



2015 TRB Annual Meeting Papers Related to Winter Maintenance

Materials

Improved User Experience and Scientific Understanding of Anti-icing and Pre-wetting for Winter Maintenance in North America

Paper number 15-5823, <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/218-1.1813256/15-5823-1.1801999/15-5823-1.1802000>

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Abstract: In recent years, North American highway agencies are increasingly adopting innovative snow and ice control strategies, including anti-icing and pre-wetting practices. In 2005, to synthesize the benefits and outcomes of implementing such strategies, a survey on the practice of anti-icing and pre-wetting was conducted; however, insufficient information and limited understanding were summarized to account for their low usage at that time. A decade later, research is needed to document improved user experience and scientific understanding on these strategies, which can be used in a comparative manner. Through a follow-up survey launched in April 2014 with the same focus as the 2005 survey, a contrastive synthesis is presented which summarizes changes in the evolution of anti-icing and pre-wetting in the past decade, including the occupancy of snow and ice control strategies, related costs, environmental concerns, corrosion, and community response. The research demonstrates the elevated and indispensable status of anti-icing and pre-wetting strategies in current winter maintenance activities relative to their limited use ten years ago. The research further supports their positive effects on economic, environmental and social goals, which is attributable to the proactive and environmentally responsible performance of anti-icing and pre-wetting. Finally gaps in current practical operations and the need for further work are discussed.

Ice Formation and the Effectiveness of Deicing Agent on Porous Asphalt and Stone Mastic Asphalt

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Abstract: Porous asphalt (PA) and stone mastic asphalt (SMA) are widely used by multiple transportation agencies and public works officials. However, best winter maintenance practices for PA and SMA are unclear and generally unquantified. In this study, laboratory tests under controlled, artificial wintry conditions were conducted to evaluate the winter performance of PA and SMA. The tests results are summarized as follows. (1) PA is effective at reducing both the amount of water that forms an ice layer on the pavement surface and the thickness of the ice layer. SMA has intermediate effects between those of dense-graded asphalt (DGA) and PA. (2) In terms of the effectiveness of the deicer, the rate of decrease in ice layer thickness was found to be the largest for PA, and that for SMA was intermediate between those

for DGA and PA. (3) The features described above are dependent on the temperature and the amount of water applied. Analysis of the experimental data found that the coefficient of friction has a strong correlation with ice layer thickness and that the ice layer thickness can be predicted from mean profile depth, permeability, temperature, water dosage, deicer application amount and number of wheel passes. Accordingly, the study suggests the possibility of determining the ice layer thickness at which friction-generating contact between the pavement and the tire is reduced and how much deicer is needed to maintain a certain level of service based on pavement type, weather conditions and traffic volume.

The Temperature Dependence of Solution Induced Weakening of Compacted Snow

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Abstract: Snow that compacts on roads is difficult to remove and may become slippery at temperatures close to the melting point. To avoid snow compaction, chemicals are often applied before or during a snowstorm. Initially chemicals act by melting snow. The solution which forms then reduces the ability of snow to compact by weakening the bonds between individual snow crystals. While the melting capacity of different chemicals has been thoroughly studied at different temperatures, the temperature dependence of the anti-compactive effect that liquid solution has on snow is unknown. This anti-compactive effect was studied in an experiment where snow was mixed with a solution at equilibrium with ice and compacted to a constant dry density. The degree of compaction was indicated with a micro penetration hardness test. The experiment was performed at three different temperatures; -2°C , -6°C and -17°C (28°F , 21°F and 1°F). The results showed that the liquid solution became less efficient at lower temperatures. To achieve the same snow hardness at -17°C , five and three times more solution was required compared to at -2°C and -6°C respectively. At -6°C approximately 1.7 times more solution was required compared to at -2°C . The combination of an increased solution content at lower temperatures with the increased concentration required for a solution to remain liquid, leads to a large increase in required salt application as the temperature decreases. This combination can likely contribute to why chemicals lose their practical effectiveness in winter maintenance at temperatures substantially higher than the eutectic temperature.

Effectiveness of Liquid Agricultural By-Products and Solid Complex Chlorides for Snow and Ice Control

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Abstract: Agro-based products and complex chlorides/minerals (CCM) based products are increasingly employed in snow and ice control operations, either used alone or more commonly as additives for chloride-based products. Recent studies have shown that agro-based or CCM based products have the potential to improve the overall deicing and/or anti-icing performance and reduce the corrosion and environmental impacts. However, the effectiveness of such products has been limited to qualitative field observations and their specific role in snow and ice control is poorly understood. This work consists of a systematic laboratory investigation, with a focus on the thermal properties, ice melting behavior, and corrosivity of four agro-based deicers and two CCM based deicers. First, CCM based deicers do not exhibit significantly better ability to lower the freezing point of water when compared with NaCl, but they feature slightly better ice melting capacity at 15 F than NaCl. Second, agro-based additives seem to significantly lowered the freezing point of 23 wt.% NaCl brine but did not significantly improve the ice melting capacity at 15 F or 25 F, implying their role as ‘cryoprotectants’. Third, CCM and agro-based deicers do not exhibit significantly lower characteristic temperature than reagent-grade NaCl. A very strong positive linear relationship exists between the eutectic temperature (T_e) and the characteristic temperature (T_c) of the tested liquids, indirectly confirming the validity of using DSC thermograms to

assess liquid deicers. The gravimetric method reveals that CCM based deicers exhibit slightly lower corrosivity to carbon steel than NaCl and agro-based additives exhibit significant benefits in reducing the corrosivity of 23 wt.% NaCl brine. The electrochemical method reveals that while the beet-based additives do not significantly alter the corrosion potential of carbon steel, the other type of additives moved the corrosion potential to a much more positive level, implying anodic type inhibitor at work.

