SURVEY OF THE RATIONALIZATION OF THE SPREADING OF ANTI-ICING CHEMICAL IN NIIGATA PREFECTURE

Hiroshige OHANA *[1] Noriyasu KANEKO *[1] Kenichi SAITO *[2] Junichi OSHIMA *[3]

*1 Road Maintenance Division, Public Works Department, Niigata Prefectural Government
Telephone/+81-25-285-5511, Faxphone/+81-25-284-5096
E-mail/ T0800403@mail.pref.niigata.jp

*2 Muikamachi Public Works Office, Public Works Department, Niigata Prefectural Government
Telephone/+81-257-72-2249, Faxphone/+81-257-72-2618
E-mail/ T0811206@mail.pref.niigata.jp

*3 Planning and Coordination Department, Snow Research Center
Telephone/+81-3-3261-2941 / Faxphone/+81-3-3261-2764
E-mail/ snow@yukicenter.or.jp

1. Abstract

Since the April 1991 prohibition on the use of spike tires that was a effective way to prevent winter-time skidding accidents, traffic congestion and skidding accidents caused by the icing of road surfaces have become serious social problems.

To prevent such road surface icing, Niigata Prefecture has been carrying out road maintenance based on the installation of snow melting and removal systems and the spreading of anti-icing chemical, but in response to increased social and economic activities in the winter and a rise in the level of services demanded by the public and road users seen in recent years, the prefecture has been increasing the quantity of anti-icing chemical it has spread. For example, the quantity spread per unit distance of treated road has doubled during the past 10 years. And to deal with new challenges such as tight financial constraints and the need to protect the global environment, the prefecture must now spread anti-icing chemical that achieves increasingly efficient and more environmentally friendly winter road surface maintenance.

Planned to meet the above needs by improving road maintenance performed by spreading anti-icing chemical, this study focussed on advance spreading that prevents road surface icing from occurring to rationalize the quantity spread and the spreading locations based on a field survey. Based on the results, the authors have proposed a rational and effective spreading method implemented by preparing and applying an anti-icing chemical spreading map that reflects weather conditions and the state of the road at the site.

This study also compared actual spreading on a model road in January and February 2000 with the results of a calculation of the quantity that would have been spread by applying the anti-icing chemical spreading map obtained by this study. The results of the trial calculation show that it is possible to reduce the quantity spread by about 14%. Calculating the cost of spreading anti-icing chemical throughout the prefecture (in January and February 2000), showed that it would reduce this cost by about ¥63 million, revealing that efficient spreading can be performed by spreading the chemical in advance based on an anti-icing chemical spreading map.

2. Introduction

2-1. Winter Weather in Niigata Prefecture

Niigata Prefecture is, as shown by Figure 2-1-1, located at almost the mid-point of the Coast of the Japan Sea, occupies a total of 12,580 km^2, and is home to a population of about 2.5 million people.

During the winter, seasonal north-westerly winds pass over the warm Tsushima Current, and elevating large quantities of moisture, strike the mountain ridges producing heavy snowfall in Niigata Prefecture. Because the mean January temperature in the prefecture's major cities of Niigata and Takada is high between 2.0 and 2.5°C, this snow is characteristically heavy and has a high moisture content.

In Niigata Prefecture, meteorological observation stations are located on the 6,000 kilometers of roads managed by the prefecture, and Table 2-1-1 shows the depth of the snow cover recorded during the past 30 years in five typical cities. The snow cover ranged from 0.5 m to 1.5 m in Niigata, Shibata, and other cities on the coastal plains, while it was between 2.0 m and 3.0 m at Tokamachi City in the mountains. The accumulated snow depth obtained by totaling daily snowfall exceeds 10 m in the mountains.

Table 2-1-1 Maximum Depth of Snow Cover and Accumulated Snow Depth (Averages for the Past 30 Years) (cm)

	Shibata	Niigata	Nagaoka	Tokamachi	Joetsu	Average
Max. Depth of Snow Cover	73	35	120	213	129	114
Accumulated Snow Depth	391	162	603	1,142	586	577

Note: Average from 1971 to 2000

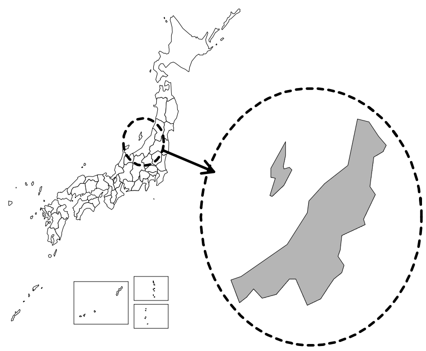

Figure 2-1-1 Location of Niigata Prefecture

2-2. State of Anti-icing Chemical Spreading

In Niigata Prefecture, anti-icing chemical is spread on 900 km of roadway that corresponds to about 17% of the total of 5,100 km of road where snow is removed. This is done by mechanized spreading, primarily of sodium chloride (NaCl).

