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2013 TRB Annual Meeting
Papers Related to Winter Maintenance

Materials

Wet Pavement Anti-icing: Proposed Physical Mechanism and Calculation for Minimum Application Rate

Paper Number 13-0547, not available online

Alex Klein-Paste, Norwegian University of Science and Technology, Alex.Klein-Paste@ntnu.no

Abstract: A commonly accepted mechanism for anti-icing of wet pavements is freezing point depression. However, not all aspects of anti-icing can satisfactorily be explained with the freezing point depression theory. In this study we tested the hypothesis that brine inclusions weaken the ice such that it does not withstand the loading from traffic. An experimental set-up was developed to freeze thin saline ice layers on pavement surfaces and test their resistance against simulated traffic load. It was found that the ice became too weak to withstand the imposed load when the combination of temperature and concentration resulted in an equilibrium brine fraction less than 0.3. The results from the lab experiments are compared with field measurements performed on wet roads in Norway. It shows that situations can occur where there is too little salt present to prevent freezing, jet traffic still goes as normal and the pavement was not experienced slippery. These measurements provide direct evidence that anti-icing of wet pavements is not solely based on freezing point depression. A new criterion, based on the equilibrium brine fraction, is proposed to determine the minimum amount of salt needed on pavement surfaces. This criterion predicts significantly lower amounts than predicted by the freezing curve. The notion of the weakening effect of anti-icing salts gives also an explanation why a certain amount of traffic is needed on pavements to achieve an effective anti-icing operation.

Effect of Common Deicing Chemicals on Ice-Bond Formation in Compacted Snow

Paper Number 13-2508, http://amonline.trb.org/2vd88k/

Johan Wåhlin, Norwegian University of Science and Technology
Alex Klein-Paste, Norwegian University of Science and Technology, Alex.Klein-Paste@ntnu.no

Abstract: Application of chemicals during snowfall in order to keep the snow plowable is a common road maintenance practice to ensure regularity and improve traffic safety during winter. However use of chemicals has adverse effects on environment and structures. In order to optimize chemical usage for anti-compaction measures, more knowledge is needed on the mechanism behind it. Earlier studies have shown that the presence of a sodium chloride (NaCl) solution in snow reduces the strength of the bonds that form between grains when snow is compressed, and thereby decreases the hardness of compacted snow. It is however not clear whether this is an effect of the introduction of liquid water into the snow or if it is an effect of the solutes present in the solution. By measuring the hardness of compressed snow saturated with

solutions of six common deicers, it was shown that the solutes do have an effect on the inter-particle bonds in snow. By comparing the effect of potassium formate (KCOOH) with NaCl solution on snow containing between 5-50 w% solution it becomes clear that the effect of the solutes can be substantial. To achieve the same snow hardness, only half the amount of KCOOH solution was needed compared to the NaCl solution.

Accuracy of SOBO-20 in Measurement of Salt on Winter Pavements

Paper Number 13-2606, http://amonline.trb.org/2vd9ih/

Kai Rune Lysbakken, Norwegian University of Science and Technology, kai-rune.lysbakken@vegvesen.no
Anne Lalagüe, Norwegian University of Science and Technology

Abstract: The use of chemicals is essential in snow and ice control operations. Sodium chloride (salt) is normally used, as it is efficient, widely available and rather inexpensive. However it is harmful for the environment if encountered in too great quantities, and there is nowadays a great attention placed upon the importance of reducing the usage of salt, while still maintaining road serviceability and safety. Optimizing the use of salt requires to accurately knowing how much salt is on the pavement surface. Unfortunately, there is currently no well-documented method available to determine this quantity. SOBO-20 is one of the most common instruments used by the winter maintenance community to calculate salt amounts, although the reliability of the instrument has not been shown yet. The present work aims to fill this gap by carrying out measurements on brine (dissolved salt), dry salt particles and re-crystallized salt. The presented results support the conclusion that SOBO-20 is an accurate and reliable instrument for measuring brine on asphalt pavements. However, it largely underestimates the amount of dry or re-crystallized salt, and much attention should be paid when using SOBO-20 on dry pavements. Compliance with the manufacturer's recommendations regarding the proportion of acetone in the measuring fluid is also essential for accurate salt readings. These results on the instrument performance should lead to a better understanding of the salt distribution and action time.

