2014 TRB Annual Meeting
Papers Related to Winter Maintenance

Materials

Evaluation of Snow and Ice Control Materials for Highway Maintenance Operations: Renewed, Data-Driven Perspective

Paper number 14-1469, http://amonline.trb.org/2014-1.405766/14-1469-1.414823

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Abstract: The use of chemicals and abrasives for highway winter maintenance operations is an essential strategy for ensuring a reasonably high level of service, yet the performance of such materials has to be balanced with their potential negative impacts on motor vehicles, transportation infrastructure and the natural environment. In this context, this work presents a comprehensive and quantitative evaluation of snow and ice control materials currently used by various Idaho Transportation Department (ITD) districts for highway maintenance operations, including: rock salts (mainly solid sodium chloride), IceSlicer products (solid sodium chloride with trace amounts of other chlorides), salt brines, a corrosion-inhibited magnesium chloride brine, and sand-salt mixtures. The analysis has been enabled by the utilization of existing lab and field test data along with reasonable assumptions. This case study is the first attempt to incorporate the most up-to-date information into a multi-criteria decision making framework for the data-driven, holistic examination of various snow and ice control materials used by a maintenance agency.

Deicing Performance of Road Salt: Modeling and Applications

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Abstract: This paper describes the results of a field study aiming at quantifying the effects of various factors on the snow melting performance of salt. A large number of tests were conducted in a realistic environment over two winter seasons, covering more than 70 snow events, with temperatures ranging from -14°C to 3°C and snowfalls from ~0.2 cm to 21.0 cm. For each snow event, salts were applied to a set of test sections following specific application rates and time series performance and condition data were collected, such as snow coverage or bare pavement status, friction, pavement and air temperature, sky-view, and humidity. An exploratory data analysis was performed to identify the key factors influencing the snow melting performance of salt, such as application rate, temperature, and snow amount. A multiple linear regression model was calibrated for the relationship between the key snow melting performance indicators –bare pavement regain time and various influencing factors. The calibrated model was then applied to determine the minimum amount of salt required for achieving a given level of service

under specific weather events. While the research was motivated by the need to develop optimal salt application rates for parking lots and sidewalks, the results could be equally applicable for other transportation facilities after facility specific factors, such as traffic and dilution, are accounted.

Toxicological Effects of Chloride-Based Deicers in the Natural Environment: Synthesis of Existing Research

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Abstract: State departments of transportation (DOTs) are continually challenged to provide a high level of service (LOS) on winter roadways to improve safety and mobility in a cost□effective manner, while at the same time minimizing adverse effects to the environment, vehicles, and transportation infrastructure. This work presents current and previous research to develop a better understanding of the impacts of chloride based deicers to the environment. Information presented to date in the published domain generally includes chemical composition and engineering properties of deicers; and additional information on their aquatic toxicity is needed to enable fully-informed decisions by stakeholders. Toxicity associated with the direct effect of deicers or with the indirect effect via their interactions with runoff chemistry is presented.

Comparison of Alternative Chemicals for Deicing Operations

Paper number 14-4797, http://amonline.trb.org/2014-1.405766/14-4797-1.414672

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Abstract: This paper presents the results of an extensive field study on the comparative performance of alternative materials for snow and ice control of parking lots and sidewalks. Approximately 300 tests were conducted in a real-world environment, covering four alternative materials, and 21 snow events. Each of the alternatives is compared to regular rock salt in terms of snow melting performance - bare-pavement regain time. The study confirmed the relative advantage of these alternatives over the regular salt, but also showed that their performance varied largely depending on some external conditions. Performance models were calibrated and then used for developing application rate adjustment factors which can be applied by maintenance operations for determining the optimal application rates for specific weather events and pavement conditions.

Equipment and Facilities

Protecting Maintenance Equipment Against Chloride Roadway Deicers: Corrosion Mechanisms, Test Methods, and Proactive Approaches

Paper number 14-3991, http://amonline.trb.org/2014-1.405766/14-3991-1.415067

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Abstract: Roadway maintenance equipment in cold climates is exposed to high amounts of chloride-based deicers that are inherently corrosive. As such, various structural, hydraulic, and electrical components on maintenance equipment are vulnerable to the deleterious effects of chloride roadway deicers and their premature deterioration can negatively affect the performance, reliability and service life of the equipment

fleet. This work aims to shed more light on this important asset management issue, by providing an overview of the relevant corrosion mechanisms, corrosion-prone parts, and test methods. More importantly, this work presents an overview of current approaches available to manage the risk of deicer corrosion to equipment assets, including design considerations, materials selection, and maintenance strategies. The information aims to enable equipment engineers and managers to gain a better understanding of this technical issue and to make more informed decisions in corrosion risk management.

