2016 TRB Annual Meeting
Papers Related to Winter Maintenance

Contents

Materials

Effectiveness of Salt Removers and Sugarbeet Byproduct in Protecting Metals from Corrosion by Magnesium Chloride Deicer

Paper number 16-6157, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/417-1.2820076/16-6157-1.2819702/16-6157-1.2820077

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Abstract: This work evaluates the best practices for managing the corrosive effect of chloride-based deicers on the metallic components of equipment fleet. The first part evaluates the effectiveness of salt removers for washing the bare metals. Dip-dry tests were used to simulate the field condition. Carbon steel (C1010), Aluminum alloy (Al1100) and stainless steel (SS304L) were included in the test program to evaluate the use of water, soapy water, and a commercial salt remover in washing practices. The corrosion behavior of metals was periodically characterized using linear polarization and electrochemical impedance spectroscopy measurements. The morphology of corrosion coupons were examined by scanning electron microscopy and digital photos. Salt remover could significantly enhance the anti-corrosion performance of carbon steel and stainless steel in 30% $MgCl_2$ solution, but not that of the aluminum alloy. The second part is focused on the evaluation of an innovative sugar beet by-product for use as a deicer additive. Modified dip-dry tests were used to simulate the field condition. Bare and coated C1010 samples were included in the test program to evaluate the potential benefits of this “green” deicer additive. The corrosion behavior of the samples was periodically characterized using electrochemical impedance spectroscopy. The results reveal that the use of sugar beet by-product can enhance the corrosion resistance of carbon steel and the mechanism of protection is the formation of an adsorbed protective organic layer on the metallic surface. The role of this additive in the corrosion of coated steel is more complicated.

Effect of Granularity of Salt and Pretreatment on Deicing Performance
Paper number 16-3948, http://amonline.trb.org/trb60693-2016-1.2807374/t033-1.2813800/563-1.2814103/16-3948-1.2814104/16-3948-1.2814105

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Abstract: Large amount of salts are used in cold regions every winter to keep users of roads, parking lots and sidewalks safe. While effective for snow and ice control, salts at high concentrations are detrimental to the environment and corrosive to vehicles and infrastructure. Therefore, reducing the salt usage, with new technologies such as pretreating, and substituting the conventional chloride salts with alternative materials (organic based) are sought. This paper presents the field test results on the deicing performance of coarse and fine salt pretreated with alternative agents of Snowmelt, Fusion and Safepaw. The performance of pretreated salts was field evaluated under a wide variety of weather conditions. Additionally, the performance of the coarse salt and fine salt was also compared to investigate the effect of particle size on deicing performance. The analysis indicated that pre-treating salt with alternative liquids did not increase the deicing effectiveness significantly under the experienced winter conditions. Also, it was observed that fine salt (with smaller particles) was more effective in increasing pavement clearing speed than coarse salt (with larger particles).

Chemical Melting of Ice: Effect of Solution Freezing Point on Melting Rate
Paper number 16-1151, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/563-1.2820029/16-1151-1.2819683/16-1151-1.2820032

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Abstract: Wintertime, icy roads presents a hazard for road users. It is therefore desirable to maintain bare roads. To achieve this, deicing chemicals are typically applied. One important property of the chemicals which are used, is how fast they can melt ice. The understanding of what affects the melting rate is, however, limited. An experiment was therefore designed to study how the driving force for the melting, the chemical potential difference between ice and solution, affects the chemical melting rate of ice. The driving force was, in this study, represented by the solution freezing points. The experiment was performed at -5°C (23°F) using solutions of four different chemicals; sodium-, magnesium- and calcium-chloride as well as potassium formate. These four solutions were mixed to four different freezing points each; -10°C (14°F), -18°C (-0.4°F), -30°C (-22°F) and the chemical eutectic temperature. The results showed that there was a clear correlation between solution freezing point and how fast the solution could melt ice. The solution with the lowest freezing point melted ice 4-5 times faster than the solutions with the highest freezing point. The importance of solution freezing point was attributed its direct relation to the solution chemical potential. A low freezing point giving a large driving force for the phase change. In addition, it was found that the type of chemical plays a role on the melting rate of ice. The fastest melting chemical (potassium formate) melted ice 45% faster than the slowest (magnesium chloride). The explanation for this is believed to be a higher ion mobility, which gives a faster transport of solute to the ice-solution interface.

