EFFICIENT WINTER ROAD MANAGEMENT USING A CONTACT AREA INFORMATION SENSING (CAIS)-BASED ROAD SURFACE CONDITION JUDGMENT SYSTEM

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ABSTRACT

Plowing and salting are indispensable for providing safe, pleasant driving conditions in winter. However, excess salting adversely affects the structures. It is our mandate to realize efficient, effective expressway maintenance and to develop a system that reduces snow and ice control costs, including those of salting.

Our conventional salting depends on visual observations by experienced operators. Their assessments, while excellent, tend to be qualitative and to secure an excessive margin of safety. Toward quantitative winter road surface assessment on expressways in Hokkaido Japan, we developed the Road Surface Condition Judgment System (RSCJS) based on Contact Area Information Sensing (CAIS®) and we installed it on a patrol vehicle that is dispatched every 3 to 4 hours. Furthermore, we developed the Automatic Salting-Control System (ASCS). Using the data provided by RSCJS and stored in an online database, the ASCS varies the salting rate of the spreader to meet the road surface conditions.

In this study, the analysis was made on the effectiveness of the RSCJS in reducing salt application on expressways. Late-winter tests investigated whether the ASCS was able to localize salting to the snowmelt-wetted road sections. We report on a salt-reduction draft plan that enables salt to be applied only where necessary.

1. INTRODUCTION

In Hokkaido, the northernmost island and prefecture of Japan, cities are widely dispersed. Thus, expressways that link the major cities are indispensable for socioeconomic activities. Winter arrives earlier and snow stays on the ground longer in Hokkaido than elsewhere in Japan. Sapporo, the prefectural capital, is home to 1.82 million people, and the normal annual average snowfall is 630 cm. Among cities around the world whose population exceeds 1.5 million, Sapporo is exceptionally snowy and populous. To provide safe, pleasant driving conditions, snow and ice control, including plowing and salting, are indispensable for expressways.

Heavy salting is known to adversely affect structures. Eighteen percent the snow and ice control budget for expressways in Hokkaido is spent on salting. With the price of salt having risen in recent years, efficient and effective winter maintenance that affords reductions in expressway management and maintenance costs is necessary. There is an urgent call for a system that assists in snow and ice control cost reduction.

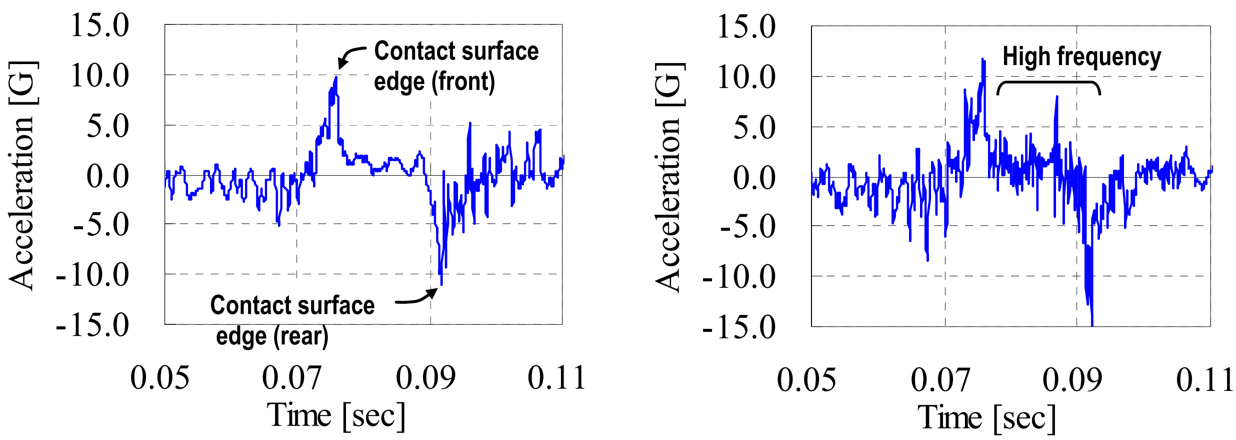
Salting operation has depended on visual observations by experienced operators. Their assessments are excellent but somewhat qualitative, and they tend to secure an excessive margin of safety. Toward quantitative winter road surface assessment, we installed the Road Surface Condition Judgment System (RSCJS) on a vehicle that is dispatched for patrol every 3 to 4 hours. Furthermore, we developed the Automatic Salting-Control System (ASCS), which automatically adjusts the salting rate according to the road surface conditions.

