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Quantifying Correlations Between Pavement Conditions and Snow and Ice Control Costs and Recalculating 2021-2022 Winter Performance Measures

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Research Project

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16. Abstract

This project consisted of an analysis of the relationship between pavement quality and winter maintenance cost, and calculation of selected winter maintenance performance measures for the last 11 winter seasons. The project included obtaining the necessary data, gathering it into a GIS, and analyzing the relationship between pavement quality and winter maintenance cost. The data included pavement quality in GIS line segments and winter maintenance costs from the MATS by maintenance garage. This data was added to the existing GIS of winter severity to answer the following research questions:

- Does degraded pavement quality result in increased winter maintenance costs?
- How does roadway priority affect the relationship between pavement condition and SIC costs?

We found that poor pavement quality does increase winter maintenance costs, but only slightly, and not nearly as much as weather severity. The second question could not be answered because it is not possible at this time to disaggregate the winter maintenance cost data to isolate costs incurred to maintain a specific roadway or route. This project also consisted of the calculation of the weighted Grip loss performance measure for the last 6 winter seasons, along with the winter severity and winter maintenance costs for the last 11 winter seasons. All data is reported by VTrans parent garage for consistency.

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Table of Contents

Figures and Tables

Executive Summary

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1 Introduction

Winter maintenance operations are among the highest-profile activities of our state DOTs, and some state DOTs expend up to 20% of their budget on winter maintenance in snowy years (Albrecht, 2020). Historically, season-to-season variability in winter weather and the absence of quantifiable methods for measuring winter severity have made planning and budgeting for roadway snow and ice control (RSIC) activities challenging.

Recent research by the Vermont Agency of Transportation (VTrans) (Dowds & Sullivan, 2019; Sullivan et al., 2016) and other snowbelt DOTs (Boustead et al., 2015; Jensen et al., 2014; Mewes, 2012; MRCC, 2019) have helped establish objective measures of storm severity, creating the opportunity to quantify relationships among winter severity and RSIC costs. Recent experiences by VTrans RSIC managers and other research has suggested that the pavement surface may also play a role in RSIC costs, particularly related to the application of friction materials (Akin et al., 2018).

For this project, the research team used a winter severity measure that has become well established, statewide measures of pavement rut depth and roughness, and statewide RSIC cost data in Vermont spanning 10 years to comprehensively assess the relationship between these variables.

Section 2 summarizes the background for the research documented in this paper, Section 3 describes the data gathered and methods used for the analyses, and Section 4 concludes with a summary of the results of the analyses and the conclusions drawn from this work.

2 Background

This project builds on nearly a decade of research by the University of Vermont for the Vermont Agency of Transportation about its RSIC practices. Previous research has sought to improve the efficiency and effectiveness of RSIC operations in Vermont through optimizing the locations of salt storage and the plow routes, as well as developing more effective methods of measuring the performance of RSIC (Sullivan et al., 2015; Sullivan et al., 2019).

Most recently, these efforts were focused on finding the best measures of winter severity and RSIC performance for Vermont, based on available data and recent advances (Dowds & Sullivan, 2019). That project concluded that the Accumulated Winter Season Severity Index (AWSSI) would be effective for quantifying winter severity in Vermont. Recent work by MRCC for the Clear Roads Pooled Fund Program (MRCC, 2019) expanded the number of weather stations for which the AWSSI is calculated and continued the calculations nationwide on an ongoing basis. With this measure of winter severity, VTrans asset managers are interested in better understanding the relationship between RSIC costs and other large budget items. Pavement maintenance is an area where VTrans also spends a lot, so the relationship between improvements in pavement maintenance and RSIC costs would be valuable. The basis of this relationship is the potential correlation between pavement quality, which is measured statewide on a biennial basis, and RSIC costs. Therefore, VTrans asset managers are interested in understanding if pavement quality affects RSIC burden.

3 Data

To support a more thorough analysis of the relationship between winter severity, pavement roughness and rut depth, and RSIC cost, a decade of historical data were obtained for regression analyses.

3.1 Winter Severity

National Oceanic and Atmosphere Administration (NOAA) weather stations provide the longest and most comprehensive continuous data history for winter severity. Though the locations of NOAA weather stations do not correspond directly with the boundaries of Vermont's RSIC districts, their reliability and broad geographic distribution provide adequate coverage to draw conclusions about weather across the state. A total of 27 NOAA stations in Vermont collect the data required to calculate the AWSSI family of severity measures. In order to compensate for the relative sparsity of weather stations in southern Vermont, four additional NOAA stations (one each in New York and Massachusetts, and two in New Hampshire) were also identified and included in the dataset, bringing the total number of stations used to 31. Daily summary weather data from all 31 of these NOAA stations were downloaded from November 2011 through April 2021. In total, this produced over 50,000 daily weather records.

The AWSSI is calculated using a daily scoring system which assigns points to each day based on temperature, snowfall, and existing snow depth on that day. These measures are intended to represent the cumulative effects of winter precipitation and accumulation since RSIC becomes more challenging as the intensity of the winter season up to that point increases. The AWSSI was calculated at each of the 31 NOAA stations for each of the 10 years of weather data, resulting in 310 data records for each measure, and one or two of these NOAA stations were associated with each VTrans garage to transfer the AWSSI values.

3.2 Winter Maintenance Costs

Winter maintenance cost data for this project were exported from the VTrans' Managing Assets for Transportation Systems (MATS) database. The MATS database records labor, equipment, and material quantities and costs at the level of the maintenance garage for a variety of activities undertaken by maintenance crews, including RSIC. Total length of plow routes each garage is responsible for are also included, enabling the calculation of RSIC costs per lane-mile in each garage's service territory. The dataset for this project includes 78,440 daily garage-level records from November 2011 through April 2021. These records were aggregated to provide approximately 390 seasonal costs, which were primarily used to analyze relationships. All RSIC costs described in this report were standardized by lane-mile of responsibility to allow for the comparison of costs across garage service areas of different sizes.

