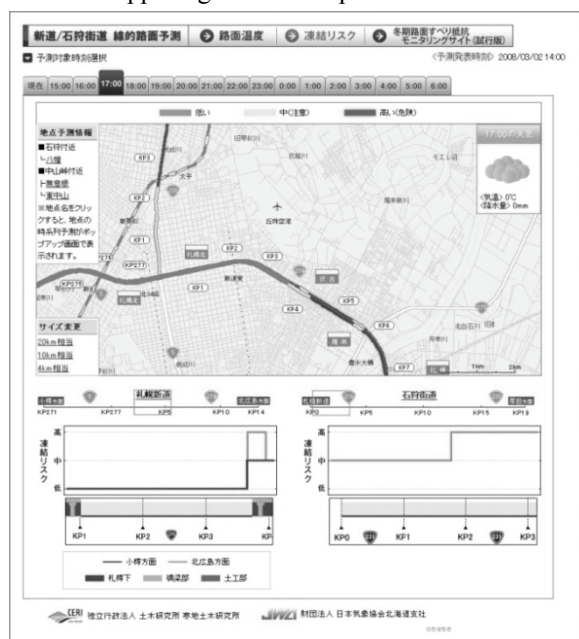

Fig. 10. Road Icing Risk Prediction Screen

4. THE STATE OF THE SYSTEM

4.1 State of the Winter Maintenance Support System
The study had a workshop with the road authority and contractors in order to recognize the effective operation of the system. The main comments about the use of this system are described in the following. Further, even if there are some comments regarding to the system's interface or operability, these are omitted in this section since those are overlapped with description in the previous sections.

-*State of Confirmation*
- Check the information on the system for every hour when the weather is unstable, especially from 5 p.m. to 8 a.m.
- Check the information 2 to 3 times a day when the weather is stable.
- When considering operation plan at night, often confirm the information if evening temperature is less than +1 degree Celsius.
- Not use the system the other way around as fixing the operational system at the time of storm.

-*Practical Use for Snow and Ice Control Operation*
- Use as reference of anti-icing activity.
- Utilize as a factor which determines time to go on patrol.

-*Expectation and Direction of Future Improvement*
- Being desirable for the predicted value of road surface condition after treatment to change by distributing of anti-icing material.
- Since accountability is further required for operational activities from now on, use positively as reliable source in that case.

4.2 Number of Accesses to the System
Fig. 11. shows the trend of number of access to the winter maintenance support system. Although the number of access has not increased immediately after opening its operation in December, 2005, the number comes to be steadily increased after the end of January, 2006. This might be due to increased cognitive level with progress of time.

At the beginning of 2006/07 winter, the number of access had hardly increased due to the effects of mild winter. However, the number came to be significantly increased with integrating this new system with the exiting one, which had used by road authorities, and with starting on information service on road icing prediction for specific route in February, 2007. This might be due to the effect of providing information highly required by road authorities and to the effect of improvement of the accessibility to information with having integrated the system. At the end of FY 2006, the total access number amounted to 22,503.

Then, the total access number reached up to almost 50,000 at the end of FY 2007. Indeed, in January and in February, the number of access per month amounted to approximately 10,000.The system's visitors are the road administrator staff, mainly maintenance staff, and contractors who actually carry out snow and ice control activities. As for contractor, it is expected that the number of visitors is less than 50 since a staff in charge on the day mainly looks at the system. Therefore, the study finds that the system came to be used quite frequently with increased cognitive level.
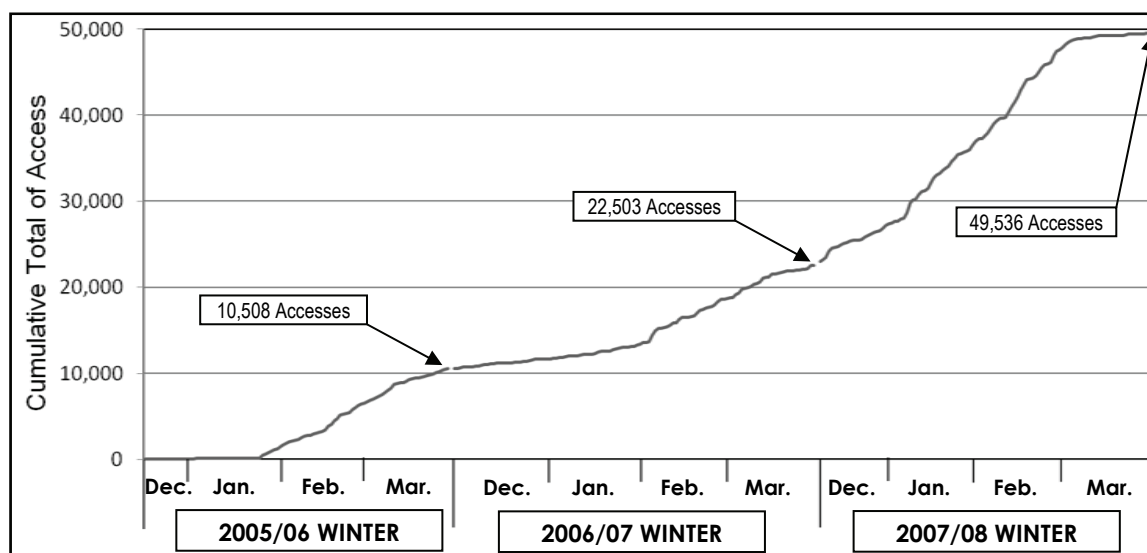
Fig. 11. Trend of Number of Access to the System

5. CONCLUSIONS AND FUTURE THEME

This paper describes the background of developing the winter maintenance support program, the conceptual framework of this information system, and the state of the tentative operation. The system supports the road authority's decision-making for snow and ice control operation. Then, it is expected to contribute to effective and efficient winter road management programs by avoiding the excess spreading of anti-ice and anti-slip materials or the missing of areas that require treatment with improving the accuracy of information on forecast. Therefore, we would like to enhance the system more useful and reliable for road authority with improving prediction accuracy, utilizing geographical information system (GIS), and supplementing a function which presents proposed measures.

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