A STUDY ON USE OF QUANTITATIVE INDICATOR TO SUPPORT THE IMPROVEMENT OF WINTER ROAD MANAGEMENT

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ABSTRACT

With an aim to propose efficient winter road service in view of the recent financial constraints in Japan and characteristics of snowy cold regions, the authors in this study conducted desk research to investigate into reports from Japan and other countries regarding criteria for winter road surface management, methods for quantitative assessment of winter road surface, and utilization of quantitative assessment results. Using the research results, the authors also conducted experiments for comparing the friction measurements taken by various testers. The characteristics of these testers and their measuring accuracy were examined. Furthermore, a Continuous Friction Tester (CFT) was used for monitoring friction on winter road surfaces in the city of Sapporo. Additionally, a tool for providing information was developed to support decision-making with regard to winter road management, and the tool was tested through information service to road maintenance supervisors and operators. Lastly, accumulated data on weather conditions and monitored friction values were used to analyze the characteristics of friction on winter road surface for the purpose of studying the usability of these data to develop a feedback tool that supports performance evaluation of winter road service and decision-making on long-term road management.

1. INTRODUCTION

In order to ensure efficient and effective surface management as part of winter road service in snowy cold regions, decisions should be made on the basis of accurate understanding of surface conditions. The authors worked on (I) ~ (IV) below with an aim to propose criteria for the management and maintenance of winter road surface, the criteria that are appropriate for snowy cold regions in Japan.

(I) Review of the reports from Japan and other countries regarding criteria for winter road surface maintenance and methods for assessing road surface friction.

(II) Comparative experiments using a CFT and others testers were conducted to evaluate the characteristics and measuring accuracy of each tester.

(III) Monitoring of friction with the CFT on a section of a NH in Sapporo in winter; development of a tool for providing information useful to adequate and swift decision-making regarding winter road surface management; and supply of information on a trial basis to supervisors and maintenance workers of road surface maintenance operations.

(IV) Analysis of the characteristics of skid on the above-mentioned road section using the data accumulated in (III) above regarding weather conditions, friction, and winter road maintenance operation. The aim of the analysis is to study the usability of these data for a feedback tool that supports performance evaluation of winter road service and decision-making on long-term road management.

The results to date of the research outlined above and the future prospects are described below.

2. WINTER ROAD SURFACE MANAGEMENT CRITERIA AND METHODS FOR ASSESSING FRICTION IN JAPAN AND OTHER COUNTRIES

2.1. Winter road surface management criteria

Literature review was conducted for understanding management criteria of winter road surfaces in Japan and other countries. The management criteria are roughly divided into the following four types which are respectively predominant in Japan, Europe (where either qualitative or quantitative criteria are adopted) and North America.

2.1.1 Japan

In the management criteria used in Japan, a targeted state of road surface condition (e.g. dry, slushy, or compacted snow) that should be attained through maintenance operation is determined for each road type. For example, national highways in Hokkaido are managed on the basis of the goals which have been set for the surface conditions that should be maintained at predetermined time of day according to the traffic volume and the surrounding condition (i.e. urban, suburban or mountainous area) of each road section[1]. Road surface conditions have been classified into 14 types: Dry or wet surface and 12 types of snow and ice covered surface. In order to ensure that this classification is correctly understood, a table showing the criteria of each road surface type is made available. The criteria include existence of snow/ice, glaze of the surface, tire tread marks on the surface, color of snow, and thickness of snow covering.

2.1.2 Europe

Snow and Ice Data Book [2] of Permanent International Association of Road Congresses (PIARC) shows that roads are classified into three or more types in many European countries and that management goals are set according to the traffic volume and the road structure of each road type. The details of the winter road surface management criteria vary country by country. For example, Denmark and Estonia have qualitative criteria. In these countries, targeted results of maintenance operations are clearly specified for each road type, and compacted snow on the surface is accepted in some road types of low importance. Estonia has four levels of management criteria which are applied to maintenance operation according to road types and average daily traffic (ADT). For instance, the highest level of the management criteria is applied to highways for exclusive use of cars and arterial roads with ADT of 8,000 or more vehicles. The surface of these roads should be free of snow and ice 24 hours a day. In Denmark, target service levels should be reached within maximum allowable hours. Countries such as Austria, Belgium and Germany do not have strict standards for road surface conditions that need to be maintained. In these countries, winter road maintenance procedures (i.e. methods and time of day for implementing maintenance work, and hours of day in which certain road surface conditions should be maintained) are determined according to road types, weather conditions or traffic conditions. On the other hand, four North European countries (i.e. Finland, Norway, Iceland and Sweden) use quantitative criteria that are based on road surface friction. In Sweden, surface maintenance levels applicable to road sections are determined on the basis of annual average daily traffic (AADT). These four countries have been using accelerometers for measuring friction, but they have been working to introduce new devices such as non-contact measuring device in recent years.