Equipment and Facilities

Quantitative Assessment of Snow Plow Sensor Failure Impacts on Winter Maintenance Operations
Paper number 16-1916, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/418-1.2820073/16-1916-1.2813763/16-1916-1.2820074

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Abstract: Implementing GPS/AVL systems and combining other remote sensing data such as weather and traffic data allows transportation agencies to better monitor equipment and materials as well as to develop performance measures to track the benefits of winter maintenance operations. However, these sensors are

placed in a harsh environment, where they are exposed to cold temperatures, moisture, and corrosive materials. As a result, sensors placed on trucks may fail or require recalibration to regain the ability to record accurate data. Typically, mechanics focus on major mechanical issues such as engine and transmission maintenance and repair while ignoring issues with sensors. However, a paradigm shift may be necessary as vehicle sensors become more prevalent and agencies begin to rely more heavily on sensor data when making winter maintenance decisions. Winter maintenance data collected in the field were utilized to analyze sensors instrumented on snow plow trucks deployed by the Ohio Department of Transportation. It was found that the location and speed sensors rarely failed, while the bed scale weight sensors did not report data 32% of the time they were operational. The bed scale sensors were evaluated for accuracy and reported weight values within 2.2% of the ground truth weight values when calibrated and within 8.4% of the ground truth weight values when not calibrated. The cost difference between trucks with calibrated sensors and those having sensors that are not calibrated ranges from $150 to $270 per truck, depending on the number of snowfall events during a winter season.

Development of a Novel Blower Snow Fence

Paper number 16-2191, http://amonline.trb.org/trb60693-2016-1.2807374/t033-1.2813800/728-1.2813943/16-2191-1.2813944/16-2191-1.2813945

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Abstract: There are two types of snowstorm-induced traffic hindrances on roads: visibility hindrance, which causes collision accidents, and snowdrifts, which cause vehicle stranding. Blowing-snow control measures, therefore, are extremely important in winter road management. Snow fences are frequently used as blowing-snow control measures. In the United States, snow fence installation has been promoted in many states, including Wyoming. Based on knowledge of snow fence uses in the U.S., the installation of types of snow fences used in the U.S. was promoted in Japan, too. However, it gradually became difficult to lease land, such as that of upland and paddy fields, for fence installation, because land for fence installation is scarce in Japan. As a result of land procurement difficulties, the "blower snow fence", which can be installed at the immediate roadside, was developed. This fence has become widely used in Japan. However, the blower snow fence has a problem that needs to be solved. When the incident wind is oblique to the fence or when the clearance along the bottom of the fence is blocked with accumulated snow, the fence loses its effectiveness. In this study, with the aim of improving this problematic characteristic of the conventional blower snow fence, a new blower snow fence that can be installed at the immediate roadside similar to conventional blower fences was experimentally created. Onsite investigation on the snow control effectiveness of the new fence clarified that the new fence had greater effectiveness than conventional blower fences.

Road Weather Information Systems and Technology

Optimizing Environmental Sensor Station Locations for Road Weather Management: Overview and a Generalized Modeling Framework

Paper number 16-6348, http://amonline.trb.org/trb60693-2016-1.2807374/t020-1.2818429/276-1.2819368/16-6348-1.2814737/16-6348-1.2819369

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Abstract: Adverse weather poses a significant threat to transportation safety. Road weather information systems (RWIS) aim to mitigate the impact of adverse weather. Due to the lack of a detailed, unified guideline and diverse weather conditions across the United States, state and city transportation agencies follow different practices for choosing locations for environmental sensor stations (ESS). To fill this gap, this paper proposes a comprehensive cell-based methodology that optimizes overall benefits of RWIS based on weather-sensitive crash characterizations using both normal and adverse weather crash data. The

proposed approach is especially suited for optimizing region-wide ESS locations involving a large number of road segments. A case study concerning RWIS deployment in Austin, Texas was conducted using the Crash Records Information System (CRIS) data between 2010 and 2013.

Spatiotemporal Variability of Road Weather Conditions and Optimal RWIS Density—Case Studies
Paper number 16-4749, http://amonline.trb.org/trb60693-2016-1.2807374/t001-1.2823436/276-1.2823585/16-4749-1.2814350/16-4749-1.2823586

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Abstract: This paper presents a study aiming at understanding the relationship between the spatiotemporal characteristics of the road weather conditions in a region and the minimum number of RWIS stations required to provide adequate regional coverage. Case studies using data from three US states - Iowa, Minnesota, and Utah, are conducted, focusing on characterizing and comparing their unique topological and climate patterns and the effects on their respective RWIS network. Without loss of generality, road surface temperature (RST) is selected as the variable of interest to represent the overall road weather conditions. For each state, a semivariogram model is constructed to determine the spatial variability of RST, especially, autocorrelation range – a separation distance at which the measurements are no longer correlated to each other. In addition, an optimal RWIS density is determined through an optimization process that minimizes the total condition inference errors across the underlying road network. It is shown that Iowa and Minnesota, both of which consist of a gently rolling plain and flat prairie (plain/flatland), have a large autocorrelation range, whereas Utah with extremely varied topography and terrain (mountainous) has a relatively shorter range. The study further reveals that the range of spatial autocorrelation is related to the optimal density of RWIS network – the region with a longer range (Iowa and Minnesota) requires a less number of RWIS stations per unit area, than the region having a shorter range (Utah).