Truck Cab Scoring Tool: An Ergonomic and Anthropometric Analysis Tool for Assisting Fleet-Purchasing Decisions

Paper number 14-3108, http://amonline.trb.org/2014-1.405766/14-3108-1.416630

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Abstract: This paper presents a tool developed as part of a capstone design class at Oregon State University. The Cab Analysis and Scoring Tool (CAST) system was developed to assist Oregon DOT fleet services assess and select truck candidates, from an ergonomic perspective. The motivator to focus on ergonomic standards is the number of ergonomically induced truck driver related injuries in the United States. As a result, musculoskeletal disorders are one of the leading causes for on the job injuries. ODOT's maintenance fleet must perform a variety of maintenance functions such as snow plows, asphalt application, sanding and as roadside vegetation control. As a result, a specific set of controls must be implemented in the truck cabs, resulting in awkward positioning, which increases the risk of MSD related injuries. As a result, the capstone project involved a team of three industrial engineering students that followed the engineering design method to analyze the problem and design a tool to evaluate truck cabs based on ergonomic standards. The goal of the CAST is to benchmark candidate trucks, based on ergonomic and anthropometric standards to assist with the Fleet Management Department's purchase decisions. The resulting Cab Analysis and Scoring Tool (CAST) has the potential to assist departments of transportation, private fleet managers or any transportation organization in the evaluation and selection of truck cabs based on ergonomic standards to minimize ergonomic related injuries.

Road Weather Information Systems and Technology

Analysis of Road Surface Temperature for Each Road Section in Winter Using Thermal Mapping System

Paper number 14-2671, http://amonline.trb.org/2014-1.405766/14-2671-1.414604

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Abstract: According to the road accidents statistics of Korea, 33% of fatalities in 2011 occurred in winter. As many factors can be the causes of the accidents in winter season, road freezing is the most important factor among them. If a road manager has information or can predict the road surface condition or temperature, the accidents related with road surface freezing can be reduced. In this study, a thermal mapping system was developed to measure road surface temperatures. And the road surface temperature (RST) and air temperature were measured along the various road sections such as normal road sections, bridge, tunnel and cut slope sections in winter. As a result, although the RST in normal paved road sections was higher than air temperature during night time, the RST in bridges and cut slope sections was

lower than air temperature. Moreover, the average RST in bridges and cut slope sections showed lower values than in normal paved road sections. In order to compare the RST among each road section, the ANOVA test was used and the result showed that the RST for normal paved road section and bridge, cut slope road section has statistical significant difference. In this study, we suggest that significant attention is required in bridges and cut slope sections during winter.

Dual Polarimetric Weather Radar and Crowd-Sourced Weather Observations for Managing Winter Operations

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Abstract: Agencies spend millions of dollars deploying winter operation teams to plow snow and de-ice roadways. Accurate and timely weather information is critical for effective decision making. In Spring 2013, the National Weather Service (NWS) finished upgrading its Weather Surveillance Radar-1988 Doppler (WSR-88D) network with dual polarization capability, improving WSR's ability to detect precipitation variables. The National Severe Storms Laboratory (NSSL) released a mobile phone application as a part of its Meteorological Phenomena Identification Near the Ground (mPING) Project in Fall 2012, allowing anyone with a GPS-enabled smartphone to report meteorological observations. Combined, these new weather data sources can potentially provide near real-time information of type, intensity, and accumulation of precipitation.

The objective of this paper is to explore the applicability of dual polarization radar products and mPING observations to road maintenance operations during inclement weather. Case studies were conducted in which dual polarization products, mPING observations, and traffic space mean speed data were overlaid during inclement weather events to serve as a proxy for the need of winter operations. Results showed dual polarization radar products proved to be a rough discriminator between liquid and solid precipitation. The dual polarization precipitation classification algorithm often did classify precipitation types accurately, in comparison to the mPING observations; however it did struggle classifying precipitation type near the radar. Observations from mPING were found to be a useful tool in detecting changes in precipitation type and will likely be an important asset in enhancing dual polarization algorithms that predict precipitation type on roadways.

Optimizing Road Weather Information System Sites Considering Traffic and Regional Weather Conditions

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Abstract: Road Weather Information System (RWIS), designed for collecting and monitoring weather and road conditions, has been proven effective to support winter road maintenance by improving safety, mobility and efficiency. Traditional practices of choosing RWIS sites heavily rely on maintenance and operation personnel. This study develops a model to optimize site locations subject to three selection criteria (i.e., weather, traffic condition, and distance to existing RWIS sites). GIS is used to store and manage database, as well as display the optimization results. The model is applied in a case study, which can be expanded by taking practical constraints to satisfy specific requirements of various agencies.