Correlating Laboratory and Field Tests for Evaluation of Deicing and Anti-icing Chemicals: A Renewed Perspective

Paper Number 13-4742, http://amonline.trb.org/2vec7j/

Xianming Shi, Western Transportation Institute, Montana State University, xianming_s@coe.montana.edu
Anburaj Muthumani, Western Transportation Institute, Montana State University
Laura Fay, Western Transportation Institute, Montana State University
Michelle Akin, Western Transportation Institute, Montana State University
Shaowei Wang, Western Transportation Institute, Montana State University

Abstract: Numerous laboratory and field studies have been conducted to evaluate the performance of deicing and anti-icing products and their resulting friction coefficient of treated pavement. However, laboratory results often do not translate to the field performance due to varying temperatures, wind, traffic, etc. in actual field conditions. Also, the existing laboratory tests fail to address all the significant issues in the actual field environment or to provide actual performance of deicers to guide practitioners. This study sheds light on the challenges of developing a laboratory test that correlates the field test based on literature reviews and interviews from various agencies and practitioners. Recommendations for laboratory testing include the use of environmental chamber that can control and monitor air temperature,

humidity, air speed and solar radiation. In addition, it is recommended to incorporate a plowing mechanism into the laboratory test to better simulate the field operations. Two friction-measuring devices were recommended that can be used both in laboratory and in field. In addition, it may be preferable to use a friction trailer if the necessary laboratory space can be obtained. For field testing, it is preferable to conduct the research in a controlled field environment. Recommendations from this study may assist in developing a test method that would closely mimic the actual performance.

Equipment and Facilities

Development and Evaluation of Snowplow Instrumentation and Data Collection System
Paper Number 13-3697, not available online

Enad Mahmoud, Bradley University
Souhail Elhouar
Drew Dragoo
Cliff Sugisawa
Tim Peters

Abstract: Removal of ice and snow from road surfaces is a critical task in the northern tier states of the United States. Most of the research effort in the snow and ice control area is focused on application of chemical and roadway pretreatment techniques. Plowing is the only technique that effectively removes snow from roadways, and it is imperative that this technique should be studied to maximize its efficiency and effectiveness. In this study instrumentation and data collection system for front mounted Illinois Department of Transportation (IDOT) snow plow truck was developed, the system included twelve strain gauges, twelve control modules, a data acquisition system, a rear view camera, and a front view camera that is capable of recording GPS and truck speed. After being calibrated the strain gauges were installed on an Alaskan snow plow, and the system was evaluated with dry runs on asphalt and concrete pavements and soil-dry runs on concrete pavements. The instrumentation and data collection system was fully functional and distinguished between external field factors: pavement type, blade saver option (on/off), and dry soil plowing. A reduction in stresses developed in the snow plow and the carrier structure was observed for asphalt pavement compared to concrete pavement, and when the blade saver option was on.

Corrosion of Chloride Deicers on Highway Maintenance Equipment: Renewed Perspective and Preliminary Laboratory Investigation
Paper Number 13-3127, not available online

Xianming Shi, Western Transportation Institute, Montana State University, xianming_s@coe.montana.edu
Yongxin Li
Yida Fang
Nicholas Seeley
Scott Jungwirth
Emily Jackson

Abstract: This paper reports on the relevant information collected from data through a two-year research project, with the goal of identifying, evaluating and synthesizing best practices that can

be implemented to minimize the corrosive effects of chloride deicers on DOT winter application equipment and vehicles. The practices identified include: design improvements, maintenance practices, anti-corrosion coatings, corrosion inhibitors, salt removers, etc. A nationwide survey was conducted of stakeholder groups, in order to capture the current knowledge in: estimating the deicer corrosion costs to vehicles and equipment, defining the chloride deicer corrosion problem and identifying best practices or products for managing the problem. The survey results suggest that chloride-based deicers are the most commonly used products for highway winter maintenance operations and pose significant corrosion risk to DOT equipment and vehicles. The survey identified four anti-corrosion coating products (Zero Rust Red, Zero Rust Black, Rust Bullet and Lubra-Seal), four spray-on corrosion inhibitors (Krown, Ship-2-Shore, Vegetable Oil and Rust Oleum), and five salt removers (MR 35, HoldTight, ChloRid, SaltAway and Soap Water) as best products based on user experience. Subsequently, a screening test and a 2-week test were conducted to assess the effectiveness of these select products in reducing the corrosion of magnesium chloride solution to carbon steel, using electrochemical impedance spectroscopy (EIS) measurements. Under the investigated conditions, the best-performing coating (Rust Bullet), inhibitor (Krown) and salt removers (HoldTight and ChlorRid) were identified and they all showed outstanding performance in corrosion protection.