Effect of Pre-wetting Brines on the Ice Melting Rate of Salt at Very Cold Temperatures

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Abstract: At temperatures close to its eutectic, NaCl is shown to have substantial ice melting capacity, but the ice melting rate is very slow. The effects of MgCl₂, NaCl, and mixed MgCl₂/NaCl brines on the ice melting rate of pre-wetted sodium chloride rock salt at temperatures close to the NaCl eutectic were measured. The solid salt component of a 50/50 mixture of salt and 26.0% MgCl₂ brine melted ice 7.1 times faster than dry salt after 3 hours, 3.5 times faster after 7 hours, and 1.7 times faster after 24 hours at an average temperature of -4.4 °F (-20.2 °C). The solid salt component of a 50/50 mixture of salt and 23.3% NaCl brine melted ice 2.9 times faster than dry salt after 3 hours, 2.0 times faster after 7 hours, and 1.6 times faster after 24 hours at the same temperature. Ice melting rates with mixed MgCl₂/NaCl pre-wetting brines were intermediate between those of the straight NaCl and MgCl₂ pre-wetting brines. Above a ratio of pre-wetting brine to salt high enough so that the ice was completely covered with brine, there was no significant increase in ice melting rate with increased pre-wetting brine application rate. Preliminary evidence suggests that a contribution to the rate enhancement caused by MgCl₂ may be enhanced diffusion of NaCl from the dissolving salt crystals in the MgCl₂ brines.

Method for Predicting Change in Skid Resistance on Icy Road Surface by Deicing Salt

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Abstract: This study was conducted to optimize the application of deicing agents (hereinafter collectively referred to as “salt”), whereby a method (simplified prediction method) of facilitating the prediction of road surface skid resistance values (HFN) after salt application was established. In this paper, the theory of the simplified prediction method is explained, and a quantitative evaluation of the relation between the ice thickness on a road surface and HFN, which is necessary for the establishment of the theory, is provided. In addition, by comparing the measured values of HFN obtained in the field tests with the predicted values of HFN, the applicability of the simplified prediction method was verified.

Through the study, the following knowledge was obtained. (1) HFN increases exponentially with decrease in the average ice thickness. The relation between HFN and average ice thickness was formulated. (2) By #1, it became possible to predict the HFN after salt application on the ice film of a road surface. (3) The predicted HFN value is 13.1 HFN units greater than the measured value; thus, the predicted value overestimates the measured value. (4) On the basis of #3, it was assumed that 46% of the salt that was spread scattered beyond the roadway due to the passage of vehicles or flowed off the road due to the road gradient.

Equipment and Facilities

Safety Effects of Fixed Automated Spray Technology Systems

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Abstract: Fixed Automated Spray Technology (FAST) has emerged as a solution to provide quick, effective service delivery to such high-risk locations prone to icy conditions and/or with high traffic volumes. The Colorado Department of Transportation (CDOT) has installed and used FAST on bridges since 1998, with 32 units currently installed on bridges around the state. There is some concern regarding how effective they are in reducing accidents during winter weather. Previous FAST studies have considered the changes to crash occurrence following deployment, but these have been basic and compared seasonal figures or rates without accounting for site conditions. To address this shortcoming, an observational before-after study with the Empirical Bayes technique was used to determine the effect of FAST systems on crash frequencies. Results revealed that at sites where crashes were reduced, FAST systems contributed to an annual reduction of 2 percent on multilane rural highways, 16 to 70 percent on urban interstates, 31 to 57 percent on rural interstates and 19 to 40 percent on interchange ramps between interstates. However, at some sites, safety deteriorated with an increase in crashes. While the precise causes of such increases are not completely clear, they may have been the result of increased traffic, systems not being maintained properly, or systems applying fluids in improper amounts or at the wrong time. Based on the collective results, high traffic, high crash severity locations are most suitable for FAST deployments.

Fixed Automated Spray Technology: Current Practices and a Case Study

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Abstract: Anti-icing is an application of chemicals before a storm event in order to prevent the formation of black ice and to prevent or weaken the bond between ice and the road surface. Compared with traditional methods for snow and ice control (e.g., deicing and sanding), anti-icing can lead to decreased applications of chemicals and abrasives, decreased maintenance costs, improved level of service, and lower accident rates. Fixed Automated Spray Technology (FAST) systems are designed as a fixed asset technology for anti-icing operations at specific target areas such as bridges, tunnels, ramps and other elevated roadways. This work synthesizes information obtained from agency surveys and a field investigation on the state of the practice of FAST systems. The key findings from the study are as follows. First, every installed FAST system (reported in this survey) needed significant maintenance activities for its successful operation. Second, inconsistency in proper functioning of FAST systems is mostly due to the poor design, poor quality of installation and lack of maintenance practices for some cases. Last, non-invasive technology may help improve the reliability of FAST technology.