New Ways of Providing and Taking Advantage of Road Weather Information

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Abstract: Information about weather and road conditions (i.e. road weather information) can be used to improve the efficiency of the road network. This paper will examine the different ways that road weather information is acquired, managed and utilized as a variety of services are supplied to road users. Weather and forecast services refining and distributing this information to road users and to network and maintenance operators can generate significant benefits to stakeholders and society. Until recently, the distribution of weather-related information to individuals and organizations making travel and transportation decisions in a meaningful way has been a bottleneck in realizing the full potential inherent in the concept of taking prevailing and predicted weather and road conditions into account when planning for the movement of people and goods. The increasing number of mobile devices will provide one solution to this problem: mobile devices can be used to provide up-to-date information to road users and parties responsible for performing maintenance operations. Mobile devices are also increasingly used as sensors to produce information in addition to just presenting it. Furthermore, an important future research topic is identified: typically, road weather information is discussed in the context of the main road network. However, urban environments with their high traffic network utilization rates and varying surface materials pose some interesting challenges to measuring and predicting the road surface condition, and innovative solutions are needed to respond to them and contributing to making cities even smarter.

Deploying Weather Responsive Traffic Signal Operations in Utah

Paper number 14-2835, http://amonline.trb.org/2014-1.405766/14-2835-1.418215

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Abstract: Proactive management of traffic signal operations during weather events remains a priority with the Utah Department of Transportation (UDOT). With the assistance of the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP), UDOT recently deployed an advanced concept of traffic signal operations during weather events (WX-SIG). The concept relies upon systems, tools, and technologies to measure and forecast roadway weather conditions and traffic signal performance during inclement weather to fine-tune traffic signal timing responses throughout the duration of the event. UDOT meteorologists and traffic signal operators use these systems to assess current traffic conditions and determine when and how to deploy special weather responsive traffic signal timing plans. UDOT traffic signal operators use system performance monitoring tools, such as Purdue Coordination Diagrams and real-time corridor speed measures, to assess the effectiveness of special weather responsive signal timing plans and to make fine-tuning adjustments in signal timing strategies. This paper provides a description of the tools and technologies developed and deployed by UDOT to assist in developing proactive traffic signal timing responses to weather events, the standard operating procedures used by UDOT operators to decide when, where, why, and how to implement weather traffic signal timing responses. This paper also provides some results of an assessment of the effectiveness of these initial responses during the winter of 2013. The paper also contains lessons learned from this initial deployment related to the deployment corridor itself as well as weather responsive traffic signal operations in general.

Strategic Environmental Sensor Station (ESS) Location Determination Method Based on Weather-Related Crash Data for Road Weather Information System (RWIS)

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Abstract: Adverse weather leads to over 1.5 million vehicular crashes resulting in 800,000 injuries and 7,000 fatalities nationally, and the appropriate deployment of Road Weather Information Systems (RWIS) has been considered effective strategies to address these safety concerns. However, the current practice of selecting the locations of RWIS stations primarily depends upon the knowledge and experiences of field operators. Limited research has been conducted on methodologies that can identify RWIS locations systematically based on the widely available safety and GIS data. This paper proposes a spatial optimization method to identify strategic locations for deploying RWIS stations within a large regional transportation network. Using weather-related crash data converted into a Safety Concern Index, routes that provided good spatial coverage of the region were examined for optimal locations for RWIS stations through a maximization algorithm. The proposed method is evaluated by using crash and GIS data from a tri-county region in Texas assuming 10-mile effective coverage for each RWIS station. The resulting locations illustrate the promising potential for the proposed RWIS location optimization algorithm. Additional sensitivity analysis is also conducted by evaluating the resulting changes from yearly crash data variations.

Program Management

Estimating Winter Weather Road Restoration Time Using Outsourced Traffic Data: Three Case Studies in Maryland

Paper number 14-2996, http://amonline.trb.org/2014-1.405766/14-2996-1.414483

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Abstract: The objective of this study is to examine the I-95 Vehicle Probe Project (VPP) data to determine if the speed and travel time data can be used as a basis to calculate winter weather road restoration performance measures, specifically by identifying the time required to restore the roadway to normal operating conditions. A candidate algorithm based on reduction of speed and change in confidence score within the VPP has been proposed and tested. The algorithm is evaluated during three known snow events in the state of Maryland to determine if it successfully identifies the onset and clearance of hazardous road conditions.