A look at recent trends in the spreading of anti-icing chemicals shows that during the ten years since the April 1991 prohibition of spike tires, the quantity spread per kilometer per day when the temperature is below freezing has doubled (Figure 2-2-1). Two factors that explain this trend are the increasingly frequent accidents caused by skidding as a result of the fact that icing and packed snow occur more readily on road surfaces and rising public needs created by an expansion of social and economic activities in the winter season.

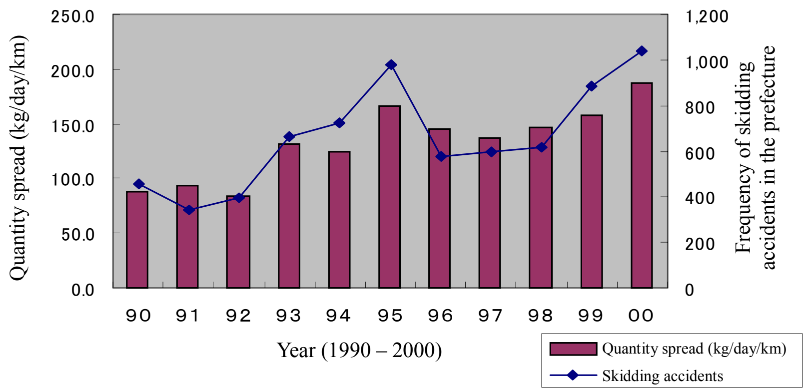

Figure 2-2-1 Trends in the Quantity of Anti-icing Spread (Roads Managed by Niigata Prefecture)

In Niigata Prefecture, heavy snowfall is accompanied by temperature variations during the winter, causing the snow cover to repeatedly freeze and thaw and to easily form packed snow. For this reason, one characteristic of road surface management in Niigata is the frequent application of the process: initial snow removal followed by chemical spreading to melt remaining snow before it can form packed snow. If this is included in advance spreading performed to prevent these phenomena, about 85% of all spreading done by spreading trucks throughout the prefecture is advance spreading. The remaining 15% is spreading performed to melt road surfaces after icing has occurred, and this is done primarily using calcium chloride ($CaCl_2$).

2-3. Shortcomings of anti-icing chemical spreading

Clear spreading standards governing the spreading of anti-icing chemical have not been established for the roads managed by Niigata Prefecture. Consequently, decisions concerning the time to dispatch spreading trucks, the quantity spread, and spreading locations are, in fact, made by snow removal managers of each public works office managing roads and by operators employed by companies contracted to do the spreading based on their own experience and observations of weather conditions.

Problems that this approach can cause include a high probability of excessive or inadequate spreading or discrepancies in the level of management of road surfaces in different sections of a single road by the spreading contractors responsible for each section.

3. Outline of the survey

3-1. Purpose of the survey

Niigata Prefecture is attempting to resolve these problems by constructing an efficient and effective advance spreading management system by rationalizing the quantity spread, spreading locations, and spreading times in accordance with rational management standards as a way to improve road management based on the spreading of anti-icing chemical.

This survey was a basic survey performed by applying the results of thermal mapping of a selected model road to prepare anti-icing spreading maps that reflect both the characteristics of a region's weather and the characteristics of its road surfaces in the quantity spread and spreading range (below called “spreading map”) and the application of spreading maps to verify its effectiveness and its future potential.

3-2. Content of the survey

This survey was performed according to the overall survey flow chart shown in Figure 3-2-1. As the model route for the survey, the authors selected a 16 km section of National Highway No. 253 beginning in Yokawa in Muikamachi in Minami Uonuma Gun and ending in Yamamoto in Tokamachi City a route in a region with extremely heavy snowfall. This route is a road over a mountain pass whose elevation varies by about 330 m as it crosses the Uonuma Hills and passes through the Hakka Tunnel (L = 1,180 m) and many snow protection structures including snow sheds and snow shelters constructed on both sides of the tunnel.