2.1.3 North America

In North America (i.e. the U.S. and Canada), detailed criteria such as those used in North European countries have not been set, mainly because in principle winter surface management is implemented for maintaining bare pavement [3]. Road surface friction is also measured in North America, but there are no unified standards regarding measuring methods and devices because measurements are taken only for the purpose of confirming whether bare pavement is maintained or not.

2.2. Techniques for measuring friction

Techniques for measuring friction of road surface in Japan and other countries are reviewed below according to the types of measurement principles.

2.2.1 Measurement of stopping distance after sudden braking

Measurement of road surface friction on winter started in the 1940s in various countries for the purpose of confirming safe conditions of airport runways [4]. Friction is calculated on the basis of the stopping distance and the amount of time required for a heavy truck, loaded with sand traveling at a speed of 30km/h, to stop after sudden braking.

2.2.2 Measurement of locked wheel friction

In Japan, the former Ministry of Construction (now the Ministry of Land, Infrastructure, Transport and Tourism) introduced LWFTs which are now used as standard devices for measuring friction of the road surface in road management operation. LWFT is a test vehicle equipped with a measuring wheel as the fifth wheel (Photo 1). The vehicle travels at a constant speed with the measuring wheel being locked and following the road surface under a certain load. The friction coefficient is calculated from the ratio of the friction during travel to the load applied. Although values obtained with this measuring method are highly reliable, major alterations necessary for a vehicle to serve as a test vehicle are very costly. Additionally, LWFTs are not available for continuous measurement of friction because measurements are taken each time when the measuring wheel is locked.

Photo 1 - LWFT and its measuring wheel

2.2.3 Measurement with an accelerometer

Friction of the road surface is also measured with an accelerometer. A vehicle equipped with an accelerometer travels at a constant speed and is suddenly stopped by applying sudden braking for one second at a point of measurement. The friction is calculated from the braking deceleration (Figure 1). The advantages in using an accelerometer include reasonable cost of the device and non-necessity of refurbishing a vehicle for measurement. Use of an accelerometer has some disadvantages, too. For example, measurement results are sensitive to differences of drivers and vehicles, accelerometers are not suitable for use in road with a lot of traffic, measurements are taken from point to point and not continuously in a road section, and measurement values are affected by road gradients [5].

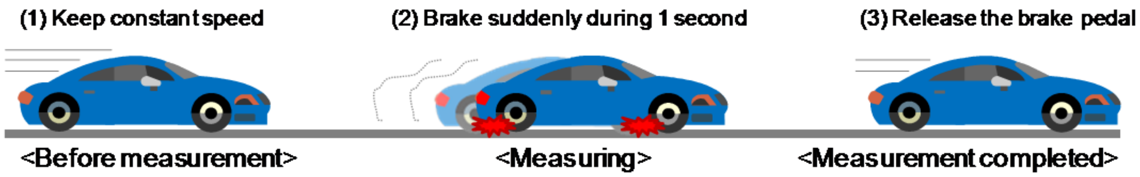

Figure 1 - Measurement principle of the accelerometer

2.2.4 Measurement using slip ratios

When there is a disparity between the traveling speed of a vehicle and the rotational speed of its tires, the slip ratio is affecting the friction coefficient of the road surface [6]. Tires rotating freely have a slip ratio of 0% and locked tires have a slip ratio of 100%. A constant slip ratio or a variable slip ratio is used for measuring friction. Traction Watcher One (TWO) is a device that utilizes a constant slip ratio (Photo 2). TWO has two measuring wheels. One of them rotates slower than the other one, and the friction of the slowly-rotating wheel is used for calculating a friction coefficient. This device is available at a relatively reasonable cost, but improvement is desirable because the current model needs to be equipped with special tires which are manufactured exclusively for this device. Road Analyzer and Recorder (RoAR) Mark III and Optimum Surface Contamination Analyzer & Recorder (OSCAR) used in Norway take measurements by using variable slip ratio. RoAR Mark III can take measurements traveling at a speed of 20~130 km/h, and it can be either used as a stand-alone device or towed by a vehicle. But this device is very expensive.

Photo 2 - Traction Watcher One (TWO)

2.2.5 Measurement using side force

When the tires of a vehicle are rolling in the same direction as the direction that the vehicle is traveling toward and external force is acting on the tire's ground contact area at a right angle to the traveling direction, side force works to resist the external force. The friction coefficient is calculated from the ratio of this side force to the wheel load. Specifically, a slip angle is applied to the measuring wheel, and the side force acting on the wheel while traveling is measured.

A typical device utilizing side force for measurement is Sideway-force Routine Investigation Machine (SCRIM) developed in the U.K. [7]. The measuring wheels are mounted mid-vehicle, in both the nearside and offside wheel paths, at a slip angle of 20 degrees to the direction of travel. Continuous measurement is possible with SCRIM, but the test vehicle needs to be large enough to resist large side force acting on the measuring wheel. Additionally, it is necessary to reinforce the vehicle body and the part of the body where measuring instrument is installed to make them robust, and thus the test vehicle quipped with SCRIM is very expensive.