Estimation of Maintenance Fleet Size for Spreading Operations Considering Road Geometry, Weather, and Traffic

Paper Number 13-3119, http://amonline.trb.org/2vdh35/

I-Jy Chien, New Jersey Institute of Technology, chien@adm.njit.edu
Shengyan Gao, New Jersey Institute of Technology
Jay N. Meegoda, New Jersey Institute of Technology
Taha Marhaba, New Jersey Institute of Technology

Abstract: Plowing and salt spreading are the most common counter-measures for snowy and icy pavement surfaces. To help highway maintenance authorities with better planning and allocation of winter highway maintenance resources, this research introduces an analytical model to estimate the required number of spreading trucks to complete the spreading operation within the service time by considering road geometry, weather and traffic. The complexity of the spreading problem lies in dealing with the non-uniform road geometry of each road section, different spreading patterns depending on the road geometry, dynamic traffic speeds under different weather and traffic conditions and the situation with heterogeneous spreading truck capacity for the spreading operations. In this study, a spreading model is developed and applied to a maintenance yard with three road sections in New Jersey. It was found that the developed model is fairly flexible to implement and easy to capture the diverse operational conditions, such as geographical location, climatic and weather conditions, equipment and etc.

Program Management

Estimating Statewide Benefits of Winter Maintenance Operations

Paper Number 13-2148, http://amonline.trb.org/2vd32q/

Zhirui Ye, Southeast University
David A. Veneziano, Western Transportation Institute, Montana State University, david.veneziano@coe.montana.edu
Xianming Shi, Western Transportation Institute, Montana State University

Abstract: Winter highway maintenance activities offer direct and indirect benefits to the public. However, the cost of such activities is such a major outlay that it demands close scrutiny. There is a need to better understand and quantitatively estimate the benefits of winter road maintenance. Therefore, the work discussed in this paper was undertaken to quantitatively assess the benefits of winter highway operations at the state level. Methodologies were developed for estimating the major benefits of winter maintenance, including safety improvements, travel time savings and fuel savings. A Minnesota case was used to demonstrate the methodologies and quantify those benefits. Results of the case study showed that the benefits of winter highway maintenance by the Minnesota Department of Transportation to be $227 million per winter season, with $168 million of safety benefits, $11 million of mobility benefits, and $48 million of fuel savings. The benefit-cost ratio of winter highway operations in Minnesota was 6.2, in which material costs were taken into account.

Approach to Optimization of Winter Road Management Operation by Taxi Probe Data

Paper Number 13-0952, http://amonline.trb.org/2vcho7/

Kazunori Munehiro, Civil Engineering Research Institute for Cold Region, PWRI, k-munehiro@ceri.go.jp
Hiroyuki Kageyama, Civil Engineering Research Institute for Cold Region, PWRI
Naoto Takahashi, Civil Engineering Research Institute for Cold Region, PWRI
Tateki Ishida, Civil Engineering Research Institute for Cold Region, PWRI
Motoki Asano, Civil Engineering Research Institute for Cold Region, PWRI

Abstract: Traffic smoothness must be ensured through winter road management. The average travel speed is a key of indicator that represents traffic smoothness. In this study, we used taxi probe data to obtain average travel speeds in the Sapporo urban area, Japan for a long period of time, and analyzed the relationship between the average travel speed and various winter weather and road surface conditions. Also, we calculated the monetary value of the increase in average travel speed afforded by snow and ice control operations. We had been acquired taxi probe data 6 months from October 1st, 2010 to March 31st, 2011, with the cooperation of a taxi company. Differences in average travel speed between the winter season and the non-winter season have been found to vary depending on weather and road surface conditions. Our survey has found that snow and ice control operations increase the average travel speed of road users. Improved average travel speed increases the benefits for road users. The cost-benefit analysis of snow and ice control operations for national highways in Sapporo found that the estimated benefits of winter road management operations far exceeded the cost of such work operations. This paper proposes an approach to a balance and optimization of winter road management and winter service using the taxi probe data.