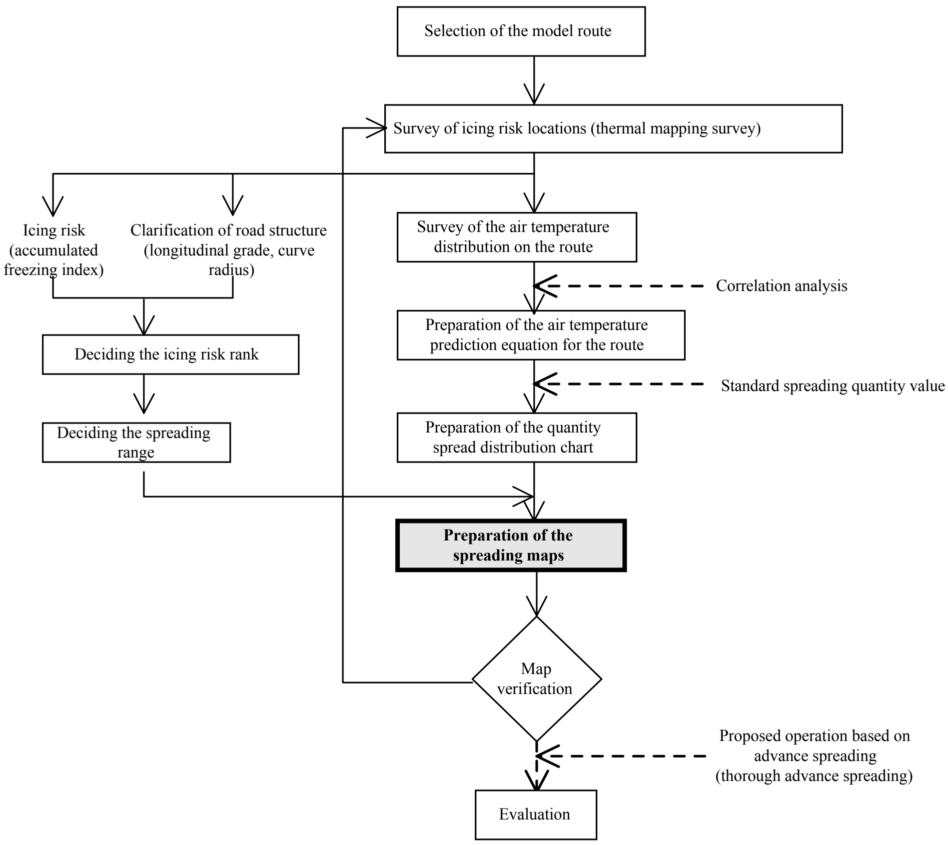

Figure 3-2-1 Overall Survey Flow Chart

4. Thermal mapping survey [1)]

The thermal mapping survey was performed by a mobile road surface data collection vehicle assembled by equipping an observation vehicle with a road surface thermometer, an air temperature thermometer, and other sensors (Snow Research Center, Japan Highway Public Corporation, 1999). The survey was performed a total of 30 times beginning in the evening and continuing through the night till the early morning—a period when icing occurs readily—from January 17 to 24, 2000. Midway through the period, snow fell continuously from January 20 to 22 and the road was either packed snow or sherbet, but on other days it was often clear or cloudy and the road surface was either dry or wet.

The survey linearly collected air temperature and road surface temperature data for 20 m intervals and the results were converted to the accumulated freezing index to linearly clarify the sections prone to icing. The accumulated freezing index is an index obtained by totaling road surface temperatures of 0°C or less from each observation cycle. Figure 4-4-1 shows the accumulated freezing index based on the results of the 30 observations and accumulated freezing index obtained by converting data from meteorological observation stations in Niigata Prefecture (Hakka Pass) referred to above to one-month data for January 2000 (31 days, total of 744 hours).

As the elevation increases from the Muikamachi side that is the start point of the observations to the 6 km point that is the location of the Hakka Tunnel, the accumulated freezing index gradually rises, but near the snow sheds and snow shelters concentrated at both ends of the Hakka Tunnel, the accumulated freezing index fluctuates abruptly, and is very low within the tunnel and similar places. Continuing through the tunnel and towards the Tokamachi side, the accumulated freezing index gradually falls, but it peaks abruptly at a bridge (Nakanosawa Bridge, L = 21.5 m) at the 9 km point.

These results show that because the road surface temperature fluctuates particularly before and after the Hakka Tunnel, this is a section where there is a high probability of traffic accidents occurring and the need for priority road management in this part is particularly high.