Road Weather Information Systems and Technology

Relationship of Winter Road Weather Monitoring to Winter Driving Crash Statistics

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Abstract: The deployment of Road Weather Information Systems (RWIS) using state of the art non-invasive pavement sensors together with the atmospheric sensors has advanced the capabilities of the Idaho Transportation Department (ITD) maintenance crews to better plan their winter storm response, both in treatment chemical selection and application timing. The results of the winter maintenance activities are now measured through a Winter Performance Measurement program that evaluates how well each maintenance crew is doing with regards to achieving and maintaining safe grip roads during and after storm events.

The results of this recent focus towards data driven maintenance operations has revolutionized the level of service ITD provides its customers in terms of year round safety and mobility. ITD has developed a quantitative data collection procedure to measure the effectiveness of the RWIS and Winter Performance Measure program in improving safety, which was evaluated through a benefit/cost study.

This paper compares winter driving crash statistics on road segments prior to the deployment of RWIS sites to crash statistics after winter road condition data became available through RWIS deployment and then calculates a benefit/cost metric. For the study period (2010-2013) the benefit/cost is, which concludes that strategically deployed RWIS sites and proper utilization of the data easily justifies the investment in infrastructure and operations.

For the 3-year study period and the highway segments being analyzed, winter driving fatalities dropped from 5 in the baseline season to 1 in the second season to zero in the third season.

Optimization of Winter Road Maintenance under Traffic and Weather Information

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Abstract: The total estimated direct annual cost of winter maintenance amounts to \$1 billion for Canada and \$2 billion for the United States. Municipalities seek technology-based solutions such as information systems to optimize operations and reduce costs. As an example, Advanced Road Weather Information Systems provide real time weather forecasts which, coupled with traffic information systems, can be influential in reducing maintenance costs. We present, in this paper, a model for managing winter road maintenance operations under weather and traffic information. The model captures the interactions between plow (spreader) trucks, height of snow on ground, and corridor traffic. An extension of the original model is formulated which considers multi-segment corridors with on-ramps and off-ramps. Results show that traffic is barely affected in cases where the storm peak occurs later than the traffic peak. The model also indicates the benefits of sending multiple plow (or spreader) trucks. In general, dispatching multiple maintenance trucks is justified in cases where the storm peak is relatively close to the traffic peak. Sensitivity analysis on the multi-segment corridor model shows that having a higher number of maintenance trucks increases dispatching flexibility which can consequently reduce delays extensively.

Road Condition Imaging—Model Development

Paper number 15-0885; <http://amonline.trb.org/trb57535-2015-1.1793793/t021-1.1814337/815-1.1802781/15-0885-1.1814362/15-0885-1.1814363>

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Abstract: It is important to classify road conditions to plan winter road maintenance, carry out proper actions and issue warnings to road users. Existing sensor systems only cover parts of the road surface and manual observations can vary depending on those who classify the observations. One challenge is to classify road conditions with automatic monitoring systems. This paper presents a model based on data from winter 2013-2014, retrieved from two installations in Sweden and Norway. To address that challenge an innovative and cost effective road condition imaging system, capable of classifying individual pixels of an image as dry, wet, icy or snowy, is evaluated. The system uses a near infra-red image detector and optical wavelength filters. By combining data from images taken from different wavelength filters it is possible to determine the road status by using multiclass classifiers. One classifier for each road condition was developed, which implies that a pixel can be classified to two or more road conditions at the same time. This multiclass problem is solved by developing a Bayesian Network that uses road weather information system data for the calculation of the probabilities for different road conditions.

Optimizing Environmental Sensor Station (ESS) Location Through Weather-Sensitive Hotspot Analysis

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Abstract: Optimizing environmental sensor station (ESS) location is a central task in roadside weather information system (RWIS) design and planning. In this paper, we propose a data-driven approach for optimizing region-wide ESS locations. The idea lies in identifying crash hotspots that are sensitive to weathers, and monitoring these hotspots more closely than other non-sensitive locations. To this end, we derive a distribution-free statistic that can faithfully capture the weather-sensitivity attribute, and formulate a nonlinear program to maximize the total utility of ESS based on diagnosis of weather-sensitive hotspots. The proposed approach is simple to implement, so it is especially suited for large-scale applications involving complex road networks or a large number of road segments. We demonstrate its application with data of Austin, Texas.

Program Management

Effectiveness of Video Camera-Based Remote Roadway Condition Monitoring on Snow Removal-Related Maintenance Operations

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Abstract: Remote monitoring through the use of cameras is widely utilized for traffic operation, but has not been utilized widely for roadway maintenance operations. The Utah Department of Transportation has implemented a new remote monitoring system, referred to as a Cloud-enabled Remote Video Streaming

(CRVS) camera system for snow removal-related maintenance operations. This study evaluated the effectiveness of the use of the CRVS camera system in snow removal-related maintenance operations and was conducted in two parts: opinion surveys of maintenance station supervisors and an analysis on snow removal-related maintenance costs. On a scale of 1 (least effective) to 5 (most effective), the average overall effectiveness given by the station supervisors was 4.3 for both direct interviews and online questionnaire. The average reduction in expedition trips after the installation of the camera was estimated to be about 33 percent. An expedition cost comparison was performed for 10 sets of maintenance stations within Utah. It was difficult to make any definitive inferences from the comparison of expedition costs; hence, a statistical analysis was performed using the Mixed Model ANOVA, resulting in an average of 14% higher ratio of expedition costs at maintenance stations with a CRVS camera before the installation. This difference was not proven to be statistically significant at the 95% confident level, but indicated that the CRVS cameras were on the average helpful in reducing expedition costs and may be considered practically significant.