Equipment Routing

Snowplow Routing Optimization Under Resource Constraints: Formulation, Algorithm, and Decision-Support System

Paper Number 13-0795, http://amonline.trb.org/2vcfmr/

Leila Hajibabai, University of Illinois at Urbana-Champaign
Seyed Mohammad Nourbakhsh, University of Illinois at Urbana-Champaign
Yanfeng Ouyang, University of Illinois at Urbana-Champaign, yfouyang@illinois.edu
Fan Peng, University of Illinois at Urbana-Champaign

Abstract: Snow control is a key component of the winter maintenance responsibilities of many urban and regional agencies, especially in jurisdictions with heavy snowfall. Main activities involve routing snow plow trucks to plow roadways and spreading salt/chemicals via these trucks. In this paper, a mixed integer linear program (MILP) model is proposed to minimize the total operation time of all snow plow trucks needed to complete a given set of snow routes, and to reduce the longest individual truck time. To solve this problem, a set of customized construction and local search methods are developed and applied to an empirical case study. The computational results show that the proposed solution approach is able to solve the problem efficiently. The proposed models and algorithms are incorporated into the development of a state-of-art snow plow routing software that helps planners optimize snow routes and evaluate resource allocation options.

Global Positioning System (GPS)/Automatic Vehicle Location (AVL) Use, Challenges, and Cost-Benefit in Operations

Paper Number 13-5123, http://amonline.trb.org/2vehmd/

Marie Venner, Venner Consulting, Inc., mvenner@vennerconsulting.com

Abstract: Automatic Vehicle Location (AVL) systems are helping DOTs achieve a variety of new efficiencies while improving or maintaining LOS through periods of state budget shortfalls. The trucking, emergency response, and transit communities have used GPS/AVL for years. Now DOTs are realizing new efficiencies with this technology as well. Recent findings on the challenges and cost-benefit advantages DOTs are finding with these technologies are discussed in this paper, summarizing the author's 2011 and 2012 surveys of DOTs on this topic. For example, in addition to the 10% materials savings that DOTs in the US and Canada have reported, automated data collection associated with GPS/AVL is saving DOT maintenance forces thousands of hours filling out paperwork, boosting morale as well as effectiveness. WSDOT estimated the agency and the public benefit from an additional 10,000 hours per year that maintenance employees are out plowing instead of filling out paperwork, equating to a biennial savings of $700,000 in labor costs. The savings they found were such that WSDOT now aims to have all winter material application records, and material inventory issues recorded automatically, and the agency will begin to use their GPS/AVL equipment to help automate documentation of the maintenance staff performs on the state's permanent stormwater control structures in the right-of-way, associating hours worked with GPS located stormwater facilities, to better understand life cycle costs, maintenance requirements, and document and communicate maintenance needs to the state legislature, for better funding.

Vehicle Routing of Urban Snow Plowing Operations: Case Study for City of Edmonton, Canada

Paper Number 13-0491, http://amonline.trb.org/2vcbla/

Gang Liu, University of Alberta
Yongfeng Ge, University of Alberta
Tony Z. Qiu, University of Alberta, zhijunqiu@ualberta.ca
Hamid R. Soleymani, University of Alberta

Abstract: Canadian municipalities spend significant capital for snow plowing to provide safe and reliable mobility for road users. Any improvement in winter snow plowing will not only result in significant capital savings for road agencies, but also improve the safety and mobility of road users. The problem of routing for snow plowing operations is generally considered a network optimization problem in the existing research. However, the formulation and solution approaches can be very different and diverse, since each area has its own unique environmental conditions and operational constraints. Assuming a district and a single depot are given, the problem is to determine a set of routes that will ensure that all road links are serviced, all the operational constraints are satisfied and the total cost is minimized. This study presents a mathematical optimization model based on the Capacitated Arc Routing Problem (CARP) to minimize the total travel distance for winter road snow plowing in the City of Edmonton. A metaheuristic algorithm is used to solve this model. The model and algorithm are applied to a road sub-network for the south part of Edmonton, Canada. The results show that the model and algorithm are capable of achieving good solutions. Sensitivity analyses also show that the final results are sensitive to the depot location and number of routes. The proposed model needs to be expanded by considering more operational constraints in the City of Edmonton.

Optimal Routing for Minimum Service Time of Winter Road Maintenance with Truck Capacity and Fleet Size Constraints

Paper Number 13-2287, http://amonline.trb.org/2vd5d8/

I-Jy Chien, New Jersey Institute of Technology, chien@adm.njit.edu
Haifeng Yu, New Jersey Institute of Technology

Abstract: To improve road safety under adverse weather (e.g., snow and ice condition), a designated network has to be anti-iced/de-iced before and/or after the arrival of a snow storm or freezing rain. A model is developed to optimize vehicle routing that minimizes the service time needed for anti-icing/anti-icing/de-icing operation, subject to truck capacity and fleet size constraints. With network transformation techniques and the fair workload concept, the study vehicle routing problem can be solved via dynamic programming (DP). The solution approach was tested on a general network with practical operational data. The results are promising and computationally efficient. A sensitivity analysis is conducted by varying the model parameters, including fleet size, truck capacity and operating speed.