In this study, the analysis was made on the effectiveness of the RSCJS in reducing salt application on expressways. Late-winter tests investigated whether the ASCS is able to localize salting to snowmelt-wetted road sections. Finally, we report on a salt reduction draft plan that enables salt to be applied only where necessary.

2. METHOD

2.1 Road Surface Condition Judgment System (RSCJS)

Contact Area Information Sensing (CAIS®) is a tire-sensor-based technology that relies on analysis of the readings from the sensor installed in the rubber of the tire contact surface [1]. The acceleration waveforms of tire vibrations differ by road surface conditions (Figure 1). For dry pavement, low frequency is observed for acceleration waveforms of vibrations on the contact surface between tire and pavement, because the tread rubber of the tire is well gripped by the pavement, whereas for icy pavement, high frequency is observed, because frequent minute sliding of the tire along the road surface occurs even during normal driving. The RSCJS discriminates between the seven road surface conditions of dry, slightly wet, wet, slushy, fresh snow, compacted snow and icy by quantitatively analyzing acceleration waveforms captured by a sensor installed in the tire rubber (Figure 2). The results of road surface condition judgment and the road images are sent to a Web server from which real-time information is provided to organizations such as disaster prevention offices (Figure 3).



(a) Dry pavement (b) Icy pavement

Figure 1 - The tire circumferential-direction waveforms measured in the tire tread

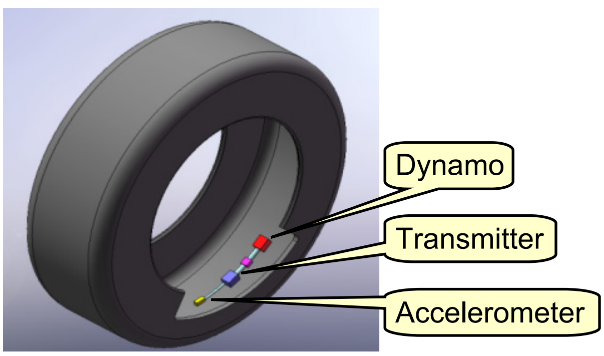


Figure 2 - Acceleration sensors installed inside the tire tread

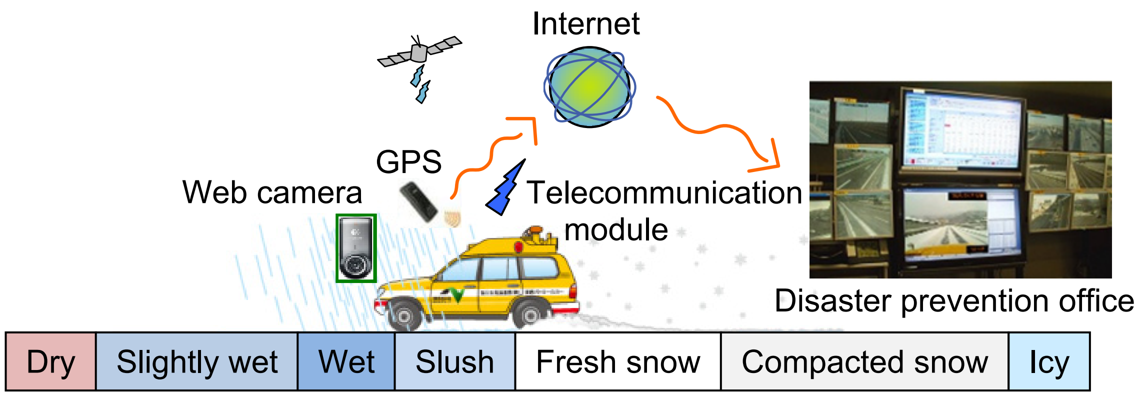


Figure 3 - Road Surface Condition Judgment System (RSCJS)

2.2 Automatic Salting-Control System (ASCS)

The ASCS consists of a database of information obtained by the RSCJS, a Web server, a device for automatically controlling the rate of salting by spreader, and an automatic salting-control software application. The spreader is equipped with the device for automatically controlling the rate of salting by spreader, a touch panel, and a GPS and telecommunication module (Figure 4). Automatic salting rate control is facilitated by the serial connection between the device for automatically controlling the rate of salting and the salting operation console of the salt spreader.

When leftover salt is kept in a spreader, the salt solidifies and causes problems for the spreading device and the next salting operation. This has been the reason for difficulties of real-time changes in salting rate by road surface condition. Either all the salt that is loaded in the spreader is applied to the road, regardless of need, or huge amounts of leftover salt are returned to the tank at the depot when localized salting is conducted in late winter. Consequently, toward varying the salting rate by road surface condition, it is necessary to accurately estimate the amount of salt to be loaded in the salt spreader.