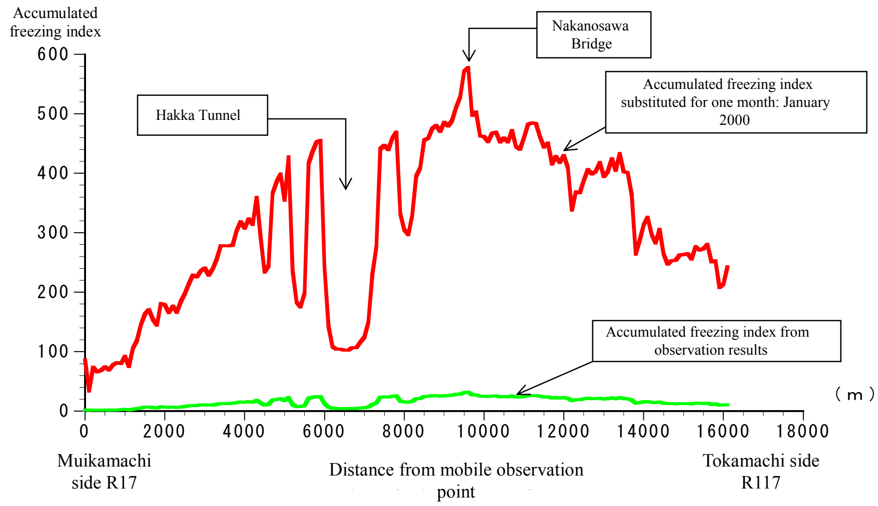

Figure 4-1-1 Thermal Mapping Survey Result

5. Preparation of the Anti-icing Chemical Spreading Map

5-1. Basic Concept of the Rationalization

The rationalization of the spreading of anti-icing chemical focused on the rationalization of the quantity that should be spread and the spreading range in the case of advance spreading. Specifically, rationalization was achieved by setting the quantity spread based on short term predictions of the air temperature on a model route obtained in accordance with the results of a thermal mapping survey, and setting the spreading range according to the "icing risk ranking" that accurately reflects the characteristics of the road and of the weather along its route.

And to establish a method of applying these results as a practical method, spreading maps that show the quantity to be spread within the spreading range on the road were prepared. It is assumed that performing spreading based on a spreading map will clarify the quantity that should be spread (g/m²) in each section of the road, and will permit objective and unified spreading that reflects the characteristics of each road and the weather conditions along its route.

5-2. Quantity spread distribution chart based on the short term air temperature predictions

Because the spreading effects [2)] (depression of freezing point and improvement of resistance to sliding) are substantially effected by the spreading density (g/m²) and the air temperature during spreading, the air temperature on the model route was linearly predicted (short term air prediction of the temperature one hour in advance) to set rational spreading quantities with salt (NaCl) as the standard for each 100 m of route length.

The short term air temperature predictions for this survey were performed by inputting the air temperature at a meteorological observation station (Muikamachi in this case) to predict the air temperature distribution at 20 m intervals along the route. Specifically, as shown in Figure 5-2-1, air temperature data from three meteorological stations near the model route (Tokamachi, Muikamachi, and Hakko Pass) and air temperature data collected by the thermal mapping survey were used to select the meteorological observation point that is the most closely correlated with each point along the route (20 m intervals) to prepare a correlation equation.

Figure 5-2-2 shows an example of a prediction of air temperature distribution within the model route obtained by this correlation equation. The same figure also shows the results of a prediction of the air temperature distribution obtained by inputting the air temperature at Muikamachi (0°C, -3°C, -6°C).

The quantity spread (spreading density, g/m²) was set by accounting for weather conditions along the model route and applying the standard quantity spread of the Hokuriku Regional Bureau of the Ministry of Land, Infrastructure, and Transport that is assumed appropriate (quantity of salt spread by air temperature) as the standard for the quantity spread (see Table 5-2-1). The quantity spread was then set for each 100 m section of the model route based on the results of the short term predictions of air temperature and on the standard quantity spread.

Figure 5-2-3 shows an example of a quantity spread distribution chart. The quantity spread is set at four levels: 0 (no spreading), 20, 30, and 40 g/m², and for convenience the set quantities spread are represented by the digits 0, 1, 2, and 3 on the map.