CFT (Photo 3) has a rotatable measuring wheel set in a frame, and it takes measurements while being towed by a vehicle. Because the slip angle is as small as 1 ~ 2 degrees, neither the measuring instrument nor the towing vehicle needs to be large. Friction values obtained by CFTs are called Halliday Friction Numbers (HFNs) as Halliday is the name of a person who developed CFT. The state of no side force when a measuring wheel is spinning free is expressed as HFN: 0. HFN is 100 when side force is acting on the measuring wheel on the dry pavement surface with a surface temperature of −17.8 ° C. HFNs are expressed as integers on a scale of 0 to 100. More than seventy CFTs are being used in Sweden, Japan and some regions in North America as of June 2012. Continuous measuring at a sampling rate of 10Hz is available with a CFT while traveling. However, a change in the steering angle of the towing vehicle affects the slip angle of the measuring wheel and thus the measurement results are also affected. This is a disadvantage of CFTs that measure side force acting on the measuring wheel. In measuring with a CFT, friction of the road surface is measured with a steering angle variable within a range of ±14, and measurement results are corrected for the influence of the variation in the steering angle.

Photo 3 - Continuous Friction Tester (CFT)

2.2.6 Measurement using tire vibrations or vehicle behaviours

Computerized control technologies for vehicles have been greatly advanced in recent years, and many sensing devices are used for monitoring and controlling vehicle behaviours during travelling. Technologies have been also developed for evaluating road surface conditions on the basis of tire vibrations, minor load on tires, or vehicle behaviours. For example, because tires are the only parts of a vehicle that are in contact with the road surface, research and development has been conducted to use tires with sensing function to determine road surface conditions. Specifically, waveform characteristics of tire vibrations are utilized [8]. Many efforts that have been made to research and develop new technologies include R&D of a Multi-axial Sensing System (MASS) vehicle that is available for detailed measurement of the triaxial force acting on the interface between a tire and the road surface and the brake force during braking [9]. Technologies have been also developed for sending information on ABS's actuation from traveling vehicles to a server. The current and past information on ABS's actuation in the area where these vehicles are traveling is used for warning drivers approaching the area of risks of skidding accidents [10].

In order to evaluate road surface conditions by using a vehicle with sensing features, the vehicle needs to be specially built and be equipped with instruments for accurate measurement of vehicle behaviours. This type of vehicle is not actually used yet, because accuracy of the evaluation using such a vehicle has not been fully verified. Development of versatile technologies is desirable.

2.2.7 Measurement using non-contact sensors

Non-contact sensors have been developed in recent years. With these types of sensors, it is not necessary to depend on the force acting on the interface between tires and the road surface for measurement, nor require a test vehicle to travel for measurement. Measurement is possible with a standing test vehicle. The sensors developed for this purpose utilizes near infrared rays (Photo 4) [11], visible light [12], or a microwave radiometer [13]. A measuring device utilizing near infrared rays was tested in the ROADIDEA project in Europe, and the test results showed a consistency with the values obtained by accelerometers [11]. Introduction of this device is considered in Europe and the U.S.

Photo 4 - Non-contact sensor utilizing infrared rays

3. COMPARATIVE STUDY OF FRICTION MEASURING DEVICES

Based on the review results described above, researchers at CERI conducted comparative tests in January 2013, using the LWFT, a standard tester for measuring friction of the road surface in Japan, a CFT and a non-contact sensor (IR), for the purpose of examining the characteristics and measurement accuracy of the CFT and the IR.

3.1. Outline of the comparative testing

Comparative tests of the measuring devices mentioned above were conducted at Tomakomai Winter Test Track of CERI. In addition to the dry surface of the straight road section, wet, compacted snow and thin ice covered conditions were artificially created (Photo 5). The test vehicle travelled under each of these surface conditions, and road surface conditions were evaluated by each of the devices. The dry road section (L = 600 m) was paved with fine gap-graded asphalt concrete.

Photo 5 - Surface conditions prepared in the test track

For creating wet surface condition in a road section (L = 600 m), a sprinkler truck sprinkled the dry surface with water to a thickness of 0.5~1.0 mm. The road section covered with compacted snow (L = 400 m) was created by covering snow to a thickness of 15 cm (flatness: 20 mm). The snow was compacted by 300 vehicles traveling on the surface. The road section covered with thin ice (L = 600 m) was prepared by sprinkling water when the temperature fell to the freezing point. The ice was 0.5 ~ 1.0 mm thick.