Expanding the Road Weather Information System for Avalanche Support
Paper number 16-4723, http://amonline.trb.org/trb60693-2016-1.2807374/t028-1.2815409/725-1.2815441/16-4723-1.2813953/16-4723-1.2815442

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Abstract: Transportation agencies employ road weather information systems to support operations, maintenance, and informed travel decisions. Road weather capabilities have been further expanded through the FHWA Weather Responsive Traffic Management's advisory, control, and treatment strategies to address weather-related roadway impacts. Monitoring conditions that precede avalanches offers a new opportunity to leverage the road weather information system's infrastructure. Wet avalanches, particularly wet slab avalanches, pose considerable risk. They can occur simultaneously across an extensive area, encompass a greater mass of material, create considerable energy, cause significant road closures, and potentially lead to major injuries and fatalities. Roadside and at-altitude avalanche indicators can be monitored by adding additional sensors to existing road weather environmental sensor stations, deploying new environmental sensor stations at both roadside and at-altitude locations, and creating new, collaborative partnerships. The traditional road weather information system sensor suite can be augmented with new meteorological and snowpack sensors to monitor pre-avalanche conditions. Calibrated present weather detector sensors and heated precipitation gauges can provide improved estimates of the precipitation's liquid water equivalent. Thermistor strings and lysimeters can provide snow pack stability evaluations. Adding environmental sensor stations, both at roadside and at-altitude, can provide strategic observations of the atmospheric and snowpack conditions. Increased coordination between agencies on site selection, sensor choices, and data distribution can expand the role of road weather information system to support avalanche forecasting.

Program Management

Resource Replenishment Location Planning for Service Trucks under Network Congestion and Routing Constraints

Paper number 16-6931, http://amonline.trb.org/trb60693-2016-1.2807374/t033-1.2813800/205-1.2814422/16-6931-1.2813626/16-6931-1.2814423

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Abstract: It is often very challenging to plan expedient and cost-effective operations for service trucks under network design constraints, particularly on congested urban roadways. Hence, it is beneficial to simultaneously account for truck facility location design and network expansion decisions to mitigate the additional congestion caused by trucks and facilitate their routing. This paper develops an integrated mathematical model for the facility location design under network routing and congestion constraints. The model determines the optimal number and location of replenishment facilities, minimizes truck routing costs based on the proposed network design, assigns traffic in the network (for both general roadway users and service trucks), and selects candidate links for possible roadway capacity expansion. The model aims to minimize the total cost for new facility construction, truck routing, transportation infrastructure expansion, and transportation delay. A genetic algorithm framework is developed that incorporates a continuous approximation model for truck routing cost estimation and a traffic assignment algorithm. The numerical results show that the integrated solution technique can solve the problem effectively.

Pavements and Bridges

Thermal Behavior of Typical and Darkened Portland Cement Concrete Pavement: Applications to Winter Maintenance

Paper number 16-6135, http://amonline.trb.org/trb60693-2016-1.2807374/t019-1.2819465/756-1.2819505/16-6135-1.2817970/16-6135-1.2819506

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Abstract: With applications to winter maintenance, the purpose of this research was to investigate the effects of lower concrete albedo on the thermal behavior of concrete pavement by directly comparing surface and subsurface temperatures of darkened concrete and typical concrete. This research was connected to a field site in northern Utah. The procedures involved site layout, site instrumentation, pavement construction, field testing, and laboratory testing. The results of the study show that a strong positive correlation exists between the surface and subsurface pavement temperatures and the air temperature. The difference between the surface temperatures of the darkened and typical pavements decreases as the air temperature decreases. When the air temperature is 32°F, the surface temperature of the darkened concrete is just 0.2°F higher than that of the typical concrete; therefore, the darkened pavement is unlikely to melt snow and ice faster than the typical pavement at this site. The difference between the subsurface temperatures of the darkened and typical pavements also decreases as the air temperature decreases. In this case, when the air temperature is 32°F, the subsurface temperature of the darkened concrete is 1.1°F higher than that of the typical concrete; therefore, the darkened pavement is unlikely to provide significantly greater frost protection to subsurface layers and buried utilities during winter.

Virginia "Quieter" Pavement Demonstration Program

Paper number 16-3833, http://amonline.trb.org/trb60693-2016-1.2807374/t010-1.2820652/838-1.2820665/16-3833-1.2817927/16-3833-1.2820671

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Abstract: This paper summarizes the findings from Virginia's recent quieter pavement research. It reviews overall condition, functional performance (ride, noise, and friction), winter maintenance and use

characteristics, and other important observations made regarding a series of demonstration projects that were constructed in 2011 and 2012. The lower-noise pavement technologies included porous asphalt, conventional diamond grinding and a Next Generation Concrete Surface. The paper also summarizes results from the accelerated trafficking of Virginia materials at the National Center for Asphalt Technology Test Track. Lastly, the report reviews current federal policy and the pertinent ramifications for Virginia's program. As of spring 2015, the difference in measured tire-pavement noise between control surfaces and the most successful (lowest noise) quiet asphalt technology was no longer detectable with normal human hearing (<3 dB). The lowest noise concrete surface continues to have a noticeable (approximately 4dB) advantage over the standard concrete finish. While none of the quiet pavement technologies tested thus far provide sufficient noise reduction to singularly satisfy federal regulations for noise abatement, VDOT is encouraged to continue monitoring federal policy for changes that may incorporate pavement type as a tool for mitigating noise. VDOT should also continue to monitor (and trial as warranted) products of national and international research and development that show promise for reducing and/or eliminating traditional sound barriers.