With the ASCS, first a database of real-time road surface conditions is built with data obtained by a winter road patrol vehicle that is installed with an RSCJS and dispatched every three or four hours. Based on the road surface conditions provided by the data, a salting algorithm for the route is set. The amount of salt necessary for the route can be calculated by simple data input using the onboard touch panel of the salt spreader. The onboard device for automatically controlling the rate of salting by spreader varies the salting rate during operation on the expressway. The GPS-based vehicle location identification system identifies the vehicle location at every 100 m by kilopost. The system uses a preset salting algorithm to vary the salting rate every 100 m, for salting that is appropriate for the road surface condition. The system enables effective, efficient salting, because the amount of salt to be applied on expressways and thus to be loaded on the spreader is decided in advance, and all of the loaded salt is used, without any left over. Figure 5 is a schematic of the ASCS.

Figure 4 – Onboard device for automatically controlling the salting rate

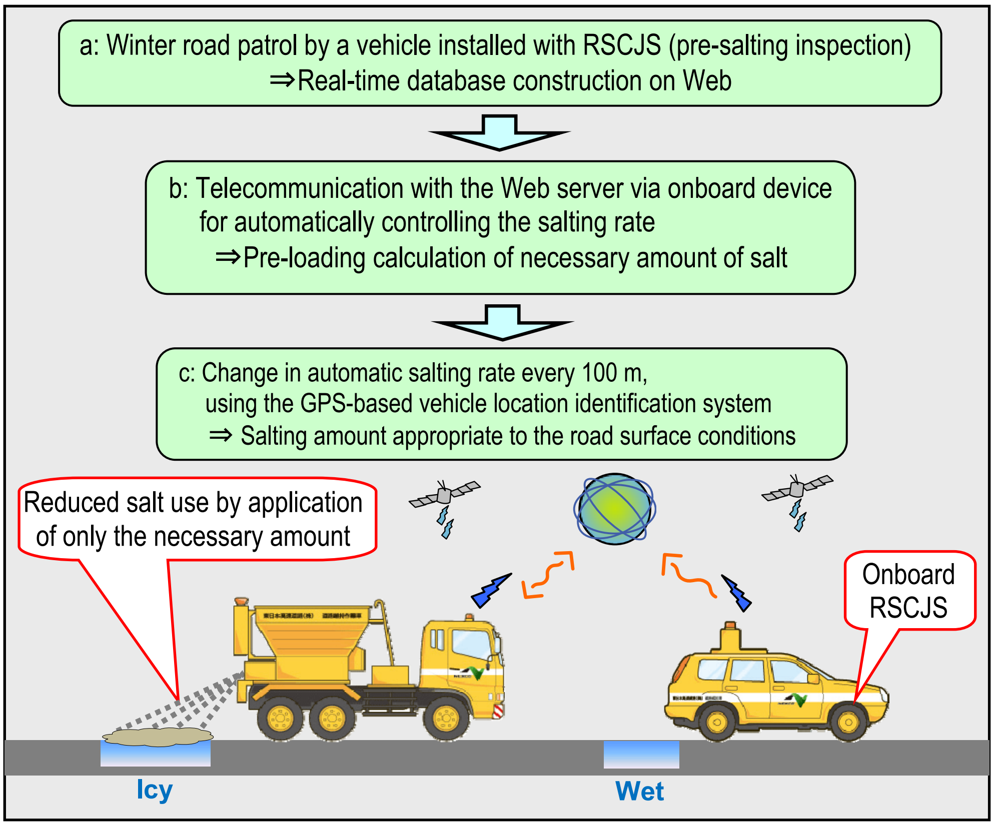


Figure 5 - Schematic of the ASCS

3. RESULTS

3.1 Analysis on the effectiveness of the RSCJS

3.1.1 Road surface conditions Web viewer

The real-time data of road surface condition judgments obtained by the onboard RSCJS are sent by the system to a Web server to build a database of road surface conditions. We developed Web viewer software that displays the latest road surface condition judgments and road images on GIS maps (Figure 6). The seven road surface conditions (dry, slightly wet, wet, slushy, fresh snow, compacted snow, icy) are indicated by color on the map. The Web viewer software application is used to display specifications and road images.

By providing the latest data and images of road surface conditions, the system supports rapid decision-making on winter maintenance.