On the day of the comparative testing, it was mostly fine and occasionally cloudy, air temperatures were -4.5 ~ 1.5 °C, and road surface temperatures were -11.0 ~ 8.0 °C. Each of the test vehicles travelled at a speed of about 40 km/h while taking measurements. The measurement items were friction coefficients (μ), friction values (HFN), air temperature, road surface temperature, surface conditions, and time of day.

In the testing with the LWFT, hard braking was applied to the measuring wheel for one second at predetermined points along each road section to measure friction coefficients. The test vehicles equipped with the CFT or the IR took measurements continuously along each road section. In order to compare the measurement results with values obtained by the LWFT, values at predetermined points were marked.

3.2. Test results

The LWFT, CFT and IR respectively obtained 68 sample values in the comparative tests. The measurement values are shown in Table 1 in terms of the basic statistics according to measuring devices and surface conditions. Figure 2 is a box plot of the same data. Regarding the LWFT, the average values (μLWFT×100) were between 21 on the thin-ice-covered surface and 79 on the dry surface. The average values (HFNs) obtained with the CFT were between 50 on the thin-ice-covered surface and 92 on the wet surface. The IR's average values (μIR×100) ranged from 11 on the compacted snow to 82 on the dry surface. The LWFT's measurement values regarding compacted snow showed the largest standard deviation. This result was obtained probably because snow was not uniformly compacted. Regarding the IR, arithmetic processing was performed within the sensor, which caused a time lag of 4 to 7 seconds in data output in comparison with the CFT (Figure 3).

Table 1 - Basic statistics of measurement results

Surface condition	Dry			Wet			Compacted Snow			Thin Ice		
Devices	LWFT (μ×100)	CFT (HFN)	IR (μ×100)	LWFT (μ×100)	CFT (HFN)	IR (μ×100)	LWFT (μ×100)	CFT (HFN)	IR (μ×100)	LWFT (μ×100)	CFT (HFN)	IR (μ×100)
Number of Data	20	20	20	20	20	20	12	12	12	16	16	16
Average Value	79.1	90.4	82.0	64.4	91.8	73.9	31.8	50.3	10.8	21.4	50.0	11.8
Median Value	78.1	89.6	82.0	64.1	91.8	78.0	29.7	50.7	11.0	18.6	45.3	11.0
Standard Deviation	3.5	3.8	0.0	2.1	1.7	8.1	10.5	5.5	0.9	5.0	9.0	1.9
Maximum Value	85.8	97.8	82.0	69.4	94.2	82.0	47.4	58.5	12.0	30.1	64.4	15.0
Minimun Value	73.1	35.3	82.0	60.6	88.8	56.0	17.9	42.9	9.0	16.3	39.5	9.0
75th percentile	82.7	93.6	82.0	65.8	92.7	79.0	40.8	55.9	11.8	27.0	59.8	13.8
25th percentile	76.5	87.4	82.0	62.7	90.9	66.5	21.7	44.2	10.0	17.2	42.0	10.0