Dynamic Snowplow Fleet Management Under Uncertain Demand and Service Disruption

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Abstract: It is sometimes challenging to plan winter maintenance operations in advance because snow storms are stochastic with respect to, e.g. start time, duration, impact area, and severity. Besides, maintenance trucks may not be readily available at all times due to stochastic service disruptions. A stochastic dynamic fleet management model is developed to assign available trucks to cover uncertain snow plowing demand. The objective is to simultaneously minimize the cost for truck deadheading and repositioning, as well as to maximize the benefits (i.e., level of service) of plowing. The problem is formulated into a dynamic programming model and solved using an approximate dynamic programming (ADP) algorithm. Piece-wise linear functional approximations are used to estimate the value function of system states (i.e., snow plow trucks location over time). We apply our model and solution approach to a snowplow operation scenario for Lake County, Illinois. Numerical results show that the proposed algorithm can solve the problem effectively and outperforms a rolling-horizon heuristic solution.

Pilot Study: Pavement Visual Condition and Friction as a Performance Measure for Winter Operations

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Abstract: Snow and ice removal and clearing roadways after a winter storm account for major portion of roadway agencies located in snowy region's maintenance budget. With the decreasing funds and increasing demand from the motoring public for mobility, roadway agencies are continuously looking for new innovative approaches for winter maintenance operations. One of the main focus of these approaches include performance measures for winter maintenance. This is specifically important when roadway agencies use contractors to perform winter maintenance tasks.

In this study, two performance measures are studied extensively. These include, visual pavement condition behind the snow plow and pavement friction behind the snow plow. Visual pavement condition was observed and recorded into one of five categories while driving behind a snow plow. Pavement friction behind snow plow is measured using a Continuous Friction Measuring (CFT) device. Since visual pavement condition provides driver's perception of the winter driving condition and friction measurements provide an objective measurement of the safety of the roadway under winter condition, a correlation of these provides a basic guideline for winter maintenance and performance measurement of winter maintenance.

During the past winter, multiple data collection cycles were performed behind different type of snow plows along I-96 in Livingston County. These preliminary data was used to obtain relationships between winter storm severity, snow plow type and the selected performance measures.

Impacts of Transportation System Operations Strategies During Non-Recurring Events: Lessons Learned from a Virginia Case Study

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Abstract: Transportation systems across the nation are significantly impacted by non-recurring events like incidents, workzones and weather, on a daily basis. To mitigate these impacts, State and local transportation agencies have been increasingly implementing operations strategies such as traffic incident management, coordinated workzone road closure, weather treatments, and traveler information. To better understand the impacts of these events and the operations strategies, and hence better manage the strategies themselves, the Virginia Department of Transportation (VDOT) recently completed a research project. The project analyzed select incidents, workzones and weather events in detail, realizing the new opportunities presented by the emerging crowd-sourced traffic speed data. Several performance measures were calculated and presented in tabular form and through visualizations. Major lessons learned during this project are presented as challenges and applied solutions under these five topics: benchmark selection, data and calculation methodology, visualization, data quality, and diversity of measures.

On-line Implementation and Evaluation of Weather Responsive Coordinated Signal Timing Operations

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Abstract: The study presents the development and application of weather responsive traffic management (WRTM) strategies and tools to support coordinated signal timing operations under the support of Traffic Estimation and Prediction System (TrEPS) models. First, a systematic framework for implementing and evaluating traffic signal operations under severe weather conditions is developed, where activities for planning, preparing and deploying signal operations are identified in real-time traffic management center (TMC) operations. Next, weather responsive coordinated signal plans are designed and evaluated using the TrEPS methodology with a locally calibrated network. On-line implementation and evaluation is conducted in Salt Lake City, making it the first documented on-line application of TrEPS to support coordinated signal operation under inclement weather. The analysis results confirm that the deployed TrEPS, which is based on DYNASMART-X, is able to help TMC operators to test appropriate signal timing plan proactively under different weather forecast before deployment, and is capable of using available real-time measurements to improve the quality and accuracy of its estimation and future prediction with the current detectors and roadside sensor coverage.