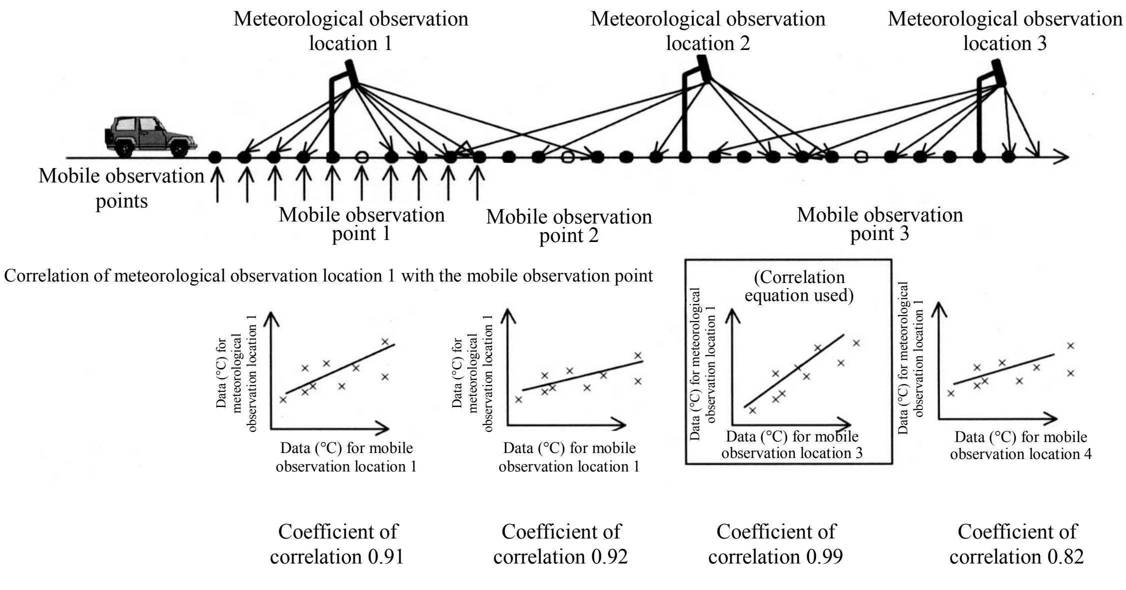

Figure 5-2-1 Short Term Air Temperature Prediction Conceptual Diagram

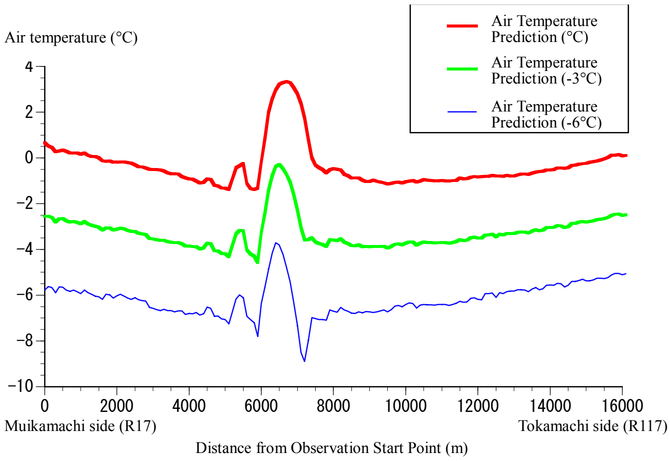

Figure 5-2-2 Example of Short Term Air Temperature Prediction Results

Table 5-2-1 Air Temperature and Standard Spreading Quantity

Air temperature range t(°C) *1	Quantity spread (g/m²)	Indication format *2
①t>0	0	0
②0≦t<-3	20	1
③-3≦t<-6	30	2
④t≦-6	40	3

*1. t (°C) represents the minimum air temperature at the spreading location (°C).
*2. Indication format are the numbers within the spreading distribution diagram: Fig. 5-2-3.

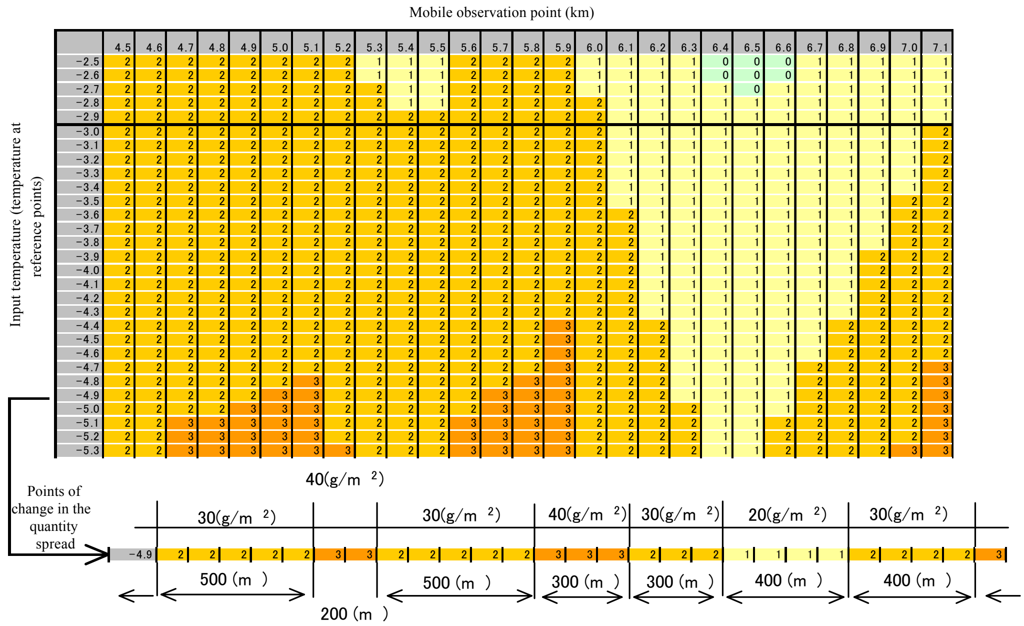

Figure 5-2-3 Example of a Quantity Spread Distribution Chart

5-3. Setting the spreading range according to the icing risk rank

For this study, a “spreading range” was set so that the quantities spread could be fixed as constant values for sections of a certain length (approximately 1 km or more) in order that mechanized spreading work by anti-icing chemical spreading trucks can be carried out smoothly and accurately. The spreading ranges were set by inputting the icing risk rank described below in order to set the spreading range for each icing risk rank.