Figure 6 - Windows of the Web viewer software

3.1.2 Diagram of road surface conditions

Figure 7 shows a diagram of road surface condition judgments (hereinafter: road surface diagram (RSD)) whose horizontal axis gives the location on the expressway by kilopost (hereinafter: KP) and whose vertical axis gives time (from top to bottom). The diagram is developed to visualize the detailed changes in the road surface conditions by KP, and the temporal changes in road surface condition for each 100-m section. The diagram is automatically made from the database built into the Web server, and it can be utilized for securing good road surface conditions by the time of peak traffic hours. On January 25 (Figure 7), the road surface was icy between 2:00 and 3:00 at around KP32 - KP67. Then, salting was done. The diagram shows that the road surface became "wet" by 9:00 to 10:00. It is easy to confirm the effects of snow and ice control operations by the diagram. In addition, the diagram facilitates quick decision-making on additional salting and other operations.

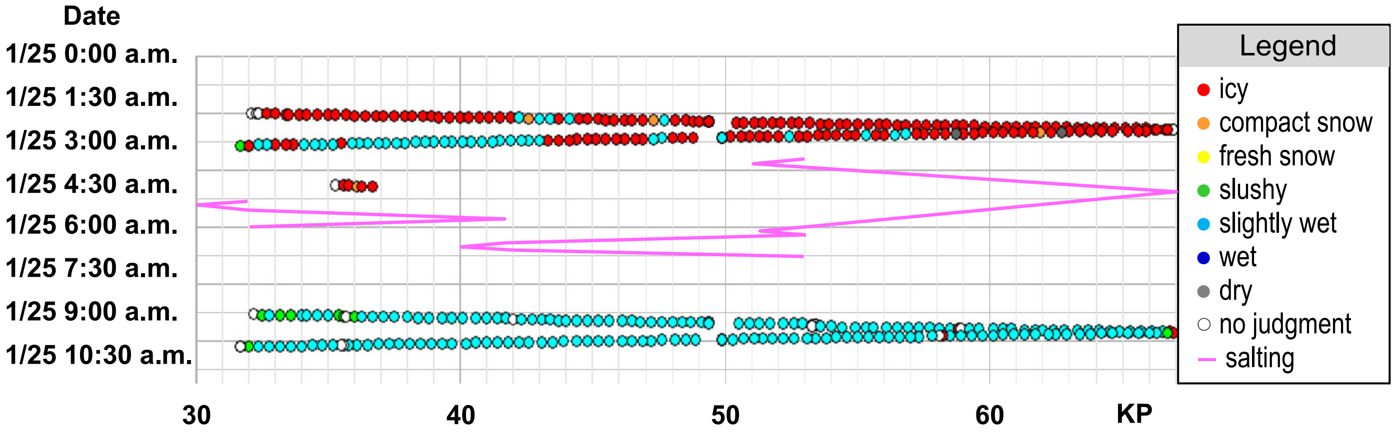


Figure 7 - Road surface diagram (RSD)(January 25, 2013)

3.1.3 Comparison of road surface condition discrimination:
Winter road patrol records vs. RSCJS

Figure 8 compares the road surface condition judgment results obtained from observation records by winter road patrol to the road surface condition judgment results obtained by the RSCJS. Conventionally, information on road surface conditions has been shared as winter road patrol records. Each road section is named according to a distinguishing feature (e.g., interchange, service area, tunnel). The road surface condition is recorded for each section. The road surface condition of the site that is considered to be the most dangerous in each 5-km section is recorded as the road surface condition of that section. Consequently, at a given location, the actual road surface conditions do not always correspond to the recorded road surface conditions.

The RSCJS provides road surface conditions by sections that are each 100 to 500 m in length. It provides much more precise information than the conventional method does. Because the road surface condition judgment by the RSCJS is for much shorter sections of expressway than with the conventional method, they correspond more closely to the actual road surface conditions than those given by the conventional method; thus, salting using the RSCJS can be done much more appropriately than that using the conventional method, which tends to secure an excessive margin of safety.