A Connected Vehicle Solution for Winter Road Surface Condition Monitoring
Paper number 16-5865, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/622-1.2819991/16-5865-1.2819992/16-5865-1.2819993

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Abstract: This paper describes a connected vehicle based winter road surface condition (RSC) monitoring solution that combines vehicle based image data with those from road weather information system (RWIS). The proposed solution was intended as an improvement to a smartphone-based system evaluated in previous research. Three machine-learning based classification methods, namely, artificial neural networks (ANNs), random trees (RTs) and random forests (RFs), were evaluated for their potential to be applied in the connected vehicle based system for RSC monitoring. Field data collected during the 2014-15 winter season were used for model calibration and validation. Results showed that all models improved the accuracy of the smartphone-based RSC classification substantially with the RF having the highest classification performance. The models were however found to lack transferability, therefore requiring local calibration prior to being used at any particular location.

Feasibility of Geothermal Heat Exchanger Piles Based Snow Melting System: A Simulation Based Analysis
Paper number 16-3990, http://amonline.trb.org/trb60693-2016-1.2807374/t003-1.2822982/563-1.2823115/16-3990-1.2820030/16-3990-1.2823116

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Abstract: The geothermal heat exchanger pile based snow melting system is an innovative snow melting technique, which adopts geothermal as a heat source to melt snow accumulated on the pavement surface. The presence of this technique conquers the issue of road corrosion as well as negative environmental effects caused by mechanical and/or chemical snow melting approaches, moreover, it performs advantage of cost-effective compared with conventional geothermal snow melting system. However, the application of geothermal heat exchanger pile based snow melting is still hindered by locations as well as limited total pile length. In this paper, a 3D numerical model is proposed to predict the energy extraction rate for the considered pile, based on which, sensitivity analyses on the influence of geothermal heat exchanger pipe arrangement type (U-shape, W-shape and spiral shape) and velocity of circulated fluid are conducted. In order to demonstrate the feasibility of geothermal heat exchanger pile based snow melting system in United States, the bridge deck (200m length by 14.8m (4 lanes) width) is assumed to utilize this system in 10 different cities, which have typical snowfall and ground temperature conditions. The results show that the pipe arranged in spiral shape performs great advantage in energy extraction, it, therefore, should be the first option for geothermal snow melting system design. In addition, the geothermal heat exchanger pile based snow melting system with spiral arranged pipe is only applicable for a) most cities at design condition of Ar=0; b) cities located in region III and IV at design condition of Ar=0.5; c) cities with similar heating demands for different Ar values.

Estimating Vehicle Shadow Impacts on Solar Irradiation of Roadways
Paper number 16-5497, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/729-1.2819919/16-5497-1.2819920/16-5497-1.2819921

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Abstract: Solar radiation has a significant effect on the snow melt rate in urban areas. The shadows of vehicles reduce the solar radiation on snow surface on streets. Right now, salt application procedures are based on temperature, precipitation and road surface condition without considering incoming solar radiation. In order to ensure quick melting, excess salt is frequently applied. However the price of salt has been rising rapidly. Additionally, salty water running into drains, culvert, streams and rivers can cause many environmental issues. This paper introduces a method to calculate the reduction caused by traffic on solar radiation on streets. Several cities in North America were selected. Based on the latitude and longitude of these cities, vehicles size and the azimuth and elevation of the sun, shadow area of single vehicle was calculated. Based upon the shadow area of single vehicle, traffic volume and traffic population on road, the total reduction on solar radiation on road was calculated. Based on the calculation, future work can be done to adjust the salt application rates to use salt efficiently and to mitigate the environmental issues.

Safety

Changes in Pavement Friction Levels during Winter Maintenance Operations and its Impact on Driving Safety
Paper number 16-1725, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/725-1.2819935/16-1725-1.2818587/16-1725-1.2819942

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Abstract: The tire-pavement friction is drastically reduced during winter storm events. Loss of tire pavement friction during winter storms causes severe safety hazard to the motoring public. Every year more than 117,000 people are injured and more than 1,300 people have died on snowy, slushy or icy roadways (1). The coefficient of friction between the vehicle tire and the pavement can be dramatically improved by winter maintenance activities such as snow plowing, deicing, anti-icing and sanding of the roadway. Although in the United States friction testing is not primarily used as a winter performance measure, a number of European countries and Japan uses this technology regularly. Friction can be determined using three methods; predicting friction using climate, traffic and other roadway conditions, direct friction measurements using an extra wheel installed on vehicles, or by traction control systems. NCHRP Web Document 136 lists three operational uses of friction measuring devices in winter operations; they can be used to measure quality of winter maintenance operations, can be used as a source of road user information to inform motorists of hazardous locations and also to determine the amount of deicing materials to be used on the roadway (2). In this study, pavement friction behind snow plows were measured during different snow events. The measured friction values were compared to base friction levels obtained during the summer months along the same roadway. As a pilot study, Interstate 96 roadway and US-23 in Livingston County, Michigan were selected and friction data were collected during snow storms during the 2013-2014 and 2014-2015 winter seasons. The study demonstrates the variation in pavement friction levels during different types of winter storms and its effect on winter driving safety.