The icing risk ranks were set by treating the accumulated freezing index obtained by the thermal mapping survey and the road structure as elements to quantify the probability of winter traffic accidents caused by road surface icing (=icing risk).

Because the accumulated freezing index is, as explained in “4. Thermal mapping survey,” an index that reflects road surface temperature conditions and is an index suitable for use in representing the likelihood of a road surface icing, the accumulated freezing index obtained from the results of the thermal mapping survey was used to classify the likelihood of a road surface icing in five levels as shown in Table 5-3-1.

Road structure was considered to represent structural factors that influence the frequency of skidding accidents and other traffic accidents on a road where surface icing has occurred, and focusing on the two factors—longitudinal grade and curve radius—the road structures were set as the levels as shown in Table 5-3-2 to account for the Road Structure Ordnance [3)4)] and for the state of the structure of the road on the model route.

These three elements that were ranked (accumulated freezing index, longitudinal grade, curve radius) were weighted according to the predicted frequency of traffic accidents to obtain the icing risk at which the maximum value was 100, and the icing risk was divided into five levels (A to E) to prepare a simplified icing risk ranking.

Table 5-3-1 Setting the Icing Risk Ranking

Accumulated freezing index \ Road structure		a_1	b_1	c_1	d_1	e_1
		(10)	(20)	(30)	(40)	(50)
C＜200	(5)	A(15)	B(25)	B(35)	C(45)	D(55)
200≦C＜300	(15)	B(25)	B(35)	C(45)	D(55)	D(65)
300≦C＜400	(25)	B(35)	C(45)	D(55)	D(65)	E(75)
400≦C＜500	(35)	C(45)	D(55)	D(65)	D(75)	E(85)
500≦C	(50)	D(50)	D(70)	D(80)	D(90)	E(100)

* Figures in ( ) represent icing risk.

Table 5-3-2 Longitudinal Grade and Curve Radius

Curve radius (m) \ Longitudinal grade (%)		i＜6	6≦i＜8	i≧8
		(5)	(15)	(25)
R＞100	(5)	a_1(10)	b_1(20)	c_1(30)
60＜R≦100	(15)	b_1(20)	c_1(30)	d_1(40)
R≦60	(25)	c_1(30)	d_1(40)	e_1(50)

* Figures in ( ) represent icing risk.

This icing risk ranking was applied to the model route to calculate the icing risk rank at 100 m intervals. And to simplify the machine spreading work now performed, the model route was grouped into fixed sections based on the icing risk rank to determine the spreading ranges by icing risk rank set for a total of 8 sections.

5-4. Preparation of the spreading maps

Spreading maps that show the quantity spread for each spreading range in the 8 sections were prepared based on the results of the processes in 5-2 and 5-3 so that it is possible to ultimately change the quantity spread in spreading range units. Figure 5-4-1 shows an example of a spreading map. The quantities spread for each spreading range were basically set by accounting for the icing risk for each spreading range to set each quantity as the most dominant spreading quantity within the spreading range from among quantities spread at 100 m intervals obtained by the short term air temperature prediction.

The spreading maps were prepared by inputting the minimum temperature at Muikamachi and preparing maps in 12 patterns according to the range of this minimum temperature.