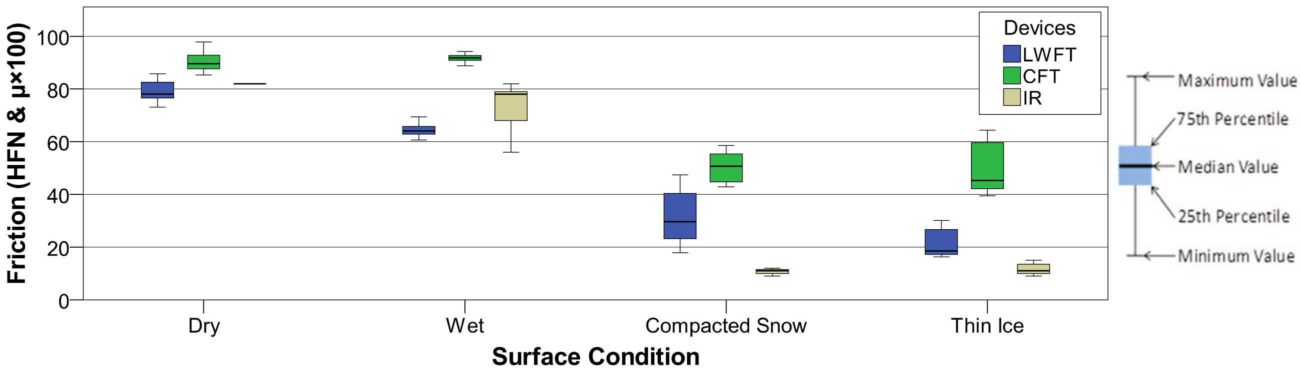

Figure 2 - Box plot of measurement values according to surface conditions

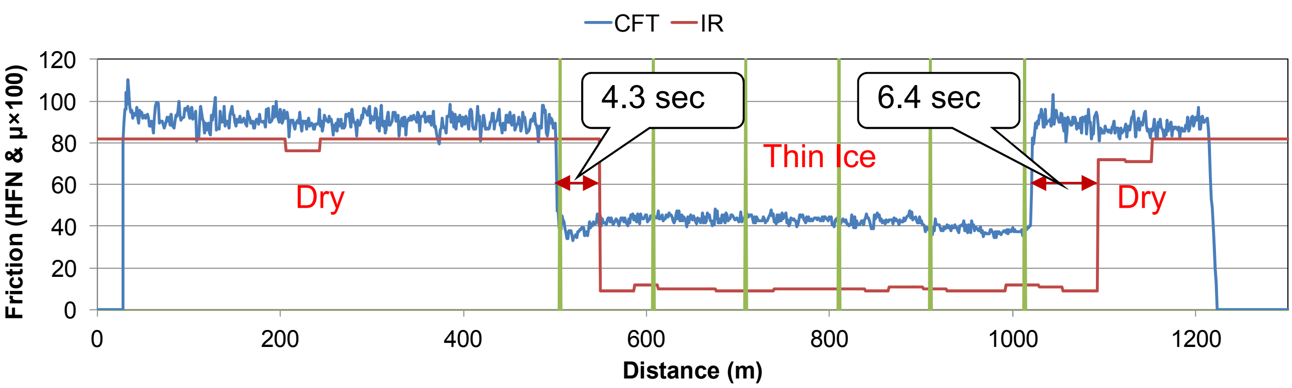

Figure 3 - IR's time lags in the friction values in comparison with the CFT

4. USE FOR DECISION-MAKING SUPPORT

CERI has been working on the development and trial run of the winter road surface management system (Figure 4) with an aim to supporting decision-making regarding management of winter road surface and also for understanding the effectiveness of maintenance operations. This system uses the Internet to provide road maintenance supervisors and maintenance workers with monitoring data on surface friction together with information on predicted conditions of roadside weather and road surface.