A Numerical Algorithm for Snowdrift Prediction Model, SMOOTH

Paper number 15-5670; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/381-1.1812979/15-5670-1.1817118/15-5670-1.1817119>

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Abstract: Prediction of snow drift is important for structure design and traffic management on snowy and windy prairie landscapes. Snow redistribution by wind is a challenging topic because of the complexity of

the process. In this study, a snow movement equation was formulated for horizontal two-dimensional sub-regional scale applications at a grid resolution of 10-30 m by incorporating snow transport, wind snow diffusion, and snow gravitational movement. The key feature of this new formulation is the snow surface diffusion in terms of the autocorrelation functions of the measurable wind velocity field using Taylor's theorem. After subtracting their moving average values from the original wind speed data, a delta correlation of the wind turbulent component was found to be acceptable. The predictive snow redistribution model, namely Snow Movement Over Open Terrain for Hydrology (SMOOTH) model, was proven to reproduce the observed equilibrium snow profiles affected by wind drifting reported in the previous study. The detailed numerical algorithm for the SMOOTH model is presented in this paper since this model requires a mechanism to limit the erosion of immobilized snow and ground after the disappearance of mobile snow. A two-dimensional model simulation using a 10-m digital elevation model in Muddy Gap and Arlington, Wyoming, is also presented for demonstration of the potential applications for road management practice, although this model was originally developed for water resources applications.

Pavements and Bridges

Performance of Conventional Portland Cement and Calcium Silicate Based Carbonated Cementitious Systems During Freezing and Thawing in the Presence of Calcium Chloride Deicing Salts

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Abstract: This paper examines the behavior of two different cementitious materials during thermal changes associated with freezing and thawing in presence of calcium chloride (CaCl₂) deicing salts. The two systems consist of a conventional portland cement based material and an alternative economically friendly cement that forms a solid by carbonating a Calcium Silicate based Cement (CSC). Low Temperature Differential Scanning Calorimetry (LT-DCS) is used to quantify the phase changes associated with ice formation, eutectic solution transformation and calcium oxychloride formation. Longitudinal guarded comparative calorimetry (LGCC) was used to detect the damage that develops due to the expansive pressures created by these phases when they form. In both systems exposed to low salt concentration the damage is primarily due to hydraulic and osmotic pressure. This type of damage is moderate at low degrees of saturation (e.g., < 90%), however as the degree of saturation increases so does the damage. In conventional cementitious systems at higher salt concentrations the damage that develops is mainly due to the formation of calcium oxychlorides. However, in the cementitious materials made by carbonating calcium silicate based cement calcium hydroxide is not present, therefore at higher salt concentrations calcium oxychloride does not form and as a result no damage develops.

Self-Heating Electrically Conductive Concrete for Pavement Deicing: A Revisit

Paper number 15-4764; <http://amonline.trb.org/trb57535-2015-1.1793793/t023-1.1813375/308-1.1813986/15-4764-1.1813993/15-4764-1.1813994>

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Abstract: The addition of conductive materials to conventional concrete to achieve electrically conductive concrete (ECC) for non-structural applications such as heating (deicing), sensing, monitoring, and electromagnetic interference shielding has been the subject of many studies in the past. The overall objective of this paper is to revisit the topic of self-heating ECC for pavement deicing applications, especially with the focus on conductive concrete mix design optimization. The paper discussed related studies reported in the literature to identify the various conductive materials that have been investigated in the past, their optimal concentration levels to achieve desirable system-level engineering properties, and the various challenges in optimizing the ECC mix design and achieving a cost-effective ECC system. These studies reveal that optimization of ECC mix design, to achieve high conductivity and at the same time maintain adequate mechanical properties (workability, strength, and durability), is a highly challenging task. Instead of using large quantities of single conductive material to achieve well-performing ECC, which can be not only expensive but also result in reduced strength properties, the combined use of various conductive materials (especially the combination of conductive fibers and powders) in concrete has the potential to achieve cost-effective and well performing ECC with adequate electrical and mechanical properties.

Safety

Winter Road Surface Condition Monitoring: Field Evaluation of a Smartphone-based System

Paper number 15-3132, <http://amonline.trb.org/trb57535-2015-1.1793793/t021-1.1814337/815-1.1802781/15-3132-1.1800141/15-3132-1.1800142>

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Abstract: This paper describes the field evaluation of a smartphone-based winter road surface condition (RSC) monitoring system. The system was deployed on eight maintenance and patrol vehicles and tested during the Winter 2013/14 season on a section of Highway 6 in Ontario, Canada, with this study focusing on data obtained from four of the vehicles. This paper details the evaluation of the system from three perspectives: spot-wise monitoring, route-level monitoring and system reliability by comparing its RSC monitoring results to manual classifications, patrol records and a Travellers Road Information Portal (TRIP), a public-facing website. The system's consistency with current RSC monitoring methods was assessed and it was found that the smartphone-based system is capable of providing reliable results in comparison with the current method of patrol reporting for route-level monitoring of winter road conditions. Key performance factors were investigated and recommendations for system improvement were made.

An Application of the Empirical Bayes Method for Identifying Winter Weather Crash Hot Spots

Paper number 15-4785, <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/381-1.1812979/15-4785-1.1817124/15-4785-1.1817125>

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Abstract: Traffic safety during winter seasons has been a serious concern for transportation agencies and road users in state with severe winters. Given the limited resources available to state agencies for winter weather operations, it is necessary to establish a prioritization technique for identifying high crash risk locations during winter conditions. Traditional methods to identify crash hot spots suffer from serious limitations including the regression-to-mean problem. These methods also typically do not consider weather information for identifying hotspots for safety countermeasure action. This paper proposes a novel approach to extract weather data from information reported by winter maintenance crew members. This approach is applied to incorporate weather-related factors (such as visibility, wind velocity, air

temperature) in developing winter-weather crash frequency models at the network level for three roadway types in Iowa. Then, this paper employs the Empirical Bayes technique to rank study roadway segments based on their potential for safety improvement. The developed winter weather crash frequency models can be used to make data driven decisions to prioritize road segments for improving winter weather operations and safety.