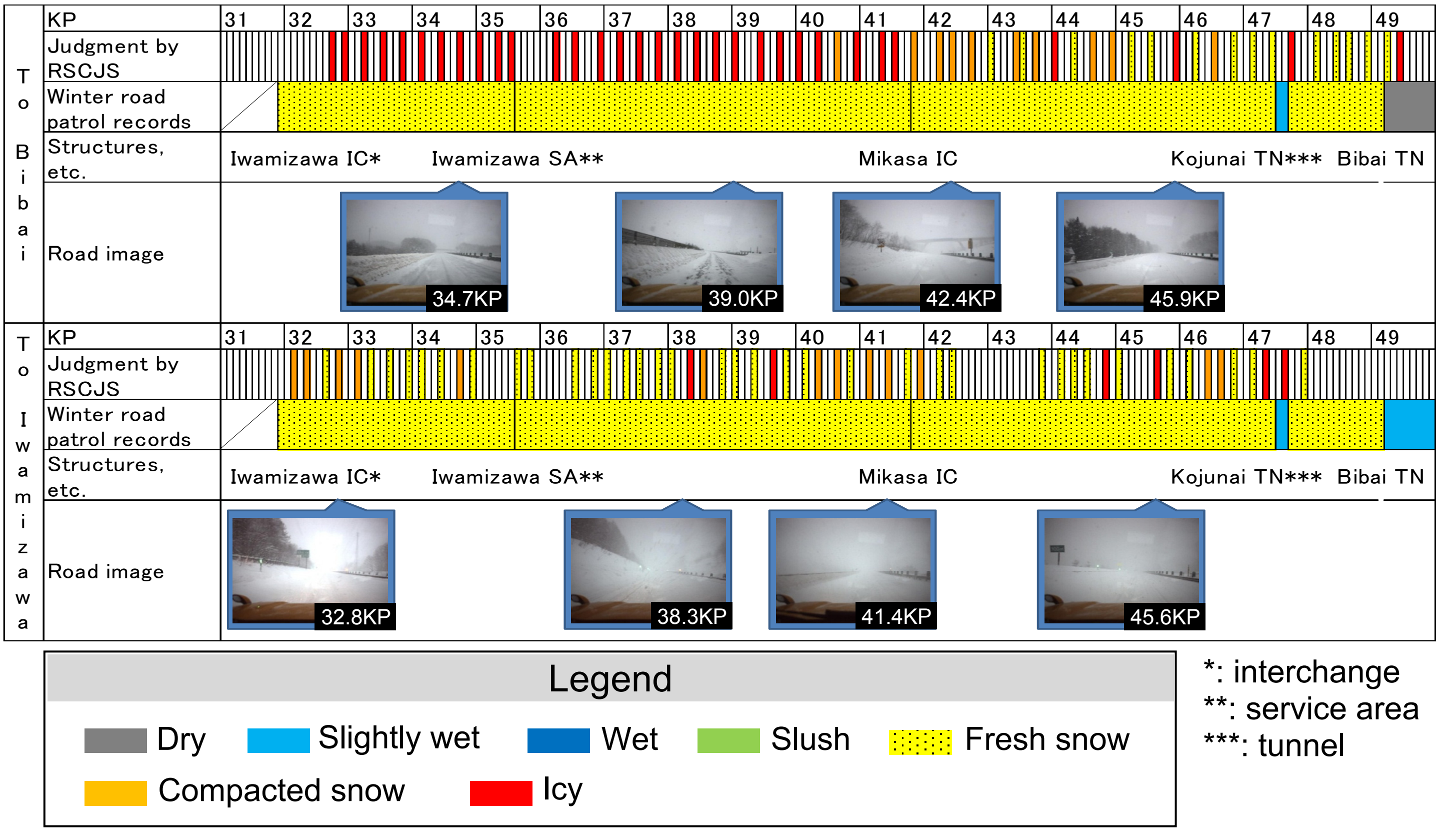


Figure 8 - Comparison of discriminations of road surface conditions: winter road patrol records vs. RSCJ System

3.2 Field test of the ASCS in late winter

3.2.1 Outline of the field test

For salting of expressways in Japan, wet salt is used. The wet salt is made by adding solid sodium chloride to a sodium chloride solution. When applied, it is watery and like salty slush. Highly adherent, it affords quick and continuous anti-freezing. Because wet salt is not prone to dispersal by wind, it is superior to the application of either solid salt or salt brine. To reduce the salt application amount, it is necessary to achieve appropriate salting by adjusting the salting rate and the mass ratio of “salt brine” to “salt brine and solid salt."