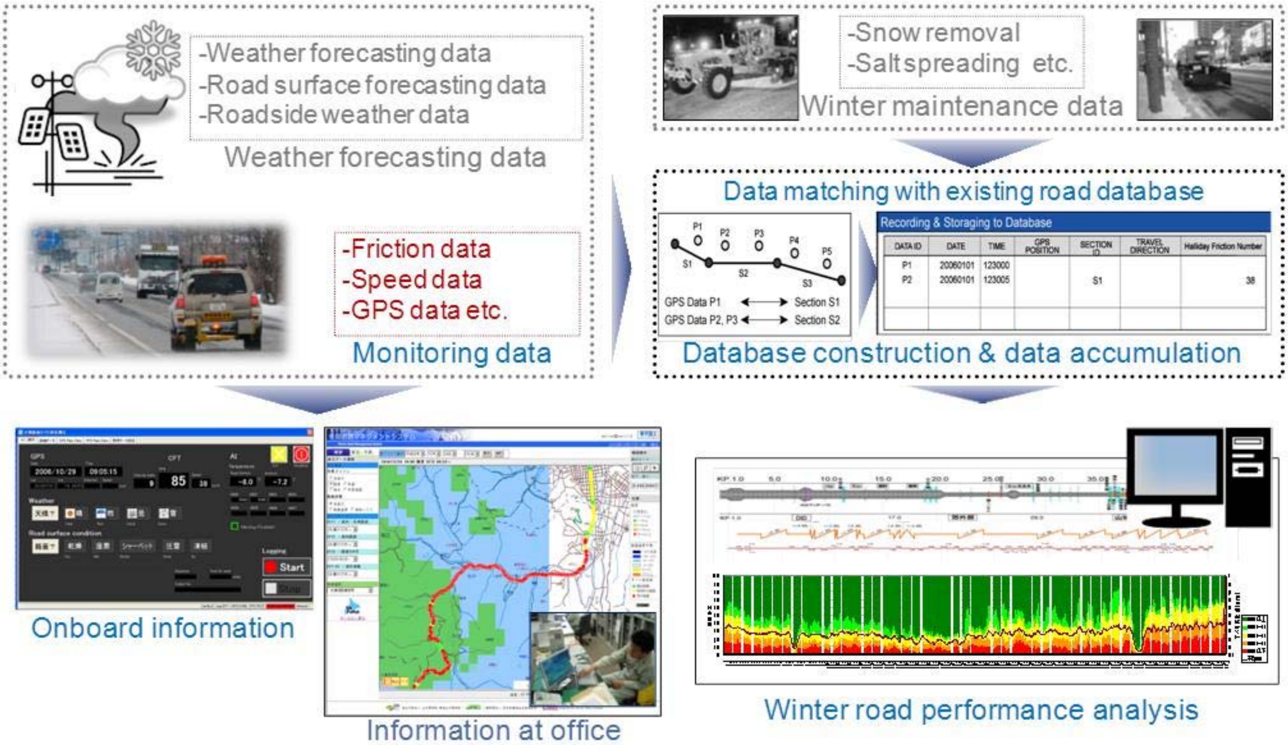

Figure 4 - Outline of the winter road surface management system

4.1. Development and trial run of a decision-making support tool that helps daily management and maintenance operations

In the winter road surface management system, maps offered for free by the Geographical Survey Institute of the Ministry of Land, Infrastructure, Transport and Tourism are utilized. The information provided by this system includes winter-time meteorological forecast (i.e. snowfall, rainfall, air temperature and visibility in snowstorms), predicted road surface conditions along 600-km major national highways in Hokkaido (i.e. surface temperatures and freezing risks), and continuous monitoring data on friction values. Meteorological forecast is provided in a mesh spacing of 1 km on maps for maximally 6 hours ahead of the current time. Predicted road surface conditions are available for a period of maximally 16 hours ahead of the current time for each road linear structure type and each telemeter (i.e. fixed measuring point) on road [14]. In providing monitoring data on friction values, HFNs measured by a CFT and weather data mentioned above are displayed on the same screen (Figure 5). The friction monitoring data collected at a sampling rate of 10 Hz is transferred to a server on a real-time basis, and at the same time is averaged every 5 seconds for making it easier to browse data. Friction values are classified into the three levels corresponding to snow and ice covered surface (HFN = ~ 44, shown in red), intermittent distribution of snow and ice (HFN = 45 ~ 59, shown in yellow), and bare pavement (HFN = 60~, shown in green), and the surface conditions on the road under monitoring are displayed in these three colours. By pointing the cursor to a dot showing a certain surface condition on the screen, detailed information on the relevant road section is displayed in a balloon. In this system, latitude and longitude data from the GPS in the measuring devices are automatically correlated with route numbers and kilo-posts (i.e. milestones) for addition to friction monitoring data. Thus, it is possible to understand road surface conditions in connection with the location shown by each kilo-post.

The winter road surface management system was only accessible from PCs in the past, but it has become accessible from smart phones and other types of mobile terminals since last winter in accordance to requests from users. In winter 2012/2013, a decision-making

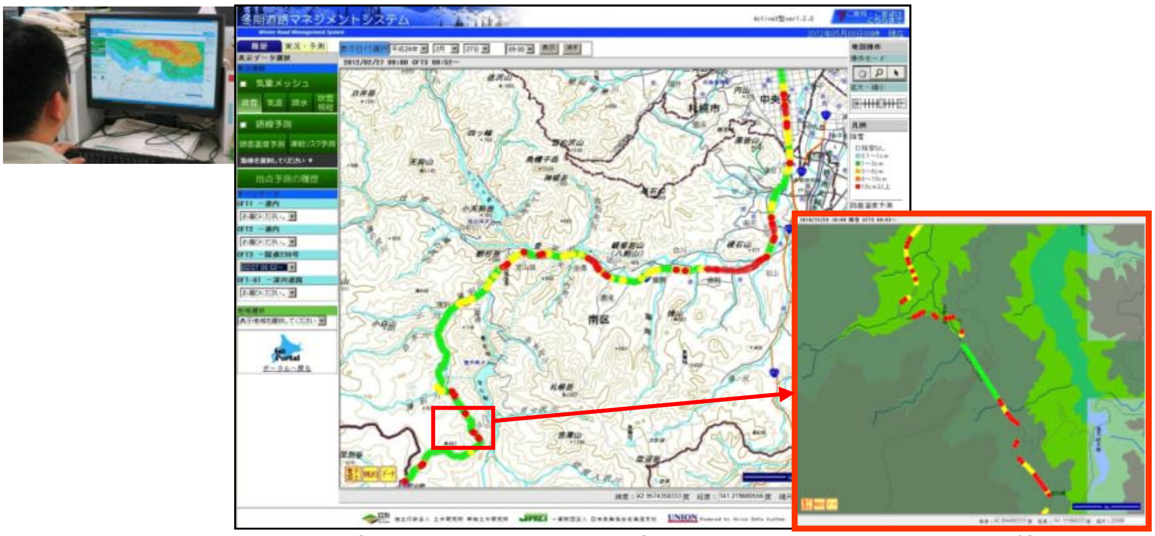

Figure 5 - A sample screen of the winter road surface management system (friction data)