Seasonal Effects of Crash Contributing Factors on Highway Safety

Paper number 15-4597, <http://amonline.trb.org/trb57535-2015-1.1793793/t006-1.1818822/386-1.1805584/15-4597-1.1819902/15-4597-1.1819903>

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Abstract: A longitudinal negative binomial model is developed in this paper that takes into account the seasonal effects of crash causality factors based on ten years (2002-2011) of Missouri Interstate highway crash data. The technique of generalized estimating equation (GEE) with autoregressive correlation structure is used. The results explain the overall effect of seasonality and whether the magnitude and/or type of various effects are different according to climatic changes. Traffic volume was found to have an appreciable effect in increasing the crash occurrence in spring and lower effect in winter, compared to the fall season. Fewer crashes were associated with higher pavement serviceability (measure of pavement surface quality, higher value is better) and this effect was found to be highest in the spring season followed by summer and winter, again when compared to the fall season. Heavy vehicles were found to reduce the likelihood of crash occurrences and this effect is higher in urban areas; although compared to other times of the year, the effect of heavy vehicles is lower during the summer season. The results indicated that the fall season is associated with the lowest crash frequency compared to the other seasons; winter season having the highest impact followed by summer and spring. This paper also evaluated the effects of the Missouri's Strategic Highway Safety Plan (MSHSP) implemented from 2005-2011. The plan was found to be effective as it reduced the crash frequency. Similar strategic plans therefore should be initiated in the future as well.

Safety Effectiveness of Variable Speed Limit (VSL) System in Adverse Weather Conditions on Challenging Roadway Geometry

Paper number 15-4452, <http://amonline.trb.org/trb57535-2015-1.1793793/t007-1.1818198/766-1.1804560/15-4452-1.1818297/15-4452-1.1818298>

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Abstract: This study examines the interaction between roadway geometric characteristics and adverse weather conditions on crash occurrence on rural Variable Speed Limit (VSL) freeway corridors through mountainous terrain. As a quantitative measure of the effect of geometrics in adverse weather conditions, a crash frequency safety performance function using Generalized Linear Regression was developed with explanatory variables including snow, ice, frost, wind, horizontal curvature and steep grades. This research concluded that the interaction between grades and horizontal curves with weather variables have a significant impact on crash occurrence and the research suggests that distinct VSL strategies should be implemented on segments with challenging roadway geometry.

Driver Behavior

Effect of Weather Conditions and Snow-Removal Operations on Travel Speed in an Urban Area

Paper number 15-0605; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/347-1.1813173/15-0605-1.1801574/15-0605-1.1801575>

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Abstract: Sapporo, the fourth-most-populous city in Japan, is the world's snowiest city with more than 1 million population. The city appropriates approximately \$150 million dollars for snow removal to support socioeconomic activities in winter, and about 76% (about \$116 million dollars) of the snow removal budget is spent on road management annually. The city of Sapporo has experienced financial pressure due to the snow removal costs.

The effective number of lanes in winter is decreased by some snow removal operations (plowing) and increased by others (hauling), and the average speed of vehicles in February 2013 (winter) was about 10 km/h slower than in October 2013 (autumn). In other words, the roads are more prone to traffic congestion in winter than in the other seasons. The objective of this study is to investigate the effects of weather conditions and snow removal operations on travel speed, toward find out the causes of winter traffic congestion in Sapporo. The study area is a 5-km section of Nishi-5-chome Tarukawa Dori. Travel speeds were obtained from taxi probe data for 06:00 to 21:00 on weekdays in February 2013. The observed weather conditions were temperature, snowfall and snow depth. Furthermore, operations to remove fresh snow and to increase the effective road width were the snow removal operations data used for analysis.

Four steps are performed to identify the relationships among traffic, weather and snow removal operation factors. The first step is to establish a dataset for analysis by combining traffic, weather and snow removal operation data. The second is to develop multiple linear regression (MLR) models with all the variables. The next step is to investigate the periodicity of the residuals, toward applying autoregressive integrated moving average (ARIMA) models between actual and predicted values by the MLR models. Then, ARIMA models or seasonal ARIMA models are developed, depending on the periodicity. The last step is to combine R-squares of the MLR and the ARIMA models. It was shown that the power of explanation for the speed prediction model is improved by combining the two models. As a result of applying the ARIMA and SARIMA models at the residuals, the R-square values were found to increase by 0.60. This study presents basic data for establishing traffic operations strategies as a part of winter road management strategies.