Winter Maintenance Asset Allocation Based on Geographic Information System Snowplow Route Optimization Model

Paper number 14-1011, http://amonline.trb.org/2014-1.405766/14-1011-1.414687

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Abstract: For many transportation agencies in the United States and various countries with cold weather, winter maintenance costs are one of the most expensive line items on their budgets. In the current economic climate finding products, methods, and materials to reduce costs are paramount. One area in which costs may be reduced is by optimizing the snow plowing routes an agency is responsible for maintaining. This paper presents a route optimization model created for the snow plow routes maintained by the Ohio Department of Transportation (ODOT) for District 4 located in northeast Ohio. The model is developed in a geographical information system (GIS) based program, and is validated using global positioning system (GPS) units placed in several snow plow trucks. Along with optimizing the snow plowing routes for the district, the model will determine cycle times and amount of salt applied for various salt application rates. These results may be used as a decision making tool for the amount of trucks needed and the application rate of salt for various levels of snowfall. A hub concept of asset reallocation during winter events is also discussed in order to optimize the equipment available to best handle winter events. This concept reduces cycle times while increasing level of service (LOS) on roadways affected by snowfall by increasing the plowing and material application capabilities without increasing costs.

Strategies for Snow and Ice Control at Extreme Temperatures: A Review of Current Practices

Paper number 14-4014, http://amonline.trb.org/2014-1.405766/14-4014-1.414675

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Abstract: Extremely cold winter storms (below about 10°F) bring about different considerations for taking care of roads than warmer winter storms, where granular salt and salt brine are cost-effective measures of melting snow and ice when used in combination with other operations (e.g., plowing). At temperatures lower than about 10°F, either extremely large quantities of salt are needed or no amount of salt can melt snow or ice pack. Chemical usage is of a widely used technique with various modifications (using deicers in daylight hours only, mixing salt with $MgCl_2$, $CaCl_2$, and/or agriculture by-products, and using high application rates) during extreme cold conditions. Additionally, plowing is still the ubiquitous and popular snow removal techniques in extreme cold conditions. Despite their environmental and hidden costs (air pollution, sedimentation, spring cleanup & disposal), abrasives are frequently used during extreme temperatures to provide temporary traction in low traffic volume and rural roads. In spite of high cost, pavement treatments offer the benefit of reducing chemical usage and associated environmental toll, enhancing agency preparedness, and quicker recovery to bare pavement. Weather forecasting system need to be better utilized in predicting the cold weather temperatures for better preparedness. Innovative strategies continue to be tested at severe temperatures, but agencies are reluctant to use due to its higher cost especially at places of uncommon extreme cold conditions. More research needs to be done to combine innovative strategies with traditional strategies keeping cost reduction as a main factor.

Customer Satisfaction and Safety Targets in Finnish Road Performance-Based Maintenance Contracts

Paper number 14-0998, http://amonline.trb.org/2014-1.405766/14-0998-1.414621

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Abstract: In Finland, safety and availability of the road network is guaranteed through meticulous maintenance. The procurement of road maintenance contracts is publicly tendered in the form of area based contracts amongst private companies. Contractors are responsible for road maintenance activities according to the Performance-Based Maintenance Contracts (PBMC) concept. Customer satisfaction surveys are done on an annual basis and the contractor has the opportunity to earn a bonus or disincentive based upon the results. The client wishes to set a zero tolerance as the safety target, which means there are

zero occupational accidents arising from road maintenance work and no accidents or injuries to third parties in connection with road maintenance and repair work. A pilot project was initiated to test a new bonus scheme that is customer-oriented and applies a Vision Zero approach to occupational and traffic safety. An additional bonus may be earned based upon the professional driver's observation team. The results for the first two years have been satisfactory. Both incentives and disincentives have been realized and the client continues to monitor progress before a broader implementation of the new safety bonus system.

Addressing the Challenges of Route Planning for Snowplowing and Salt Spreading on Hybrid Rural and Urban Network

Paper number 14-2039, http://amonline.trb.org/2014-1.405766/14-2039-1.414684

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Abstract: Winter maintenance problems have not been widely addressed in the literature. This is due to the complexity of the problems and the fact that the problems are often site-specific. Therefore numerous operational constraints have to be taken into account. This paper first describes a case study conducted in a city in the province of Quebec, Canada. An adaptive large neighborhood search metaheuristic was developed in order to design the snow plowing and salt spreading routes. It takes into account turn penalties, network hierarchy, and equipment availability. This method generates a solution within a reasonable time while taking into account the operational constraints. The algorithm can also be used to test various scenarios. The example of one truck breaking down is detailed.