Photo 6 - Friction monitoring data provided to operators on the spreader trucks

support application (Photo 6) was provided to mobile terminals used by the maintenance workers engaging in a patrol of National Highway 230 (NH230) or antifreeze agent spraying on the same route. This application makes it possible to acquire real-time friction monitoring data, and was made available as part of the trial decision-making support to road surface management. In order to understand the usability of this application, a survey was conducted by interviewing two maintenance workers who had actually used the application for maintenance operation on NH230. The survey results indicate that the surface conditions visually confirmed by the maintenance workers on site were consistent with the surface conditions displayed in different colours according to friction values (i.e. snow and ice covered surface in red, intermittent distribution of snow and ice in yellow and bare surface in green). The colour display of road surface conditions is especially useful for reducing decision-making errors of inexperienced maintenance workers. The decision-making support application also gives warning to mobile terminals that approaches a road section with slippery surface. Mobile terminals 200 m short of the slippery section receive both audio warning and colour display warning. According to the maintenance workers interviewed, this warning function is helpful for spraying antifreeze agents in an appropriate manner. Because maintenance workers understand road surface conditions 200 m ahead, they can use enough time to make accurate decisions as well as to start spraying equipment. In the future, the data communications interface of the winter road surface management system will be improved for providing users with a better information environment. Support to on-site decision-making will be also improved by adding new features to the system, so that maintenance workers will be able to use preset information on road sections for priority maintenance and forecasts of surface conditions and roadside weather conditions.

4.2. Performance assessment of winter road service

For the purpose of studying the usability of the HFN data, which had been collected and accumulated by the decision-making support tool mentioned above, for a feedback tool that supports decision-making on long-term road management, the data were checked against data on weather conditions and road maintenance operation. Analysis was conducted for identifying the appearance ratio of HFN values. An example of the analysis is described below:

A section of NH230 in Sapporo was used for analysis (i.e. a section from KP 1.0 to KP 45.0; L = 44.0 km). This road section extends from the city centre of Sapporo (DID area; altitude: 25 m) and reaches Nakayama Pass (altitude: 840 m) via suburban and mountainous districts. The weather and road-side conditions are different from place to place along the road section. A monitoring survey of this road section was conducted by letting a test car make two round trips a day for about 100 weekdays in winter (from early December to early March). The same CFT as described above was used for measuring friction values. The data on road maintenance operation used for analysis were supplied by the Hokkaido Regional Development Bureau of the MLIT which is responsible for the management of NH230. This data includes information on snow removal operation, dates of antifreeze agent spraying by each spraying vehicle, road sections to which antifreeze agents were applied, types and quantities of agents used, and widths of zones where antifreeze agents were sprayed. The analysis results are as follows:

Figure 6 - Appearance ratio of different road surface conditions and HFN values on NH230 (January, 2008~2013)

Figure 6 shows appearance ratio of HFN values measured in January every year from 2008 through 2013 on NH230. The horizontal axis shows Kilo Posts. KP 1.0 is the starting point. The vertical axis shows appearance ratio of different surface conditions. HFN values are classified into the three levels corresponding to snow and ice covered surface (HFN: ~44, shown in red), intermittent distribution of snow and ice (HFN: 45~59, shown in yellow), and bare pavement (HFN: 60~, shown in green). In other words, three levels of appearance ratio are shown by these three colours.

Regarding the appearance ratio of different road surface conditions and HFN values, basic characteristics are summarized as follows.

(1) The appearance ratios of the HFN values differ from year to year.
(2) The distribution patterns of the HFN values are similar from year to year.
(3) The appearance ratios of HFN values are not necessarily similar in the years with similar weather conditions.

Regarding (1) above, different weather conditions in each winter are the major factor that caused differences in the appearance ratio of HFN values. For example, the average monthly temperature was higher and the cumulative snowfall was smaller in January 2009 than in January of any other 5 years. The occurrence rate of snow and ice covered surface shown in red is particularly low in January 2009 in comparison with other years.

Concerning (2), snow and ice covered surface shown in red occurs more frequently with an increase of the altitude in all six years. The appearance ratio of HFN values change radically around the tunnel and the underpass shown in Figure 6. Thus it is obvious that the appearance ratio of HFN values are correlated with changes in the road structure and the altitude.

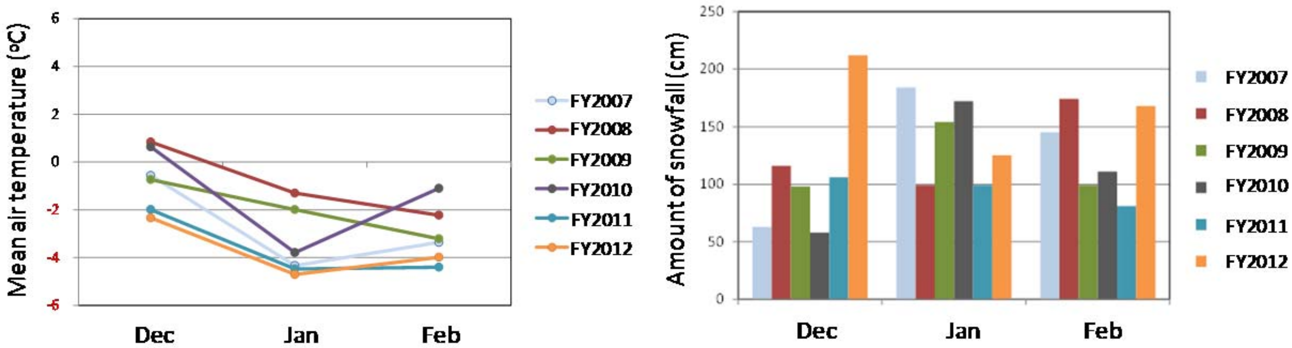

Figure 7 - Monthly average temperature and cumulative snowfall in Greater Sapporo area (FY2007~FY2012)