Comparison of Winter Road Safety Performance Models for Different Classes of Highways
Paper number 16-5441, http://amonline.trb.org/trb60693-2016-1.2807374/t029-1.2814748/622-1.2814984/16-5441-1.2814985/16-5441-1.2814986

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Abstract: Winter road safety models are essential for quantifying the benefits of winter road maintenance (WRM) programs and evaluating alternative winter focused road safety countermeasures. In this research, we compare the road safety models developed for different classes of highways. The work is motivated by the interest in investigating the differences in safety patterns among highways of different service standard.

Safety models are developed using winter collision data from 26,945 km of highways over 11 winter seasons in the province of Ontario. The safety effects of various factors such as snowstorm characteristics and road surface conditions for difference classes of highways are compared and implications of the results demonstrated through several case studies. It has been shown that the individual models developed for the different road classes can be used with confidence to evaluate various policy variables such as bare pavement recovery time and highway classification schemes.

Self-De-icing LED Signals: Concept and Laboratory Evaluation
Paper number 16-2843, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/590-1.2820019/16-2843-1.2815036/16-2843-1.2820020

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Abstract: State highway agencies and railroads rely on the effective and safe movement of vehicles and trains through various environmental conditions. These forms of transportation utilize signal aspects to convey safe movement to the driver or locomotive engineer. However, signaling systems in locations where snow and ice are common are susceptible to these signals being covered by snow and ice during winter storms. This paper introduces the concept of self deicing LED signal light that adopts a "Heated Lens Lighting Arrangement" to harvest both the light and the otherwise wasted heat generated by the same LEDs for prevention of the buildup and accumulation of ice, sleet, and snow on the lens of the signal without additional heat generators. This concept was tested in a laboratory environment, and it was found that red LED signals consumed 16.9 - 20.7 W to maintain the lens surface temperature above freezing 32° F (0° C) at an ambient temperature of below 10° F (-12.2° C). For the green LED signals, the threshold wattage was 18.1 - 22.1 W when the signal light was activated for 35 seconds throughout a cycle length of 82 seconds, but increased to 50.7 W when the activation time was reduced to 10 seconds. The yellow LED signals, whose activation time was often 3 seconds every 82 seconds, consumed 47.8 W to maintain the lens surface temperature above freezing at an ambient temperature of 19.3° F (-7.1° C).

Development of Snow Transport Estimating Models Based on Road Images
Paper number 16-3287, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/622-1.2819991/16-3287-1.2817081/16-3287-1.2819996

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Abstract: Snowdrifts on roads create serious safety problems in Hokkaido, Japan. Snow transport is commonly used for assessing hazardous conditions resulting from snowdrifts on road; however, it is difficult to measure the snow transport onsite directly. The present study objectives were as follows: (a) to propose a model for estimating snow transport according to differential weighted intensity of power spectrum (DWIPS) based on road images recorded by closed-circuit television (CCTV) cameras installed along the road, and (b) to determine whether the snow transport values determined using DWIPS are consistent with snow transport values given by a model that is based on a modified Tabler model fitted to winter weather conditions in Hokkaido (the Hokkaido model). The coefficients of determination of overall data between snow transport calculated in the two models proposed in the present study and snow transport calculated by the Hokkaido model were approximately 0.5 in the absence of snowfall. It might be possible to use the two proposed models, which are based on road images, to estimate snow transport on roads. Snow transport determined according to DWIPS better reflects the actual snow surface conditions due to the use of onsite conditions. The more cost-efficient solution for estimating snow transport would be to use the two proposed models according to DWIPS. In Hokkaido, over 1,300 CCTV cameras are already available. These models have the potential to contribute to effective countermeasures for hazardous locations on roads in winter, because road administrators would be able to determine locations made hazardous by blowing snow based on transport data provided by the two proposed models. The two models have great potential for enabling the measurement of snow transport at points along the road.