We made a late-winter field test to verify the effectiveness of the ASCS. In the test, salting was done along an expressway section where there were some locations of pavement wetted by snowmelt from nearby snow piles. First, a winter road patrol vehicle equipped with the RSCJS traveled on the expressway to identify the locations of snowmelt-wetted pavement. Then, the salt spreader equipped with the ASCS operated on the expressway to apply salt only where necessary. The test was made for three days. Three items were verified:

a: Whether salt was applied only to the wet pavement sections
b: How much salt was applied with the ASCS
c: How the ASCS compared to visual-observation-based salting decision-making

3.2.2 Salting conditions for the test of the ASCS (local application)

Figure 9 shows the salting conditions by the ASCS for the local application test. Although various salting conditions can be set for the ASCS, in this test, we selected a simple condition in which salt was applied only when the road surface was slightly wet or wet.

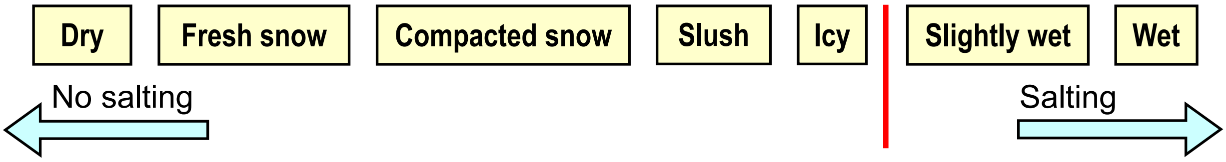


Figure 9 - Salting conditions for the test of the ASCS (local application)

3.2.3 Flow of salt application

Figure 10 shows the flow of salt application. A GPS-based vehicle location identification system gives road surface conditions and the salt application details for every 100 m based on KP. To secure a safety margin, when the slightly wet or wet surface conditions are detected in a 100-m section from the input data, that section and the two adjoining sections are set as the target of salting. This means that salt is applied to three 100-m sections: the section with snowmelt-wetted pavement, and the section on each side. The following are the settings of the salt spreader:

a: March 27: 2-lane expressway; salting rate: 15 g/m^2; salting width: 5 m; (salt brine)/(salt brine + solid salt) mass ratio of 15%

b: April 4: 2-lane expressway; salting rate: 15 g/m^2; salting width: 5 m; (salt brine)/(salt brine + solid salt) mass ratio of 20%

c: April 10: 4-lane expressway; salting rate: 15 g/m^2; salting width: 8 m; (salt brine)/(salt brine + solid salt) mass ratio of 29%

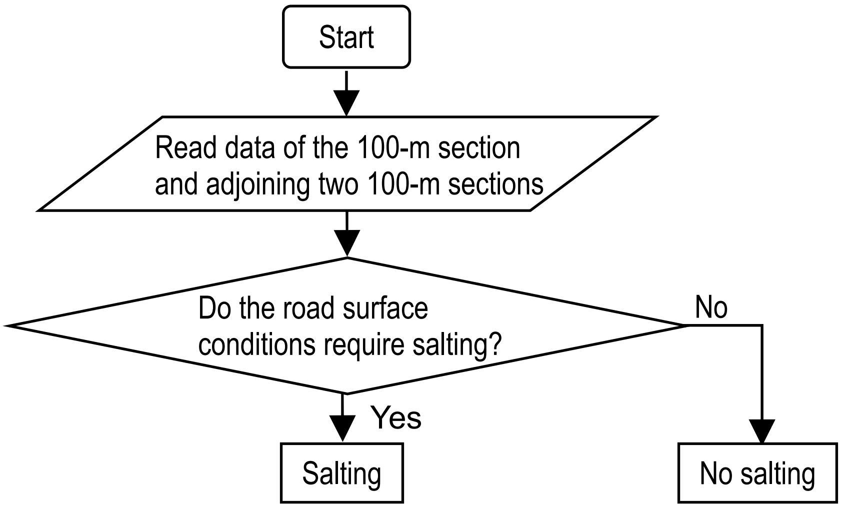


Figure 10 - Flow of salt application

3.2.4 Results

1) Local application

The locations of snowmelt-wetted pavement identified by the RSCJS were salted using the ASCS according to the salting flowchart. It was confirmed that salt was properly applied only to the identified locations in all three tests. Figure 11 shows the ASCS in use.

Figure 11 - Salting with the ASCS

2) Amount of salt applied by the ASCS

Table 1 compares the amount of salt calculated by the ASCS to be applied and that actually applied. The ASCS calculates the amount of salt to be applied based on the salting width, rate and distance. The actual application amount is calculated based on the screw speed of the spreader and the specific gravity of the salt applied. The results confirm that the calculated amounts of salt by ASCS are nearly the same as the actual application amounts.