Table 2 - Record of surface maintenance operation (FY2007~FY2012)

	Frequency of snow removal (January)			Salt spreading days (January)
	Primary	Leveling	Widening	
FY2007	80	90	75	18
FY2008	63	141	99	15
FY2009	65	151	82	14
FY2010	89	45	29	18
FY2011	75	96	47	30
FY2012	82	115	43	31

With regard to (3), it should be noted that the occurrence rate of snow and ice covered surface shown in red is higher in January 2011 than in January 2008 despite the fact that the monthly average temperature and cumulative snowfall in these two months are similar as shown in Figure 7. This difference in the occurrence rate of snow and ice covered surface was probably caused by the savings of winter road maintenance cost in fiscal 2010. Due to the recent financial constraints, the road management authority reviewed the criteria for winter road surface management with a view to implement road maintenance operation in a more cost-efficient manner than before [15]. The difference of the maintenance operation in 2010 as compared with other years is shown in Table 2. The weather conditions in January 2011 and January 2012 also deserve attention. While the average monthly temperature is similar in these two months, the cumulative snowfall in January 2011 (170 cm) is 1.7 times larger than the cumulative snowfall in January 2012 (100 cm). Despite the lager amount of cumulative snowfall in 2011, the number of road surface maintenance operations (i.e. road surface levelling, snow removal for widening road width, and application of antifreeze agents) in 2011 was about half of the number of such operations in 2012. In other words, although the average monthly snowfall in January 2012 was smaller than in January 2011, road surface maintenance operations were conducted more intensively in 2012 than in 2011. Additionally, the occurrence rate of snow and ice covered surface is higher in January 2013 than in January 2012 although the weather conditions and the road surface maintenance operations were similar in these two months. These facts suggest that the appearance ratio of the HFN values depend not only on the weather conditions and road structures but also on the intensiveness of surface maintenance operations.

5. SUMMARY AND FUTURE PROSPECTS

With the aim to propose efficient winter road service in view of the recent financial constraints in Japan and characteristics of snowy cold regions, the authors in this study conducted research on reports from various countries regarding the criteria for winter road surface management, methods for quantitative assessment of winter road surface, and utilization of quantitative assessment results for supporting decision-making.
It was confirmed that winter road surface management criteria are roughly divided into four types that are mostly used in Japan, European countries (where the criteria are qualitative), other European countries (where the criteria are quantitative) and North America respectively. In Japan, road surface management targets are set according to roadside conditions and traffic volume, and many regions are affected by heavy snow and cold weather despite the fact that these regions are not necessarily situated at very high latitudes. In view of this fact, it is desirable to refer to the friction measuring methods and the road surface management criteria used in the four North European countries mentioned above when Japan introduces friction measurement and quantitative criteria to its road surface management.

The results of comparative tests using friction measuring devices show that friction values obtained by a CFT are consistent with LWFT's measurement values, and that the CFT evaluates changes in the surface conditions accurately. Although a change in the steering angle of the towing vehicle affects the measurement results, CFTs are the most reliable and useful measuring device under the current road conditions in Japan. Non-contact sensors (e.g. IR) evaluate road surface conditions without the need for driving a test vehicle, and are capable of taking measurements in curve sections. These sensors are usable for evaluating surface conditions at intersections in urban areas with heavy traffic and also in curve sections where surface maintenance is especially important during winter. Although some technical problems such as time lags in data output remain, non-contact sensors will be increasingly introduced to winter road surface management. In view of this, the authors will continue to keep up on technological development of friction measuring devices including non-contact sensors, and will also conduct comparative tests for evaluating these devices.

Regarding the use of friction data, the decision-making support application accessible from mobile terminals has been quite useful because users can refer to friction monitoring data at any time or any place for making necessary decisions. The authors will keep working on the improvement of technologies for forecasting road surface and weather conditions as well as for providing friction monitoring data. The quality and quantity of information for supply and the method for supplying information will be further studied to support winter road service which is implemented on the basis of objective information. The data on friction that CERI has been accumulating will be used for identifying the factors that affect road surface maintenance operation and characteristics of friction on winter road surface. A feedback tool will be developed to support performance evaluation of winter road service and decision-making on long-term road management. It is expected that this tool will be used not only for identifying road sections that need special attention but also for feeding back information regarding usability of road surface management criteria in various road sections.

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