Study on Reproducibility of Friction Maps Under Snowy and Snow-Free Road Conditions

Paper number 14-3387, http://amonline.trb.org/2014-1.405766/14-3387-1.414600

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Abstract: Appropriate winter road maintenance requires that road managers identify road sections where treatment is needed, and thermal mapping has been widely used for this. Thermal mapping develops a unique surface temperature pattern for each route (a "thermal fingerprint") based on the fact that the pattern of road surface temperatures is reproducible under similar weather conditions. Another technique for clarifying road surface conditions involves determining the slipperiness of the road surface. Although the recent development of a practical device that allows continuous measurement of road surface friction has expanded the application of slip indicators in winter road maintenance, it is impossible to constantly measure changing road surface friction. If, like road surface temperature, the distribution of road surface friction is reproducible, road managers can reduce for road surface friction measurement. This study aims to verify the reproducibility of friction distribution (a "friction map") under snowy and snow-free conditions by using an expressway as a case study route. The friction distributions showed high reproducibility even in winter under similar conditions. The friction values derived from the friction fingerprints produced using friction data collected under snowy conditions were also found to show high reproducibility.

Monitoring and Analysis of Winter Maintenance Operations for Parking Lots
Paper number 14-4467, http://amonline.trb.org/2014-1.405766/14-4467-1.414477

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Abstract: This paper describes results from a unique field study focused on winter maintenance of parking lots. The study used both stationary webcams and smart scales with a Smartphone app to track the maintenance activities of 6 maintenance contractors at over 50 different parking lots in the winter season of 2012-13. Based on the data collected from over 850 maintenance operations, factors that affected the contractors' maintenance decisions, such as salt application rate and pre-application are identified, including temperature, precipitation, and event duration. Moreover, this paper also presents the results on the accuracy of the feed-rate based salt measurement system and its appropriateness as a tool for monitoring salt usage for winter maintenance of parking lots. To the best of our knowledge, this research is the first undertaking such a large scale study. The main findings and implications of the technologies used are highlighted in reference to their application to the parking lot winter maintenance industry.

Experimental Study on Effectiveness of Anti-icing Operations for Snow and Ice Control of Parking Lots and Sidewalks
Paper number 14-4398, http://amonline.trb.org/2014-1.405766/14-4398-1.414480

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Abstract: This paper describes an empirical study aimed at investigating the performance of the anti-icing strategy for snow and ice control of parking lots and sidewalks. The research is motivated by the need to address several key questions concerning various operational decisions related to the anti-icing strategy, including its relative effectiveness under different weather and site conditions, treatment options, and optimal application rates. Extensive field tests were conducted under a wide variety of weather events using regular solid road salt, brine, and two other liquid alternatives. Data collected from these tests was used to analyze the performance of anti-icing operations such as friction level, bare pavement regain time, and the effects of various external factors such as pavement temperature and application rate. The research has concluded with findings that are directly applicable in real world winter maintenance practices.

Pavements and Bridges

Snow and Ice Control on Porous and Permeable Pavements: Literature Review and State of the Practice
Paper number 14-2839, http://amonline.trb.org/2014-1.405766/14-2839-1.414681

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Abstract: Porous and permeable pavements (PPPs) have been successfully used by multiple transportation agencies in several countries and domestically as a wearing surface to help reduce water splash and spray, increase friction, reduce potential for hydroplaning, and reduce noise. Despite their inherent advantages, when used in colder climates on highways PPPs tend to freeze more rapidly, transport deicing chemicals from the road surface, clog from sands and other debris, and retain snow and ice for a longer period of time than traditional dense graded pavements (DGPs). Porosity and texture tend to be the leading material properties of PPPs that affect their behavior in winter conditions and have been noted to be the primary causes of differences between PPPs and DGPs in winter conditions. Infiltration of water and deicing

chemicals through the pores and pumping of water and salts to the surface from traffic are a direct result of the porosity of PPPs. The use of sand as a friction enhancement is not recommended because they tend to clog the pores and create additional and costly maintenance to restore the desired porosity of the pavement. The behavior of PPPs at lower temperatures is different than traditional DGPs because of the different thermodynamic properties associated with the pore space in these mixes. The coarser surface texture of PPPs can provide temporary storage of ice and snow on the surface during a storm, and if frozen, ice and snow become integrally keyed to the pavement surface making it more difficult to remove these deposits. PPPs have a longer history in Europe, and domestic sources of information on these types of pavements as they relate to winter maintenance is scarce and oftentimes conflicting.

A more comprehensive and successful approach to the effective and economical winter maintenance of PPPs in the U.S. is needed. Future research associated with this project will address this need through interviews of domestic and international winter maintenance personnel that have experience maintaining PPPs and a controlled laboratory evaluation to determine the mechanical and chemical interaction between deicers and porous pavements.