Pavements and Bridges

Field and Laboratory Evaluation of Winter Season Pavement Patching Materials in Tennessee

Paper Number 13-4772, http://amonline.trb.org/2vecl7/
Qiao Dong, University of Tennessee, qdong2@utk.edu
Baoshan Huang, University of Tennessee

Abstract: Field survey and laboratory tests were conducted to evaluate the performance of four patching materials used in winter season pothole repair in Tennessee. The adhesiveness, cohesion, moisture susceptibility and loaded wheel test were conducted to investigate the bonding, freeze-thaw resistance and rutting resistance of the patching materials. Statistical analysis on the six month field survey showed that edge disintegration and missing patch are the mainly distress of "throw and roll" patching in winter season. Severe freeze condition, high traffic level and vehicle speed accelerated the deterioration of patching. Patchings with lower depth and larger size especially longer longitudinal length deteriorated faster. Both field and adhesiveness test showed that the cold dump mix had high potential to edge disintegration and missing patch, which is probably caused by the insufficient binder content or an excessive stiff binder. One cold bag mix showed high potential to deformation and low strength performance, mainly due to its single size gradation and weak aggregate skeleton. Cohesion test conducted at different temperature and compaction times presented consistent ranking of materials. 25°C and 15 blows were recommended to evaluate the cohesion of materials at moderate temperature. Two cold mixes did not withstand the 60°C water bath in the freeze-thaw cycling due to the high air voids and 25°C was suggested instead. Reduced wheel load is recommended to improve the effectiveness of loaded wheel test for cold patching mixtures.

Use of Geothermal Deep Foundations for Bridge Deicing

Paper Number 13-4133, http://amonline.trb.org/2ve16c/
Muhannad T. Suleiman, Lehigh University, mts210@lehigh.edu
Suguang Xiao, Lehigh University
Clay J. Naito, Lehigh University
Sudhakar Neti, Lehigh University

Abstract: Winter deicing practices reduce the longevity of bridge infrastructure making it difficult to achieve the national goal of a100-year or more bridge service life that was set by the Second Strategic Highway Research Program. The vast majority of these bridges are supported on deep foundations. The goal of this study is to evaluate the concept of using geothermal deep foundation (energy piles) to heat the bridge slab minimizing or eliminating the use of deicing salt. This concept has the advantage of using the required foundation elements to also function as heat exchangers with the surrounding soil that has approximately a constant temperature below a depth of 1 to 3 m (depending on the region). This paper describes a two dimensional finite element model used to assess the power demands needed to heat a typical bridge slab. Initially, the two dimensional model of a conventional bridge (not incorporating the geothermal system) was validated using a case study for a bridge in Rhode Island where the temperature of the bridge slab was monitored for about one year. Once validated, the model was extended to include the effects of geothermal deep foundations for the weather condition in Philadelphia, Pennsylvania as an example. Analyses were conducted to simulate the performance of the

geothermal system with and without preheating of the bridge slab before the snow or ice formation event.

Performance Benchmarking of Road Weather Information System Pavement Temperature Forecasts

Paper Number 13-1764, http://amonline.trb.org/2vctpi/
Tae-Jung Kwon, University of Waterloo, tkwon@uwaterloo.ca
Liping Fu, University of Waterloo
Max S. Perchanok, Orlando Ministry of Transportation

Abstract: This paper describes a study focusing on performance evaluation of RWIS pavement temperature forecasts. To identify the factors influencing the accuracy of forecasts, five research hypotheses were constructed that RWIS forecasting accuracy would be affected by climatic patterns (e.g., maritime, continental, and mixed), locational attributes (e.g., geography), seasonal variations (e.g., shoulder months vs. non-shoulder months), time of day (e.g., day vs. night), and forecast horizon. RWIS observations and forecasts data sets provided by four North American provincial transportation agencies were pre-processed and stratified by station, hour, and month, to test the hypotheses and quantify their effects by utilizing two performance metrics, namely mean absolute error (MAE) and percent of acceptable forecasts (PAF). The overall statistics showed that maritime climate group had the highest correspondence and those from mixed climate group had the lowest correspondence, both in terms of their MAEs and PAF. As for the locational attributes, it was found that the forecasting performance of maritime region near coastal areas was found to have a negative correlation with the distance from nearby large water body. It was also found that daytime forecasts were less accurate than the ones generated for night time. Furthermore, the accuracy of forecasts was found to deteriorate quickly as the forecasting horizon increases. Lastly, forecast errors were found to exhibit seasonal variations with forecasts for the shoulder/transitional months tending to be poorer than other months.