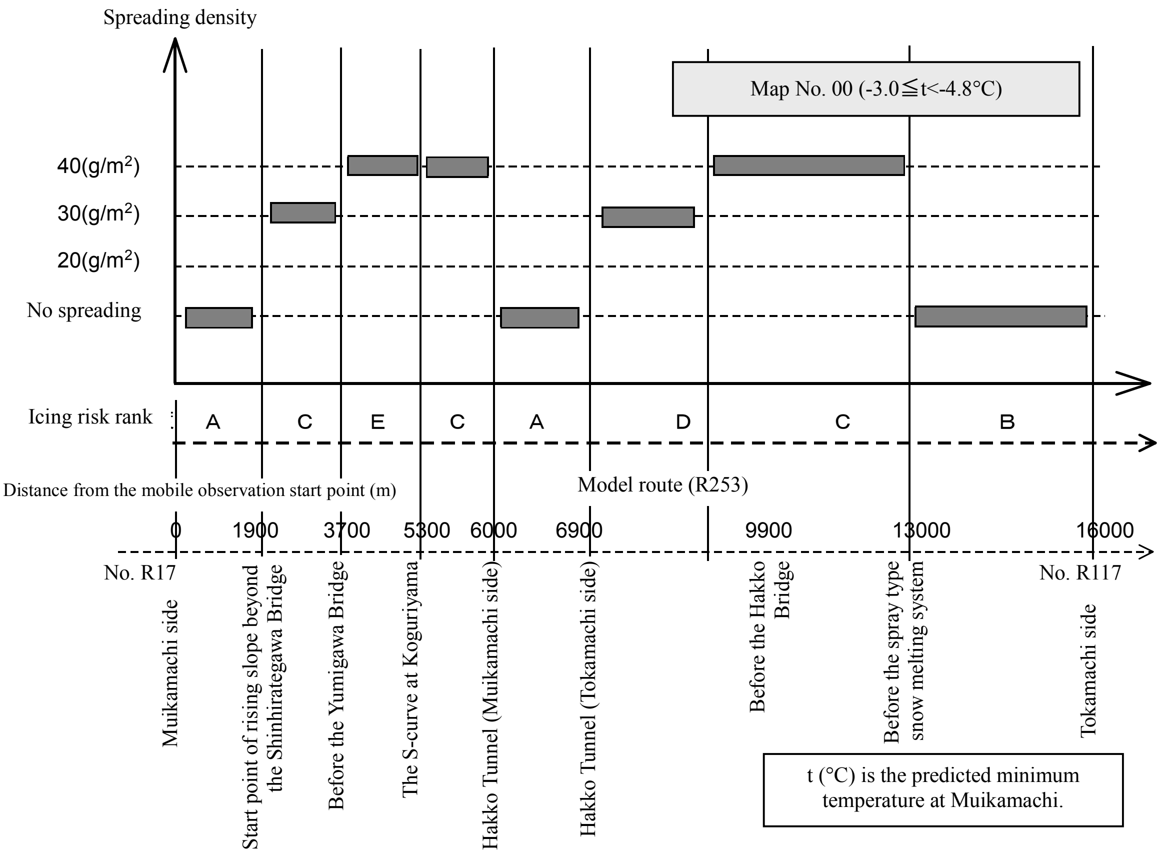

Figure 5-4-1 Example of a Spreading Map of the Model Route

6. Application of the spreading map

The spreading map for the advance spreading shows the quantities that should be spread within each spreading range on the model route. When performing advance spreading, it is important to make a long term prediction of the time when the temperature will fall to the freezing point and the temperature at that time in order to dispatch the spreading trucks at the correct time.

Because it is essential to obtain the predicted air temperature at Muikamachi in advance in order to choose the spreading map to be used for the spreading map based advance spreading work, the prediction used for this purpose was the long term air temperature prediction (24 hours) from the Nagaoka National Road Construction Office of the Hokuriku Regional Bureau of the Ministry of Land, Infrastructure, and Transport: the office that has supplied Muikamachi Public Works Office with meteorological data in the past.

Figure 6-1-1 is a flow chart of the chemical spreading map application procedure and Steps 1) to 6) below are an outline of the application process.

1) At 4:00 p.m., the management office (public works office) obtains the long term air temperature prediction.
2) A decision concerning the dispatch of spreading vehicles is made based on the time that the temperature will fall to the freezing point and the temperature it will reach at Muikamachi up to 9:00 a.m. the following day.
3) The spreading map is selected based on the predicted minimum air temperature at Muikamachi.
4) Spreading instructions are issued to the spreading contractor.
5) Spreading vehicles are dispatched (spreading work is done according to the spreading map)
6) Work reports are submitted to the management office (public works office) by the spreading contractors.