Concrete Conductivity: Effect of Temperature, Saturation, and Air Content

Paper number 14-5694, http://amonline.trb.org/2014-1.405766/14-5694-1.413641

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Abstract: The aim of the study was to observe the changes in bulk conductivity of concrete and its moisture content when exposed to freezing and thawing cycles in the presence of deicer salt solutions. To accomplish this goal, it was important to first study the effects of each stimulus separately. This paper summarizes the results of investigations on the influence of changing temperature, saturation level and air content of hardened concrete on its bulk conductivity. All conductivity measurements were performed on specimens prepared from mixtures meeting the requirements of the Indiana Department of Transportation (INDOT) for pavement concrete. It was found that the temperature dependence of the bulk conductivity of concrete closely follows the Arrhenius relationship. Formation factor, defined as the ratio of the pore solution conductivity to the bulk solution conductivity when the sample is saturated, was used to quantify the microstructure of concrete. It is a measure of the volume of the pores and their connectivity. Conductivity measurements were performed on concrete with four different air contents and it was found that the formation factor decreased with increase in the air content. This data was then used to derive a relationship between bulk conductivity of concrete and its air content. On drying, the tortuosity of the conduction path increases resulting in a decrease in the bulk conductivity of concrete. This was verified for concrete with saturation levels ranging between 80% and 100%.

Study on Three-Phase Composite Conductive Concrete for Pavement Deicing

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Abstract: Using electrically conductive concrete for deicing is an emerging material technology. Three kinds of electrically conductive concrete compositing steel fiber, carbon fiber and steel fiber-graphite are measured, and the factors affecting conductivity are analyzed. A three-phase composite conductive concrete containing steel fiber, carbon fiber and graphite is developed specially for pavement deicing. According to the test of conductive property and the compressive strength of this concrete in laboratory, it is found that the dispersion uniformity of the carbon fiber and the concrete voids have a significant impact on conductivity. The composition ratio, preparation techniques and electrode layout mode of three-phase composite conductive concrete are studied and introduced. The specimen made of three-phase composite conductive concrete with electrical resistivity 322 Ω·cm is used in heating experiment, and is proved to have good heat effects, which can meet the requirements of pavement deicing.

Acoustic Emission and Low Temperature Colorimetry Study of Freeze and Thaw Behavior in Cementitious Materials Exposed to NaCl Salt

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Abstract: This paper describes a series of experiments that were performed to assess the freeze-thaw behavior of mortar specimens exposed to NaCl solutions. A low-temperature longitudinal guarded comparative calorimeter was used to perform cyclic freeze-thaw testing on mortar specimens saturated with NaCl solutions. Heat flow and acoustic emission activity were monitored during the freeze-thaw experiment to detect ice formation and cracking. Although the conventional water-NaCl phase diagram would suggest that no freezing or damage would occur in specimens saturated with 15 % and 23.3 % NaCl solution by mass within the applied freeze-thaw temperature range, damage was observed. For these specimens, an additional heat flow peak attributed to an unexpected phase change, accompanied by acoustic activity, was detected at a temperature higher than the expected freezing point. To better understand the source of this damage, a low temperature differential scanning calorimeter was used to investigate the influence of NaCl on freeze-thaw behavior of water, two pore solutions, hydrated cement powder, and calcium hydroxide powder. The results showed that the pore solution alters the freeze-thaw behavior slightly; however, it does not exhibit the unexpected phase change at higher concentrations. The specimens made with hydrated cement powder showed the unexpected phase change in high concentrations of NaCl solution in a temperature range between 0 °C and 8 °C. While the exact nature of this phase change is not definitively known, it appears that it results in premature damage during freeze-thaw when high concentration salt solutions are used, even if freezing of the solution is not occurring.

Selection of Rapid Index Tests and Criteria for Concrete Resistant to Chloride Penetration

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Abstract: Concrete, especially for improved durability, is typically specified with prescriptive provisions. More recently there has been increasing interest in evolving towards performance-based specifications, both within state highway agencies and industry. One of the challenges in successfully implementing performance-based specifications is using test methods and criteria for concrete durability that can reliably provide the expected service life. The National Ready Mixed Concrete Association has been engaged in a state pooled fund research project to propose performance criteria for concrete that will be resistant to penetration of chlorides, cycles of freezing and thawing, and sulfate attack. This paper summarizes results pertaining to penetration of chlorides.

Chloride penetration was determined by the apparent chloride diffusion coefficient test (ASTM C1556). Following initial curing, specimens were subjected to either immersion in chloride solution as required by C1556 or to a cyclic wetting and drying exposure to a chloride solution. Measured apparent chloride diffusion coefficients were correlated with results of rapid index tests that provide an indication of transport characteristics of concrete. These tests included the rapid chloride permeability, rapid migration, conductivity, absorption, and initial and secondary sorptivity. A set of rapid index tests and criteria that can more reliably classify mixtures based on their resistance to chloride penetration are proposed.