Provision of Snowstorm Visibility Information

Paper number 16-2189, http://amonline.trb.org/trb60693-2016-1.2807374/t033-1.2813800/618-1.2814042/16-2189-1.2813026/16-2189-1.2814043

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Abstract: Traffic hindrance that is frequently caused by snowstorm-induced poor visibility or snowdrifts due to snowstorms at winter roads in snowy cold regions has a significant social impact. The Civil Engineering Research Institute of Cold Region (CERI) developed techniques for estimating visibility distances on the basis of meteorological data. In February 2013, CERI started to use its website Snowstorm Visibility Information System for informing road users of visibility forecasts. In December 2013, the Snowstorm Visibility Information System was made accessible from smartphones, and a mail delivery service was started for providing visibility forecasts. With an aim of understanding the usefulness of the visibility information, the authors asked users of the Snowstorm Visibility Information System to answer a questionnaire. The questionnaire result indicated that 80% of respondents used the system for determining whether or not to change their travel plans.

Driver Behavior

Eye Glance Behavior of Experienced and Inexperienced Maintenance Personnel During Spreading Operations

Paper number 16-1769, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/728-1.2819925/16-1769-1.2819927/16-1769-1.2819928

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Abstract: This study investigated the eye glance behavior of experienced and inexperienced workers during their observation of road surface conditions and their spreading operations, and how information provision during spreading operations affected the eye glance behavior of the two groups. 11 maintenance personnel, consisting of experienced workers who had been working as spreading operators for at least two years and inexperienced workers who had no experience with spreading operations, took part. The study results are summarized as follows. (1) During the visual assessment of the surface condition, no statistically significant differences were seen between the experienced and the inexperienced workers. (2) During the spreading operation, both the experienced and the inexperienced workers paid less visual attention to the road ahead than they did during the visual assessment of the surface condition. This was attributed to the increased workload. The increased workload had greater impact on the eye glance behavior of the inexperienced workers than on that of the experienced workers. (3) The provision of information on the surface condition ahead during spreading operation is regarded as being effective at improving performance during spreading operations for both the experienced and the inexperienced workers, with the exception of the experienced workers who were thought to be adversely affected by the information device. The results suggest the need for the development and delivery of training focused on information and communication technology (ICT) for existing maintenance personnel.

Study on the Development of Technology for Supporting Onsite Decision Making in Antifreeze Agent Spreading

Paper number 16-3168, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/ahd65-1.2819857/16-3168-1.2819858/16-3168-1.2819859

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Abstract: Budgetary constraints in recent years and environmental concerns have raised the need for efficient and effective road surface management in winter (including the use of antifreeze agent) in snowy cold regions of Japan. However, it is unclear what type of information is used in the decisions made onsite by operators of vehicles that spread antifreeze agent. In recent years, the mean age of skilled operators has been increasing and many skilled operators have left their jobs. Securing and educating new operators has become difficult. This study aims to contribute to securing and improving the accuracy of winter road surface management by developing technology for supporting antifreeze agent spreading. The technology will make it possible for operators to determine the situation appropriately without depending on experience and skills. In the winter of FY2014, tasks such as recognizing and judging the road surface conditions, and conducting spreading work were investigated for skilled and unskilled operators. The mental workload of the operators during three tasks was measured. The differences in measured values for skilled versus unskilled operators were compared. Investigations were also made as to whether the provision of information through the vehicle-mounted information terminal contributed to improvements in the performance of recognition and judgment of the road surface conditions and in antifreeze agent spreading work by the operators. This report discusses the results of this study and future prospects.

Traffic Modeling

Determination of Normal Condition Regain Time During Snow Events Using Traffic Flow Data

Paper number 16-6043, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/725-1.2819935/16-6043-1.2819936/16-6043-1.2819937

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Abstract: This paper presents an automatic process to determine the normal condition regain time (NCRT) using the traffic flow data a given snow event. To reflect the different traffic flow behavior during the day and night time periods, two types of the normal conditions are defined for each detector station. The normal condition for the day time is defined with the average speed-density patterns, while the time-dependent average speed patterns are used for representing the night time periods. In particular, the speed-density functions for the speed recovery and reduction periods were calibrated separately for a given location to address the well-known traffic hysteresis phenomenon. The resulting NCRT estimation process determines the NCRT as the time when the snow day speed recovers to the target level of the normal recovery speed at the corresponding density level for the day time periods. The application results with the snow routes in Twin Cities, Minnesota, show the promising possibilities of the estimated NCRT values as the reliable operational measures that can address the subjectivity and inconsistency issues associated with the current bare-lane regain times through the visual inspection.