Modeling the Impacts of Inclement Weather on Freeway Traffic Speed: An Exploratory Study Utilizing Social Media Data

Paper number 15-4749; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/772-1.1811937/15-4749-1.1816697/15-4749-1.1816698>

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Abstract: Recently, there has been an increased interest in quantifying and modeling the impact of inclement weather on transportation system performance. One problem that the majority of previous research studies on the topic have faced is that they largely depended on weather data merely from atmospheric weather stations, which lacked information about road surface condition. The emergence of social media platforms, such as Twitter and Facebook, provides a new opportunity to extract more

weather related data from such platforms. The current study has two primary objectives; first, to examine if real world weather events can be inferred from social media data, and secondly, to determine whether including weather variables, extracted from social media data, can improve the predictive accuracy of models developed to quantify the impact of inclement weather on freeway traffic speed. To achieve those objectives, weather data, Twitter data, and traffic information were compiled for the Buffalo-Niagara metropolitan area as a case study. A method called the Twitter Weather Events observation was then applied to the Twitter data, and the sensitivity and false alarm rate for the method was evaluated against real world weather data. Following this, linear regression models for predicting the impact of inclement weather on freeway speed were developed with and without the Twitter-based weather variables incorporated. The results indicate that Twitter data has a relatively high sensitivity for predicting inclement weather (i.e., snow) especially during the daytime and for areas with significant snowfall. They also show that the incorporation of Twitter-based weather variables can help improve the predictive accuracy of the models.

Identifying Travel Patterns During Extreme Weather Using Taxi GPS Data

Paper number 15-5556; <http://amonline.trb.org/trb57535-2015-1.1793793/t030-1.1806649/659-1.1806964/15-5556-1.1806965/15-5556-1.1806966>

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Abstract: Analysis of taxi global positioning system (GPS) pickup and dropoff records in Manhattan was conducted to compare potential differences in how and where New Yorkers travel during a major winter storm in February 2013 and during fair weather conditions. The purpose of this study was to identify unique patterns of travel during a highly disruptive weather event in New York City, assess the impacts of that event on travel behavior, and demonstrate the applications of GPS technology and use of probe data in situational analyses of the interaction between environmental conditions and transportation system operations. This study finds that travelers opted to take shorter trips during the snowstorm than during fair weather conditions, and that average travel speeds during the storm were surprisingly faster than usual during the evening rush hour as commuters left work early, but slower during the overnight hours, as the storm intensified. The analysis results also indicate that taxi trips during work hours remained relatively consistent with the fair weather day in spite of the heavy snowfall; however, taxi trip volumes in the evening and overnight hours during the storm from Friday, February 8 through Saturday, February 9 were sharply lower than during fair weather, partly due to a sharp reduction in taxi supply, which lagged taxi demand in recovery in the hours after the storm's passage.

Traffic Modeling

A Multiple-Step Traffic Speed Forecasting Strategy for Winter Freeway Operations

Paper number 15-0879; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/347-1.1813173/15-0879-1.1801571/15-0879-1.1801572>

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Abstract: Accurate and timely predictions of traffic conditions are required for congestion avoidance and route guidance in real-time freeway traffic operations. In fact, special attention to winter operations is needed because prediction error could be amplified under severe weather conditions involving snow. This study employs a vehicle detection system (VDS) to propose a speed prediction methodology using the k-nearest neighbors (KNN) algorithm. The speed prediction is further evaluated under different weather

conditions using a road weather information system (RWIS). Cross-comparisons of the mean absolute percentage error (MAPE) among three weather conditions (“normal”, light snow, and heavy snow) reveal that the MAPE tends to increase with increases in both the forecasting time-step (T) and snow intensity. The marginal MAPE over T is larger during heavy snow conditions than under the “normal” and light snow conditions. These findings indicate that for winter freeway operations, T should be selected dynamically depending on the weather condition rather than using a static strategy for all conditions. To this end, this study proposes a framework to determine a dynamic forecasting time-step associated with weather conditions.

Use of Data Mining Technology to Investigate Vehicle Speed in Winter Weather: A Case Study

Paper number 15-2382; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/347-1.1813173/15-2382-1.1801565/15-2382-1.1801566>

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Abstract: Each winter, Alberta Transportation (AT) spends significant capital on winter road maintenance. It is not enough to use only “time to bare pavement” as the performance measure for winter maintenance. In addition, the databases from various Intelligent Transportation System services in AT are growing explosively every year. New techniques and tools are needed to intelligently transform the abundant of stored data into useful information and knowledge. Previous studies have shown that vehicle speed is a good measure and a fair assessment of winter maintenance operations. This study used the Apriori algorithm, a data mining technique, to investigate the association rules between vehicle speed and various factors. The traffic, weather, and winter maintenance operation data in Alberta are collected and integrated in the SQL server databases. Results of the case study confirmed the expected effects of several weather variables, including snow intensity and pavement surface conditions. The future study will add the collision data into the database for further analysis.

A Validation of Inclement Weather Traffic Models in Buffalo, New York

Paper number 15-1967; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/772-1.1811937/15-1967-1.1816700/15-1967-1.1816701>

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Abstract: The impact of inclement weather on traffic conditions has long been a concern to drivers and transportation agencies alike. Inclement weather conditions, such as fog, rain, snow, and ice, are known to negatively impact the operational efficiency of networks, as well as user safety. Recently, the effect of inclement weather on freeway operating conditions near the city of Buffalo, NY has been the topic of multiple studies. Specifically, two studies have attempted to model average operating speed and hourly traffic volume, respectively, as a function of weather conditions. The objective of the current study is twofold. First, the current paper will attempt to determine if most recent winter (2013-2014) has been harsher compared to the previous couple of winters in Buffalo, which have tended to be milder than normal. The second objective is to test the accuracy of the models developed during the previous two studies using more recent data, which includes the most recent 2013-2014 winter. The winter of 2013-2014 was found to have significantly lower minimum and average temperatures than other years examined. In terms of the previous models’ accuracy, the speed model performed reasonably well, usually achieving results within 5 mph of the observed speed, but accuracy somewhat suffered when inclement weather conditions were harsh or when observed speeds were below 40 mph. The volume model’s accuracy was usually within 100% of the observed volume. It was also observed that the volume model tended to overestimate hourly volumes.