Safety

Evaluation of Winter Maintenance Chemicals and Crashes Using Artificial Neural Network
Paper number 14-2363, http://amonline.trb.org/2014-1.405766/14-2363-1.414486

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Abstract: The objective of this study was to investigate and evaluate the effects of winter maintenance chemicals on road safety. To this end, a winter chemical usage model was developed, and a methodology combining artificial neural network (ANN) and sensitivity analysis is presented. In this method, the ANN was used to establish the relationship between road safety and associated factors, and sensitivity analysis was to identify significant variables and quantify their effects. The chemical usage model and ANN were then applied to case studies in Idaho. The results from the case study showed that the use of winter maintenance chemicals played an important role on road safety. Furthermore, benefit-cost analysis of the case studies indicated that the use of winter maintenance chemicals produced more benefits than costs.

Comparison Between Parametric and Nonparametric Approaches for Road Safety Analysis: Case Study of Winter Road Safety
Paper number 14-3064, http://amonline.trb.org/2014-1.405766/14-3064-1.422699

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Abstract: In road safety research, a parametric approach is commonly applied in modeling road collisions, which have resulted in many different types of models such as Poisson, Negative Binomial and Poisson lognormal. While easy to apply and interpret, a parametric approach has several critical limitations due to the modeling requirement of assuming a specific probability distribution form for each model variable (e.g. collision frequency) and a pre-specified functional relationship between each model parameter and the predictors. These assumptions, if violated, could lead to biased and/or erroneous inferences on the effect of these predictors on the dependent variable. This paper introduces a data-driven, nonparametric alternative called Kernel regression, which circumvents the need for the aforementioned assumptions. This paper compares the parametric and nonparametric approaches through an empirical study using a large dataset consisting of hourly observations of collisions, road weather and surface conditions, and traffic counts from highways in Ontario, Canada, over six winter seasons. It is shown that the nonparametric approach has the advantage of being able to capture the significant nonlinear and interacting effects of some condition factors. The paper also illustrate the practical implications of the differences between the two approaches, including evaluation of the risk levels of road surface conditions for the road users and quantification of safety benefits of maintenance operations for transportation authorities.

Use of Heating Facilities in Sidewalks to Improve Pedestrian and Bicyclist Safety
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Abstract: This paper presents the use of heating facilities (known as a snow melting system) in sidewalks at Northern Arizona University (NAU) and its practice in helping with reducing labor-based snow removal and improving pedestrian and bicyclist safety. NAU is located in Flagstaff, Arizona. In the winter months with high attitude (7000 feet), temperatures in Flagstaff are extremely cold and the amount

of snowfall (approximately 108 inches per year) has been significant. As of 2012 NAU has planned to install snow melting systems in sidewalks with the goal to provide visitors, students, faculty, and staff with a stably safe environment for transportation in the snow. Hydronic system has been selected to generate heat energy using glycol-water as heat source. Pipes are embedded 4 ó" below the pavement surface with glycol water being circulated within the pavement. To help with mechanical system design, heat output values in Flagstaff from October to the following May were calculated. In January 28, 2013, a snow storm was blasting across the city. The snow melting system was turned on at midnight to heat the pavement. Based on an observation in the early morning at 7am, no snow accumulation was found on all heating sidewalks at the three project locations, provided the heat output computation was appropriate and the hydronic system embedded in the pavement was working very well to generate heat energy to melt the snow. The snow melting system has demonstrated its abilities to heat the pavement and melt the snow. The effectiveness of using heating facilities in sidewalks to improve pedestrian and bicyclist safety has been considered satisfactory.

Parking Lots and Sidewalks Under Winter Snow Events: Classification, Friction, Characteristics, and Slipping Risk

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Abstract: Pedestrian safety on parking lots and sidewalks is a main concern under adverse winter conditions due to the reduced friction level caused by snow accumulation and ice formation. While there is an intuitive understanding that the risk of slipping is related to the friction level of a pavement surface affected by snow and ice, there is limited knowledge on the underlying relationship and how friction level is affected by various factors such as contaminant type and amount, pavement type, and other factors. Knowledge on this relationship among the contaminant type, coefficient of friction, and risk of slipping is essential for establishing cost-effective level of service policy and standards for winter maintenance of these transportation facilities. This paper summarizes the results of a field study investigating the friction characteristics and associated slipping risk levels of different contaminant pavement surfaces under a variety of weather conditions. A large number of field tests were conducted on three common pavement structures - asphalt concrete, interlocked brick, and Portland cement concrete, with a variety of surface contaminants such as unplowed snow, plowed snow, slush and ice. It was found that pavement surfaces of major contaminant types have distinctive ranges of friction and slipping risk levels, and they could be inferred from each other, suggesting the feasibility of establishing a friction-based service standard.