The Effect of Weather on Travel Speed from Bluetooth Sensor Data on a Cold-City Urban Arterial
Paper number 16-3964, http://amonline.trb.org/trb60693-2016-1.2807374/t020-1.2818429/725-1.2818581/16-3964-1.2818582/16-3964-1.2818583

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Abstract: While traffic flow (volume) is associated with variations in travel times or speeds, studies have shown that weather can play a significant role especially in the winter context of North American cold cities. This study investigated the effect of weather and temporal variables on travel speeds obtained from Bluetooth sensor data collected during winter time. This research is based on data from 2013-2015 collected from permanent sensors installed along one of the main urban arterials in Montreal, Canada. The hourly weather variables included were snow, rain, temperature, visibility, and wind speed. The effects were modeled at an hourly level using three linear regression models considering the whole dataset, only winter period data and only out of winter period data. The results confirmed the major importance of snow as a hindrance to travel speed. The effect of rising temperature was expectedly found to have slightly increased travel speeds as it increased. The impact of visibility and wind speed were found to have positive and negative benefits respectively as they increased although, their effect was not as pronounced as snow. More out of winter data is needed to clarify the effects of rain on travel speed. In regards to the temporal variables, greater speed reductions were unexpectedly observed in the fall than in the winter. It is interesting to note that the hourly count of travel times provided much of the explanatory power to the models suggesting that Bluetooth data may be a good estimator of traffic volume proportions.

Impact of Weather Conditions on Traffic: Case Study of Montreal's Winter
Paper number 16-6846, http://amonline.trb.org/trb60693-2016-1.2807374/t005-1.2821934/725-1.2822099/16-6846-1.2816925/16-6846-1.2822100

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Abstract: Congestion is the number one issue in many metropolitan areas. It decreases quality of life and generates negative impacts on the environment and the economy. Apart from recurring congestion causes, many events and circumstances can affect the traffic conditions: weather, roadworks, road incidents and other special events. The former is very important especially in a northern city like Montreal, where winter conditions last four to six months each year. This study relies on GPS data from vehicle fleets combined with weather data from weather stations to assess traffic conditions on the whole highway network of the Greater Montreal Area. The proposed methodology uses logistic regression models to model the probability of congestion to describe the effects of weather conditions (snowfall), road conditions (icy) and visibility on traffic conditions, defined using the Speed Limit Ratio. This research is part of the development of a congestion monitoring and analysis tool for the region of Montreal, which is also presented.

Statistical Investigation of Truck Type Distribution on Cold Region Highways During Winter Months
Paper number 16-2139, http://amonline.trb.org/trb60693-2016-1.2807374/t012-1.2820325/302-1.2820489/16-2139-1.2819345/16-2139-1.2820490

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Abstract: Recent research on impact of weather interaction on classified traffic volume variations on provincial highways in cold regions showed that the total truck volume is not affected with severity of snowfall and cold temperature. However, no research is conducted to analyze the variations in truck distributions, despite its importance for truck counting and monitoring program. Described in this paper is the statistical investigation of association of truck type distribution on cold region highways during severe winter months and seasons in a year. The investigation is based on weigh-in-motion data collected from six sites located on five provincial highways in Alberta, Canada. Trucks were classified into three types such as single unit, single trailer, and multi trailer using the Federal Highway Administration (FHWA) vehicle classification scheme. Two statistical tests namely Chi-squared test and Binomial probability test were

applied to analyze the distributional change in three different truck classes during high snowfall and low temperature conditions. The analysis suggested that the truck type distribution does not change from winter to non-winter season for regional commuter road (Highway 2A) and long distance roads (Highway 2 and Highway 16). Also, no change in truck distribution from month to month was noticed during severe winter months. Consistent results were not found for special roads such as Highway 44 due to differences in road user characteristics. The study findings have practical implications for rationalization of the length and frequency of traffic counts including classified traffic monitoring programs throughout the year. The knowledge about independency of truck type distribution with various seasons is likely to help in effective traffic monitoring and estimation of the highway planning and design parameters like Truck Annual Average Daily Traffic (TAADT), Truck Average Daily Traffic (TADT) and Design Hour Truck Volume etc.

A Method for Estimating Urban Travel Speed in Winter Using Panel Data Models
Paper number 16-1121, http://amonline.trb.org/trb60693-2016-1.2807374/t010-1.2820652/725-1.2820749/16-1121-1.2819944/16-1121-1.2820755

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Abstract: The travel speed in winter is affected not only by the road geometric design but also by the snowfall, snow depth, temperature, and other weather conditions. The location of this study was a 4.8-km section of the Nishi-5-chome St. arterial in Sapporo, Japan, using data from December 2013 to March 2014 for analysis. In this area, the travel speed is about 5 to 10 km/h slower in winter than in autumn all day. The objective of this study is to develop a method for estimating the travel speed in winter by considering weather conditions and snow removal operations. Panel data analysis was used to determine the relationships among travel speed, weather conditions and snow removal operations. Then, multiple linear regression models were developed and compared in terms of performance. The developed models showed that temperature had a U-shaped relationship with travel speed and that snow depth had a negative correlation with travel speed. Snow removal for road widening had a positive correlation with travel speed. In contrast, fresh snow removal had a negative correlation with travel speed in a two-way fixed-effects model that incorporates time-specific effects but a positive correlation with travel speed in the other panel data models. The proposed methodology might be used for forecasting traffic congestion on urban arterials in winter and for improving winter urban road maintenance strategies.