Table 1 - Comparison of the amount of salt calculated by the ASCS and that of actual application

Test date	Road surface condition: Total length of expressway subject to salting over the length of test section (%)	The amount of salt calculated by the ASCS	Actual application amount
March 27	Wet: 7.6 km (19%)	0.485 t	0.500 t
April 4	Wet: 2.3 km (6%) Slightly wet: 1.5 km (4%)	0.228 t	0.250 t
April 10	Wet: 0.5 km (1%) Slightly wet: 2.2 km (5%)	0.230 t	0.242 t

3) Comparison of salting operation: ASCS vs. salting decision by visual observation

The correspondence between the salt application details for the ASCS and for visual observation was verified using the data of April 4. After salting by the ASCS, salting by visual observation decision was done on the same expressway section for the purpose of comparing the application amounts between the two methods. Table 2 shows the comparison.

The amount of salt applied by the ASCS as calculated according to the flow of salt application (Figure 10) was slightly greater than that by visual observation. This is because the additional 100-m sections at each end of the section with wet surface were also salted by the ASCS. If salt were applied only to the 100-m section where the pavement was wet, the salting amount by the ASCS would be 0.132 ton less than that for visual observation. When additional salt was applied only to the 100-m section preceding the section with wet surface, the salting amount by ASCS was nearly the same as that for visual observation. This is because experienced operators know that applied salt is carried in the direction of vehicle travel by wind pressure generated by passing vehicles, and they spread salt slightly preceding the sections where salting was needed. Consequently, the amount of salting by the ASCS will meet that by experienced operators by setting salting application for the sections with wet surface and the sections 100-m preceding those sections.

Table 2 - Comparison of salting operation:
ASCS vs. salting decision by visual observation

Visual observation	ASCS	
0.178 t	0.228 t	Calculated by following the flow of salt application (additional salt application on 100-m sections preceding /following the sections with wet surface)
	0.132 t	Salting of only the 100-m sections with wet surface
	0.186 t	Additional salting on the 100-m sections preceding the sections with wet surface

3.3 Salt-reduction plan

3.3.1 Salting application details

To reduce the salt application amount, it is necessary to salt appropriately by changing the salting rate and the wet salt mass ratio of “salt brine” to “salt brine and solid salt." Figure 12 shows salting conditions (draft plan) that meet the road surface conditions. The salting application details for icy and compacted snow surfaces are set as the same as those for the conventional method (salting rate: 20 g/m^2; wet salt’s mass ratio of “salt brine” to “salt brine and solid salt: 29%), while no salt applied on dry or fresh snow surfaces because the effect of salt on such surfaces is small. Because of the greater amounts of water on slushy, slightly wet or wet surfaces than on compacted snow or icy surfaces, decreased salting rate and wet salt mass ratio of “salt brine” to “salt brine and solid salt" can be applied.

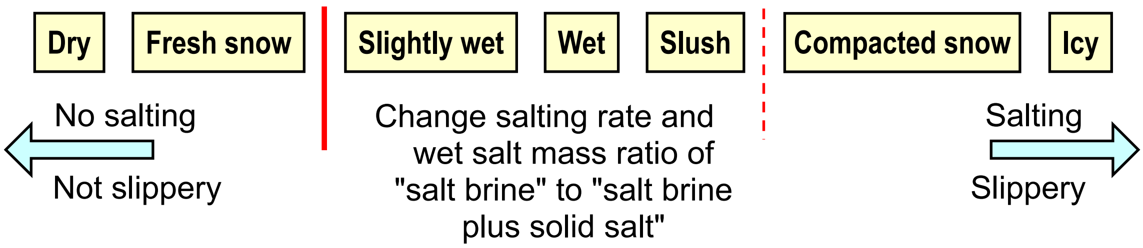


Figure 12 – Salt application details that meet the road surface conditions (draft plan)

3.3.2 Settings for appropriate salt application details

Table 3 shows the setting of salt application details that meet the road surface conditions (draft proposal). The amount of solid salt was set as the same as that for conventional salting, while salt brine was reduced according to road surface condition, because under the "slightly wet" condition, the surface of drainage pavement is only slightly wet. Thus the amount of solid salt application was reduced.