Weather-Based Safety Analysis for Effectiveness of Rural Variable Speed Limit Corridors

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Abstract: The purpose of this research was to develop a weather-based safety analysis for determining the effectiveness of the Variable Speed Limit (VSL) system. The VSL system provides variable, regulatory speed limits to drivers based on real-time traffic, weather, and roadway conditions. Crashes for the winter season (October 15 to April 15) from 2007 to 2012 on four VSL corridors along Interstate-80 in the state of Wyoming were analyzed. For establishing the Safety Performance Functions (SPF), a Negative Binomial (NB) modeling technique was found to be the preferred regression modeling technique to model the frequency of crash occurrence and explanatory variables related to weather and the use of the VSL system. Use of weather variables normalized the winter seasons before and after the VSL systems were implemented. The results from the analysis showed a significant reduction in winter crashes due to the use of the VSL systems.

Assessing the Effect of Weather States on Crash Severity and Types Using Full Bayesian Multivariate Safety Models

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Abstract: Rather than investigate the isolated effects of individual weather elements on crash occurrence, this study investigates the aggregated effect of weather states, which are defined as a combination of various weather elements (i.e., temperature, snow, rain, and wind speed), on crash occurrence. The main argument is that a combination of weather elements might better represent a particular weather condition and subsequent safety outcome. Therefore, to explore the effect of various weather states on crash severity and type, this study defined twelve weather states, based on temperature, snow, rain and wind speed, and developed multivariate safety models using 11 years of daily weather and crash data for the entire City of Edmonton. The proposed models were estimated in a Full Bayesian context via a Markov Chain Monte Carlo simulation, while a posterior predictive approach was used to assess the models' _goodness-of-fit. Results suggested that Property-Damage-Only (PDO) crashes increased by 4.5%-45% due to adverse weather states. It was also shown that PDO crashes were more affected by adverse weather states compared to severe (injury and fatal) crashes. With regard to crash type, adverse weather states were associated with an increased occurrence of 9%-73.7% for all crash types, with the highest increase recorded for Ran-Off-Road (ROR) crashes. The duration of daylight hours was found to be significant and negatively related to all crash types and PDO crashes. In addition, sudden weather changes of major snow or rain were statistically significant and positively related to all crash types. Days-of-the-week (i.e., weekdays and weekend) and seasons-of-the-year (winter, spring, summer, and fall) were used as dummy variables and were statistically significant in relation to crash occurrence.

Traffic Modeling

Direct and Lagged Effects of Adverse Winter Weather Conditions on Operating Speed in Urban and Rural Highways: Time-Series Analysis

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Abstract: This paper investigates the direct and lagged effects of adverse winter weather conditions on the operating speed of a number of highway segments in Ontario using a time-series approach. The effect of adverse weather was studied using data from multiple sites including both urban and rural highways, considering weekdays versus weekends separately. For this purpose, a large dataset containing hourly traffic data, weather variables (temperature, snow, wind speed, etc.), and surface conditions were used. Some previous studies have examined the effect of snowstorms on traffic parameters; however, little has been done regarding their spillover effects (lagged effects). Extreme events or weather conditions might have a strong effect on traffic conditions not only during these events, but also before and after such events. In this study, time-series regression techniques—in particular, Autoregressive Integrated Moving Average (ARIMA) models—were used to model highway operating speed. These methods are able to consider the serial correlation among error terms. From the results, it can be inferred that snow storms have a statistically significant effect on speed. The lagged effects are however offset by the time and intensity of winter maintenance operations during and after the event. The effect of weather also varies

depending on the type of site (urban or rural) and day of the week. The results of this study can be applied in quantifying the mobility effect of winter weather and benefits of winter road maintenance.

Framework to Predict Freeway Traffic Speed in Snowy Weather: Integration of Historical and Real-Time Patterns

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Abstract: Providing accurate and reliable predictive traffic information is fundamental for the successful operation of proactive traffic management and information strategies. In particular, traffic prediction during snowy weather conditions is of keen interest because this information results in a greater capacity reduction and crash occurrence. This study proposes a methodology for predicting freeway traffic speed in snowy weather. One feature of the proposed methodology is the incorporation of historical and real-time traffic speed patterns in the prediction of freeway traffic speed. The proposed methodology consists of three components. The first and second components use traffic speed patterns that can be obtained from the analysis of historical data recorded in the database at traffic management centers (TMCs). The last component uses one-step-ahead predicted traffic speed based on real-time data. Both road weather information systems (RWIS) and vehicle detection systems (VDS) data obtained from the Seoul-Chooncheol Freeway in Korea were used in the development of the model and the performance evaluation of transferability. The proposed methodology showed a promising result. Under normal conditions, 3.00% mean absolute percentage error (MAPE) was obtained. In addition, MAPEs of 4.70 and 6.83 were achieved during slight and heavy snow conditions, respectively. The findings of this study can be used to provide predicted traffic speed information as a component of traffic management and information systems for users, operators, and decision makers.