Deicer Effect on Concrete Bridge Decks: Practitioners' Perspective and a Method of Developing Exposure Maps

Paper Number 13-5015, http://amonline.trb.org/2veg7t/
Xianming Shi, Western Transportation Institute, Montana State University, xianming_s@coe.montana.edu
Jiang Huang, Western Transportation Institute, Montana State University
Shaowei Wang, Itsnode, LLC
Jaydeep Chaudhari, Western Transportation Institute, Montana State University
Steve Soltesz, Oregon Department of Transportation

Abstract: This work illustrates a method of developing exposure maps that can be used to better understand the potential effects that deicers and other relevant variables may impart on an agency's concrete infrastructure. To capture the practitioners' perspective on the subject, two surveys were conducted with participants from ODOT winter maintenance and bridge management practitioners. Subsequently, the method was established using the Oregon Department of Transportation (ODOT) as a case study and the study involved the collection of relevant data for developing exposure maps for select 12 representative ODOT concrete bridge decks. Through the ODOT case study, issues with data availability and quality were identified and it is recommended that deicer type and application rate, traffic volume, weather condition (air temperature, precipitation, etc.), and bridge mix design data should be documented into an

integrated bridge preservation program; or should be added to the existing bridge management systems, for any agency planning to investigate the role of such variables in the durability of its concrete bridge decks.

Novel Model-Free Algorithm for Monitoring of Weather-Induced Hazards on Road Pavement Using Temperature Data Only

Paper Number 13-3301, not available online

Hae-Bum Yun, University of Central Florida
Ganesh Sundaresan
Youngwoo Jung
Jong-Woo Kim
Ki Tae Park

Abstract: The presence of snow and ice on the pavement are major wintry hazards for roadway safety. Pavement temperature sensors are usually employed as a standard road weather element in many road weather information systems. A novel pattern detection algorithm has been developed to monitor the state changes of moisture on pavement surface (e.g., dry, wet, snow and ice) by solely analyzing the pavement temperature data. The results of both an indoor weather chamber test and a field test under realistic highway in-service traffic conditions show that the change of pavement surface condition, including dry, wet, and snowy and icy states, can be detected using the pattern detection algorithm.

Remote Sensing of Weather and Road Surface Conditions: Is Technology Mature for Reliable ITS Applications?

Paper Number 13-1997, http://amonline.trb.org/2vd0r6/

Levi Ewan, Western Transportation Institute, Montana State University
Ahmed Al-Kaisy, Western Transportation Institute, Montana State University, aalkaisy@coe.montana.edu
David A. Veneziano, Western Transportation Institute, Montana State University

Abstract: Advances in road weather sensing technologies have made non-invasive road weather sensors a valuable component in many Intelligent Transportation Systems (ITS) applications. The current study presents an investigation into the reliability of using one of the aforementioned sensors for a proposed weather-responsive variable speed limit system. The Vaisala surface state and temperature sensors (DSC-111 and DST-111) were selected for the proposed application. The sensors' ability to provide accurate and reliable data was tested under various conditions in a controlled laboratory environment. Specifically, four outputs of interest from the sensors were tested in this investigation; surface state, snow and ice depth, water depth and grip level. Testing results showed that the sensors determined the surface state (dry, moist, wet, snowy and icy) accurately and reliably. The sensor's snow depth readings were found to be inaccurate, while the sensor's ice depth measurements were found to be relatively close to the actual depths. In regards to water depth, only a limited number of readings were close to the actual depths while other readings were highly inaccurate. In an effort to test the potential of the sensor in providing reliable inputs to the proposed ITS application, a calibration was conducted for the sensor water depth measurements using various water depths and sensor installation angles. Calibration results showed that the water depth could be accurately estimated using the calibrated sensor measurements regardless of water depth or sensor installation angle. Sensor estimates of grip

level were found highly correlated to the coefficient of static friction for the conditions considered in this study.