Table 3 - Setting of salt application details
that meet the road surface conditions (draft plan)

Road surface condition	Dry	Fresh snow	Slightly wet	Wet	Slushy	Compacted snow	Icy
Salting rate	n/a	n/a	15 g/m^2	15 g/m^2	18 g/m^2	20 g/m^2	20 g/m^2
Solid	n/a	n/a	12.0 g	13.8 g	14.0 g	14.2 g	14.2 g
Solution	n/a	n/a	2.5 m^3	1 m^3	3.3 m^3	4.8 m^3	4.8 m^3
Mass ratio of “salt brine” to “salt brine and solid salt"	n/a	n/a	20%	8%	22%	29%	29%

3.3.3 Road surface diagram (RSD) of road surface with snow/ice

Figure 13 shows a RSD from 14:00 to 15:30 on February 15, 2013. Simulations were made on the amounts of salt to be applied by conventional full-length application versus those amounts under the draft plan of appropriate salt application details (Table 3). Table 4 shows the simulation results. When the road surface is icy or compacted snow, the amounts of salt application by both methods are nearly the same. However, when a large proportion of the road section is dry, salt reduction can be expected by salting only where necessary, using appropriate salt application details.

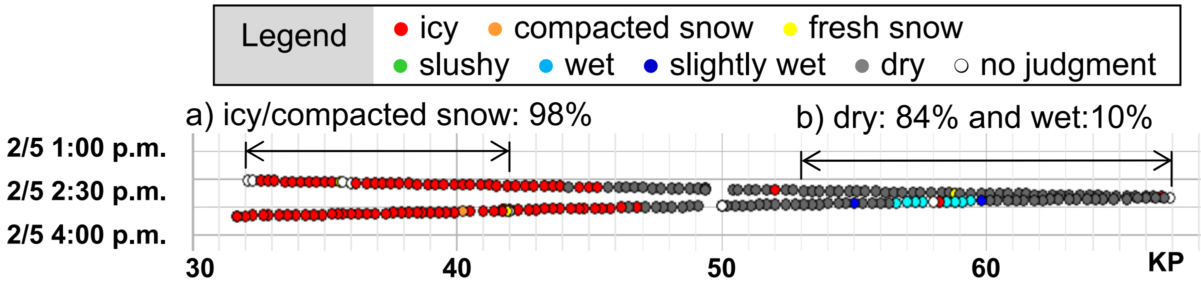


Figure 13 - Road surface diagram (February 5, 2013)

Table 4 - Comparison of simulated salt application:
full-length salting vs. salting only where necessary

Rd. sec.	Date	Time	Section	Actual salt application amount		Calculated salt application amount		Road surface condition	Comparison
				Solid	Brine	Solid	Brine		
a	2/5	2:00-3:30 p.m.	KP32 to 42	2.2 t	0.8 m^3	2.0 t	0.7 m^3	Icy	No difference, because most of the section was ice/compacted snow
b			KP53 to 67	3.1 t	1.1 m^3	0.6 t	0.1 m^3	Dry, partly wet	Great reduction in salt application, because salt is applied only where necessary, as a result of the high proportion of dry road surface

4. CONCLUSION

The study findings are summarized here.

(1) The RSCJS is an effective snow and ice control support system.

(2) By identifying the locations of snowmelt-wetted surfaces by RSCJS and by conducting automatic salting using the ASCS, it was confirmed that only the wet surface sections and the sections preceding/following wet surface sections would be salted. Consequently, these systems were proved useful.

(3) The salt amount calculated by the ASCS for application is nearly the same as the actually applied amount. When adopting a salting algorithm whose safety margin calls for salt to be applied to the 100-m sections preceding the sections with wet surface, in addition to the sections with wet surface, the salt application amount is the nearly the same as that by visual-observation-based application by experienced operators.

(4) The simulations of full-length salting and salting only where necessary show that there is no difference in the amount of salt use between them when the road surface is icy or compacted snow; however, when the road section has a high proportion of dry surface, salt reduction can be expected from salting only where necessary.

The method of applying localized salting to snowmelt-wetted road sections and appropriate salting where necessary follows the same salting algorithm with different salt application details. Because the field test of localized salting on snowmelt-wetted road sections proved to be effective in reducing salt application, it is possible to achieve appropriate salting where necessary by changing the salting rate and the mass ratio of "salt brine" to "salt brine and solid salt" to meet the road surface conditions.

By capturing road surface conditions in more detail, our future study will optimize the ASCS based on experienced operator's decision criteria, such as 1) the salting rate that is appropriate for each surface condition, 2) the salting length that is appropriate for the road structure conditions and 3) the setting of appropriate mass ratio of "salt brine" to "salt brine and solid salt."

REFERENCES

1. H. Morinaga, Y. Hanatsuka and Y. Wakao. 2006. Sensing technology tire system for road surface condition judgment. *FISITA 2006 Transactions, Vol. F2006 V104*.