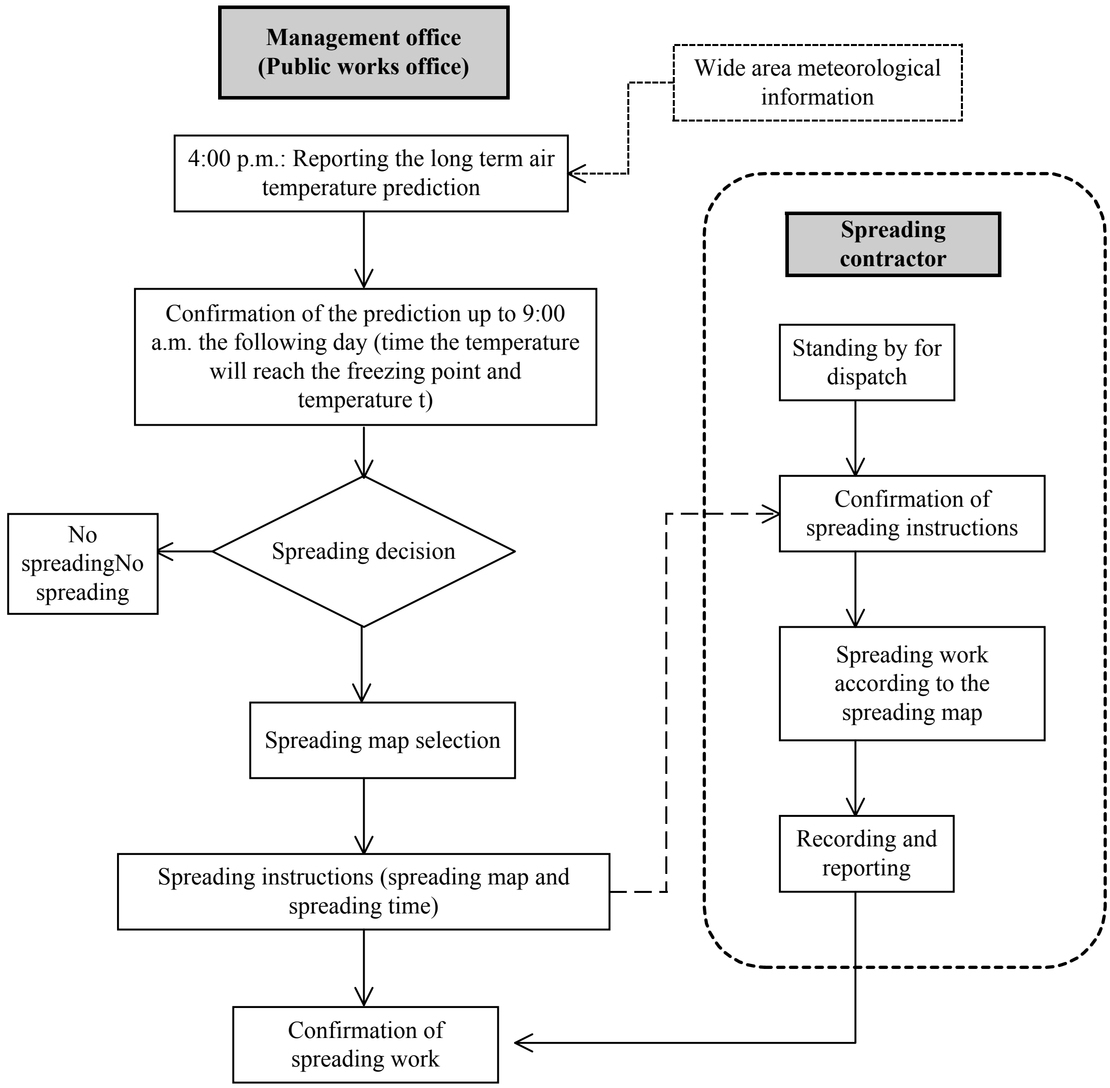

Figure 6-1-1 Flow Chart of the Application of an Anti-icing Chemical Spreading Map to the Model Route

7. Evaluation

7-1. Trial calculation of the quantity spread reduction effect

The results of a comparison of the quantity of anti-icing chemical spread on the model route from January until February 2000 with the amount obtained by a trial calculation of the quantity that would have been spread using the spreading map have shown that a reduction of 36% can be achieved by advance spreading, and that even when the total quantity including that spread during ex post facto spreading is compared, a reduction of about 14% is possible [5)6)]. Converting this result directly to the cost of anti-icing chemical throughout the prefecture (January and February 2000) reveals a cost saving of about ¥63 million.

This reveals that spreading performed based on anti-icing chemical spreading maps that reflect characteristics of the weather on a route and characteristics of the road can achieve efficient anti-icing chemical spreading.

7-2. Future challenges

Based on the results of this survey, it is possible to point out the following three tasks as challenges for the future. Present plans call for trial applications of spreading maps and surveys to continue.

1) Verification of the effects of applying spreading maps
   - Verification of icing prevention effects
   - Verification of the suitability of the icing risk ranking
2) Rationalization of spreading times
3) Establishment of feasible spreading work systems

8. Conclusions

The study obtained the following conclusions.

1) Icing risk locations were successfully linearly clarified based on accumulated freezing index obtained by performing a thermal mapping survey of the model route.
2) It has been concluded that it is possible to perform efficient anti-icing chemical spreading by carrying out advance spreading based on an anti-icing chemical spreading map that reflects the characteristics of the weather and of the road along a route.

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