Safety

Transportation System Performance Under Inclement Winter Weather: Perspectives from Weather-Induced Multiple Hazard Situations and Traveler Information

Paper Number 13-2000, http://amonline.trb.org/2vd0tt/

Jinge Hu, University at Buffalo, The State University of New York, jingehu@buffalo.edu
Qian Wang, University at Buffalo, The State University of New York
Adel W. Sadek, University at Buffalo, The State University of New York
Zhiyong Wang, University at Buffalo, The State University of New York

Abstract: This study investigated the impacts of weather-induced multiple hazard situations, such as a snow storm accompanies by a major car accident on a highway, on road network performance in urban areas. A dynamic traffic assignment model was built for the study area in Amherst, New York, using the mesoscopic dynamic traffic assignment simulation package DynusT. Various hazard scenarios were simulated, including single events such as a snow storm or a car accident only scenarios and the combination of them. Both network-wide analyses and link-based analyses were conducted to examine the impact of hazard situations on travel time. In addition, different traveler information mitigation strategies were also evaluated based on the weather-induced multiple hazard situation. The results indicate that weather-induced multiple hazard situation affects network performance more significantly than single events. As traveler information dissemination strategies are concerned, both the variable message signs (VMS) and the en-route guidance are effective in mitigating hazard impact. En-route guidance performs better from the system perspective and brings more travel time savings. In comparison, VMS are more beneficial to the vehicles that are subject to both inclement weather and weather-induced incidents. Based on the findings, practical implications were produced to help traffic operation agencies to select appropriate traveler information dissemination strategies and determine the best information coverage rate.

Analysis of Factors Affecting Winter Collision Severity

Paper Number 13-1669, http://amonline.trb.org/2vcsa7/

Taimur Usman, Ministry of Highways and Infrastructure Saskatchewan, taimurus@gmail.com
Liping Fu, University of Waterloo
Luis Fernando Miranda-Moreno, McGill University

Abstract: This paper presents the results of an analysis aiming at identifying the main injury severity factors associated with road collisions that occur during snowstorms, including traffic conditions, road geometry and environment, pavement surface conditions as well as vehicle and driver characteristics. A multilevel multinomial logit model is introduced for capturing the hierarchical nature of the collision data between individual collisions and the vehicles and persons involved. Different from past studies, the modeling effort focuses on the collisions that occurred over snowstorms so that the effect of weather related factors are not masked due to the imbalance of data sample between collisions occurred under normal conditions and those under snowstorms. This approach is also necessary for ensuring that the incremental effect of different

weather severity, as well as winter road maintenance operations, could be captured. Collisions occurred on a number of highway routes from the province of Ontario, Canada, over six winter seasons (2000-2006), were selected for this analysis. It was found that factors related to drivers (age, sex, condition), road characteristics (number of lanes, speed limit, road surface conditions), vehicle type, position in vehicle, use of safety belt, and traffic volume have statistically significant effects on collision severity outcome. In general, the modeling results indicate that good road surface conditions, high traffic volume, young and male drivers and new vehicles are associated with reduced injury severity levels. Our analysis, however, did not confirm the main finding from literature, that is, severer weather, such as higher precipitation intensity and wind speed, is associated with lesser collision severity.

Driver Behavior

Effect of Weather and Road Surface Conditions on Traffic Speed of Rural Highways
Paper Number 13-0779, http://amonline.trb.org/2vcfek/

Luchao Cao, University of Waterloo, L8cao@uwaterloo.ca
Lalita Thakali, University of Waterloo
Liping Fu, University of Waterloo
Garrett Donaher, University of Waterloo

Abstract: This paper describes a study focusing on the impact of winter weather and road surface conditions on the average vehicle speed of rural highways with the intention of examining the feasibility of using traffic speed from traffic sensors as an indicator of the performance of winter road maintenance (WRM). Detailed data on weather, road surface conditions, and traffic over three winter seasons from two two-lane and two four-lane rural highways in Iowa, US, are used for this investigation. Three modeling techniques are applied and compared for modeling the relationship between traffic speed and various road weather and surface condition factors, including multivariate linear regression, artificial neural network (ANN), and time series analysis. The modeling results have confirmed the statistically strong relationship between traffic speed and road surface conditions, suggesting that speed could potentially be used as an indicator of bare pavement conditions and thus the performance of winter road maintenance operations. The analysis has also confirmed the expected effects of several weather variables including precipitation, visibility, temperature and wind speed. Lastly, the time series model developed could be a valuable tool for predicting real-time traffic conditions based weather forecast and planned maintenance operations.