Empirical Analysis of Freeway Flow Breakdown and Recovery: The Effect of Snow Weather

Paper number 15-3817; <http://amonline.trb.org/trb57535-2015-1.1793793/t024-1.1811852/445-1.1812750/15-3817-1.1812767/15-3817-1.1812768>

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Abstract: The objective of this study is to illustrate the effect of snow on freeway flow breakdown and recovery with the use of commonly available freeway loop detector data and automated surface observing weather information. The impact of loading and reloading cycles on the performance of a single freeway facility in a selected network, instead of the whole network, is investigated with emphasis on the formation and characterization of the hysteresis patterns. A dual-regime speed-density model is applied for calibrating the general traffic flow pattern and identifying free flow speed under different weather conditions; a general procedure based on the K-means clustering algorithm is adopted for clustering traffic speed data and recognizing typical scenario clusters under the snow effect. Comparison of a scenario-based distribution throughout a single facility at critical locations suggests the characteristics of loading and reloading cycles and the inhomogeneity of the snow effect. With two typical network case studies focused on peak and off-peak traffic distribution, the analysis results provide a deeper understanding of the properties of the breakdown and recovery process for a freeway network under the snow event.

Addressing the Variability in Bottleneck Discharge Flow During Adverse Weather

Paper number 15-5009; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/616-1.1812202/15-5009-1.1816768/15-5009-1.1816769>

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Abstract: Traffic flow on basic freeway segments has been shown in prior research to be affected negatively by the input of weather. This work goes further by examining the changes in discharge flow from an active freeway bottleneck during adverse weather. After collecting data from four different sites, it was revealed that there was significant variability in discharge flow that could not be easily explained simply by rainfall intensity alone. Two different hypotheses were proposed, a simple one incorporating two additional weather elements (wind speed and visibility) and a complex hypothesis dividing up different periods of congestion into categories each with a specific set of regressors. While both hypotheses performed better than simply regressing discharge flow against rainfall intensity, the complex hypothesis was able to produce generic results across all sites with R-squared exceeding 0.50. The ability to understand changes in discharge flow during weather will undoubtedly help travel services predict future travel times.

Weather Forecasting

Trends of Future Heavy Snowfall and Accumulated Freezing Indexes in Hokkaido, Japan

Paper number 15-3719; <http://amonline.trb.org/trb57535-2015-1.1793793/t011-1.1816597/381-1.1812979/15-3719-1.1817127/15-3719-1.1817128>

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Abstract: To achieve sufficient, effective winter maintenance, it is important that long-term snow and ice hazard mitigation plans be examined and formulated by taking into consideration the influence of climate change. Due to our concern with the accuracy of global climate model output, we felt it would be preferable to calibrate the results from the climate model in order to estimate future prospects of snow and ice conditions more precisely. In this study, we have developed a method of predicting more accurately the indexes of heavy snowfall events that occur over short periods of time and future projections of winter

temperatures based on the relationship of observed data to the climate model predicted values. Subsequently, we have applied this methodology for Hokkaido, located in northernmost Japan, in order to clarify the trends for near future and century-end future period changes. The results indicate that current measures to mitigate the effects of extremely heavy snowfall in specific areas of Hokkaido may require enhancement of operational procedures, such as those pertaining to snow piling widths on roadsides. In addition, the risk of pavement damage in the colder regions is expected to increase due to the increment in the number of days of zero-crossing.

Research

Developing a “Top Ten List” for Winter Highway Maintenance

Paper number 15-1199; <http://amonline.trb.org/trb57535-2015-1.1793793/t021-1.1814337/815-1.1802781/15-1199-1.1800144/15-1199-1.1800145>

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Abstract: The winter maintenance community has used many methods in the past decade to determine research needs, including peer exchange meetings, an email list serve, and an NCHRP 20-7 project that identified Grand Challenges. This is in addition to annual, biannual, and quadrennial scientific meetings at which new research results are presented and discussed. However, at the most recent peer exchange meeting, held in September 2013, the question was raised as to whether there might be research issues that had not been discussed, as well as how such issues might be identified and how those who had not been involved in the research needs discussion might be included.

A two part approach was taken to address this potential shortcoming in the winter maintenance research needs identification process. First, the list serve was used to poll ideas for a top ten list of research needs. The same message used for the list serve was also sent to others in the International winter maintenance community, including members of the PIARC (Permanent International Association of Road Congresses) 2.4 working group. This generated a list of 181 ideas which were reviewed by the AASHTO Winter Maintenance Technical Services Program (WMTSP) Steering Committee. Committee members selected their top choices, and in addition, 74 of the ideas were used in an online survey to gather input from a broader audience. The online survey generated a top ten list of 11 ideas (two of them got identical scores) which are presented herein.