Performance Measurement

Real-Time Probe Data Dashboards for Interstate Performance Monitoring during Winter Weather and Incidents
Paper number 16-0622, http://amonline.trb.org/trb60693-2016-1.2807374/t005-1.2821934/323-1.2822540/16-0622-1.2819331/16-0622-1.2822545

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Abstract: The Indiana Department of Transportation (INDOT) manages over 1800 centerline miles of interstate that can be profoundly impacted by weather, crashes, and construction. Real-time performance measurement of interstate speeds is critical for successful traffic operations management. Agency managers and Traffic Management Center decision makers need situational awareness of the network and the ability to identify irregularities at a glance in order to manage resources and respond to media queries. One way to access this level of detail is crowdsourced probe vehicle data. Crowdsourced probe vehicle data can be obtained by collecting speed data from cell phones and GPS devices. In Indiana, approximately 2673 predefined interstate segments are used to generate over 3.8 million speed records per day. These data can be overwhelming without efficient procedures to reduce and aggregate both spatially and temporally. This

paper introduces a spatial and temporal aggregation model and an accompanying real-time dashboard to characterize the current and past congestion history of interstate roadways. The primary high level view of the aggregated data resembles a stock ticker and is called the "Congestion Ticker." The data archive allows for after-action review of major events such as ice storms, major crashes, and construction work zones. The utility of this application is demonstrated with two case studies: a snowstorm that covered northern and central Indiana in February 2015 and an I-70 back of queue crash in April 2015.

Winter Road Performance Measurement on a "2+1" Lane Highway in Hokkaido, Japan
Paper number 16-1995, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/725-1.2819935/16-1995-1.2814897/16-1995-1.2819940

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Abstract: In this study, to measure the performance of a "2+1 lane" highway in a snowy cold region, fixed-point observation and probe survey were done for the Saraki-tomanai section of National Highway 40 in Hokkaido, Japan. The evaluation indexes for the fixed-point observation of highway performance were set as percent followers and follower density. A total of 20 test subjects participated in the probe survey, with each subjects driving on the experiment section at a free travel speed. An event data recorder was installed in the test vehicle, and a wearable automated blood pressure and heartbeat monitor was worn by each test subject. The evaluation indexes of highway performance in the probe survey were driving speed; RRI (R-R interval) average, which expresses the degree of stress felt by the driver; and Lorenz Plot area. For the section with an added lane, the fixed-point observation found the percent followers and follower density to be low in summer and winter. This demonstrates that the level of service improved. From the result of the probe survey, the differences in the average driving speed according to the cross-sectional component of the highway were shown. The average RRI value and the LP area showed less variance in winter than in summer, which showed that winter driving tended to impose a greater load on the drivers than summer driving did. It was possible to measure the highway performance for each set of cross-sectional components of a "2+1 lane" highway in summer and winter.

A Connected Vehicle Solution for Winter Road Surface Condition Monitoring
Paper number 16-5865, http://amonline.trb.org/trb60693-2016-1.2807374/t017-1.2819856/622-1.2819991/16-5865-1.2819992/16-5865-1.2819993

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Abstract: This paper describes a connected vehicle based winter road surface condition (RSC) monitoring solution that combines vehicle based image data with those from road weather information system (RWIS). The proposed solution was intended as an improvement to a smartphone-based system evaluated in previous research. Three machine-learning based classification methods, namely, artificial neural networks (ANNs), random trees (RTs) and random forests (RFs), were evaluated for their potential to be applied in the connected vehicle based system for RSC monitoring. Field data collected during the 2014-15 winter season were used for model calibration and validation. Results showed that all models improved the accuracy of the smartphone-based RSC classification substantially with the RF having the highest classification performance. The models were however found to lack transferability, therefore requiring local calibration prior to being used at any particular location.

Research

Does Winter Road Maintenance Help Reduce Air Emissions and Fuel Consumption?

Paper number 16-4128, http://amonline.trb.org/trb60693-2016-1.2807374/t010-1.2820652/725-1.2820749/16-4128-1.2819939/16-4128-1.2820750

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Abstract: Winter road maintenance (WRM) has been shown to have significant benefits of improving road safety and reducing traffic delay caused by adverse weather conditions. It has also been suggested that WRM is also beneficial in terms of reducing vehicular air emissions and fuel consumptions because snow and ice on road surface often cause the drivers to reduce their vehicle speeds or to switch to high gears, thus decreasing fuel combustion efficiency. However, there has been very limited information about the underlying relationship, which is important for quantifying this particular benefit of a winter road maintenance program. This research is focused on establishing a quantitative relationship between winter road surface conditions and vehicular air emissions. Speed distribution models are developed for the selected Ontario highways using data from 22 road sites across the province of Ontario, Canada. The vehicular air emissions under different road surface conditions are calculated by coupling the speed models with the engine emission models integrated in the emission estimation model - MOVES. It was found that, on the average, a 10% improvement in road surface conditions could result in approximately 0.6% to 2% reduction in air emissions. Application of the proposed methodology is demonstrated through a case study to analyse the air emission and energy consumption effects under specific weather events.