Investigation of Impact of Severe Winter Weather on Volume of Passenger Cars and Trucks on Primary Highways
Paper Number 13-2679, http://amonline.trb.org/2vdaff/

Hyuk-Jae Roh, University of Regina, roh204@uregina.ca
Sandeep Datla, City of Edmonton
Satish Sharma, University of Regina

Abstract: Based on large traffic and weather data sets from weigh-in-motion sites, permanent traffic counters and weather stations in Alberta, Canada, an investigation is carried out to study impacts of winter weather on volume of passenger car and truck traffic. Multiple regression models are developed to relate truck and passenger car traffic variations to winter weather

conditions. Statistical validity of study results are confirmed by using statistical tests of significance. Considerable reductions in passenger car and truck volumes can be expected with decrease in cold temperatures. Such reductions are higher for passenger cars as compared to trucks. Due to cold and snow interactions, the reduction in car and truck traffic volume due to cold temperature could intensify with a rise in the amount of snowfall. For passenger cars, weekends experience higher traffic reductions as compared to weekdays. However, the impact of weather on truck traffic is generally similar for weekdays and weekends. Interestingly, an increase in truck traffic during severe weather conditions is noticed at one of the study sites. Such phenomenon is found statistically significant. None of the past studies in the literature have presented the possibility of traffic volume increases on highways during adverse weather conditions; which could happen due to shift of traffic from parallel roads with inadequate winter maintenance programs. It is believed that the findings of this study can benefit highway agencies in developing such programs and policies as efficient monitoring of passenger car and truck traffic, and plan for efficient winter roadway maintenance programs.

Traffic Modeling

Approaches and Gaps in Weather-Responsive Traffic Management: U.S. and European Perspectives

Paper Number 13-1499, http://amonline.trb.org/2vcpsn/

Roemer Alfelor, Federal Highway Administration, roemer.alfelor@dot.gov
Romain Billot, Laboratoire d'Ingénierie Circulation Transports, Université de Lyon
Nour-Eddin El Faouzi, Laboratoire d'Ingénierie Circulation Transports, Université de Lyon
Paul A. Pisano, Federal Highway Administration

Abstract: Traffic management and operations during adverse weather is a major challenge for transportation agencies around the world. Weather is a common cause of crashes and delays on the highways everywhere, accounting for large number of fatalities and hours of delay every year in the US and Europe. Significant improvements have been made in the development and implementation of weather-responsive traffic management strategies to alleviate the impacts of weather, both in the US and Europe. These include weather and traffic data collection and integration, traffic analysis and modeling, human factors analysis and performance evaluation. This paper will describe the state-of-the practice in weather-responsive traffic management in the US and Europe including the types of strategies, systems and tools being used, their similarities, and their effectiveness in traffic operations. The paper will also describe the relevant research activities being undertaken in both countries and how they can coordinate and benefit from each other's efforts. Finally, the gaps in current practices and research related to weather-responsive traffic management are identified, and recommendations on how these gaps can be filled are described

Effect of Winter Weather and Road Surface Conditions on Macroscopic Traffic Parameters

Paper Number 13-1763, http://amonline.trb.org/2vctol/

Tae-Jung Kwon, University of Waterloo, tkwon@uwaterloo.ca
Liping Fu, University of Waterloo
Chaozhe Jiang, University of Waterloo

Abstract: This paper presents an empirical study focusing on identifying the main factors that affect the capacity and free-flow-speed (FFS) of urban freeways under inclement winter weather conditions. The weather and road surface condition factors examined include air temperature, wind speed, hourly snow intensity, visibility, snow on ground, and road surface condition describing the road slipperiness caused mainly by snow events. Data on traffic operations, the associated weather and road conditions observed at two freeway locations over the 2010-2012 winter seasons were used in an extensive statistical analysis. Linear regression models were calibrated for both capacity and FFS reductions as related to various weather and road condition variables. It was found that visibility and road surface conditions have a statistically significant effect on both capacity and FFS. Snow intensity was found to be significant only when the visibility factor was excluded, suggesting the presence of confounding of these two factors on capacity and FFS. The modeling results were compared with those recommended by the Highway Capacity Manual 2010, showing that in many cases, HCM could underestimate or overestimate the effects of winter weather conditions and that the proposed models provide more reasonable estimate at a higher level of granularity.