3.3 Pavement Quality Measures

VTrans collects pavement quality metrics using an Automatic Roadway Analyzer (ARAN) vehicle. Data is collected annually for interstate and national highway routes, and every other year for state routes and major town collectors. The ARAN vehicle collects data at a high-frequency and aggregates it to every 0.1-mile segment in the network. For this study, roughness, represented by the International Roughness Index (IRI), and rut depth measures were gathered for every tenth of a mile across approximately 3,400 miles of state-maintained roadway in the state. This resulted in approximately 34,000 data records per year, or a total of approximately 340,000 records representing pavement quality across the 10-year period from 2011 through 2021. Pavement quality data were aggregated for each garage by assigning the segment to the garage responsible for its maintenance. Since the segments are uniform in length, the sum of the pavement quality measures (IRI and rut depth) divided by the total length of roadway that the garage is responsible for represents the weighted average of the pavement quality for that garage and year, or about 390 records over the 10 years of data.

3.4 Pavement Quality Indices

Five pavement-quality index variables were also obtained and investigated for use in the pavement quality analysis. They include the composite index, rutting index, IRI index, and indices for structural and transverse cracking. Index variables are calculated from other raw data within nested if/then statements. Each index variable has a range from 0 to 100, with higher values representing better pavement quality. Structural and transverse cracking indices had distributions that were significantly left-skewed, as shown in Figure 1.

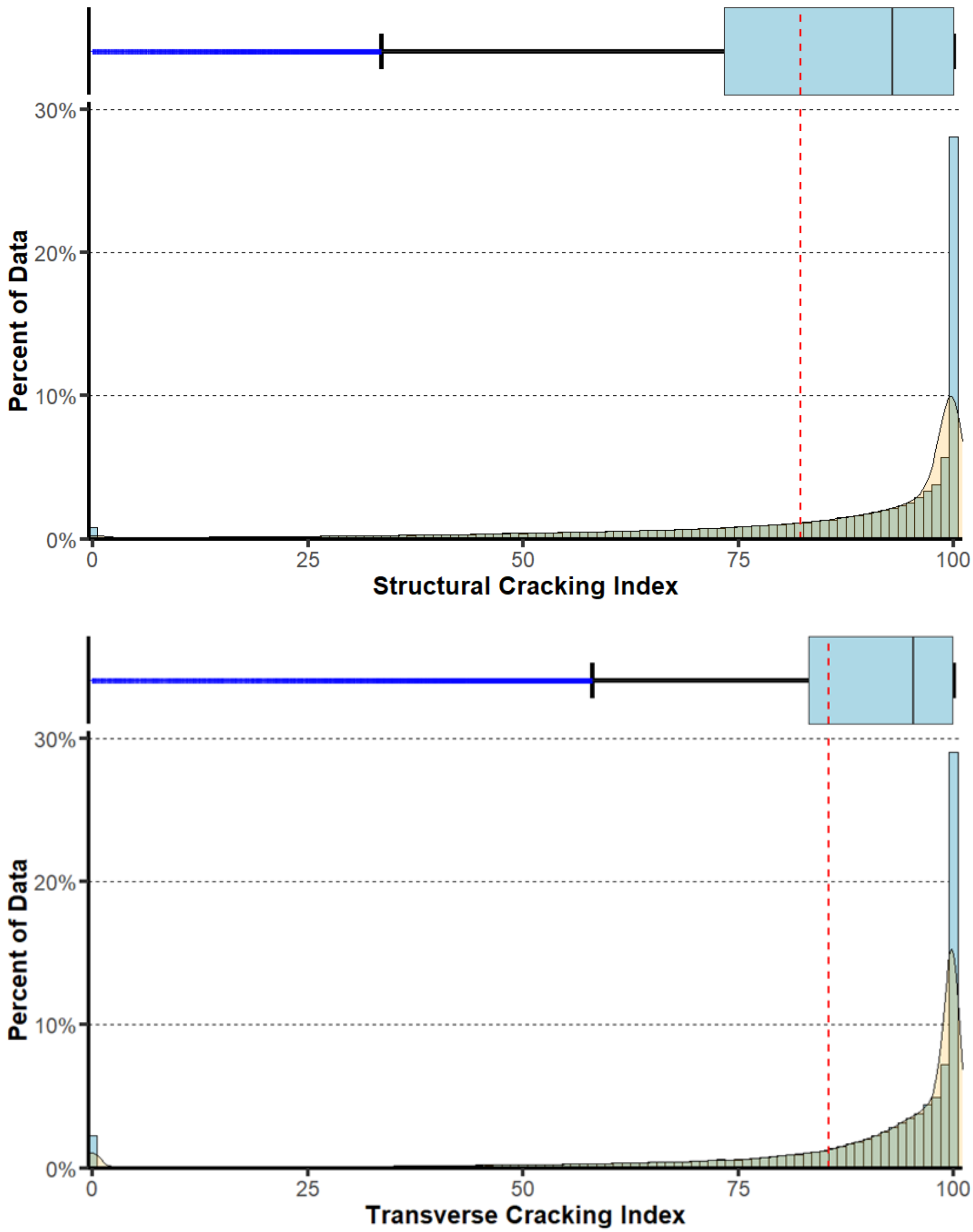


Figure 1 Histograms of cracking indices - dashed red lines are mean values and blue horizontal line is the outlier range

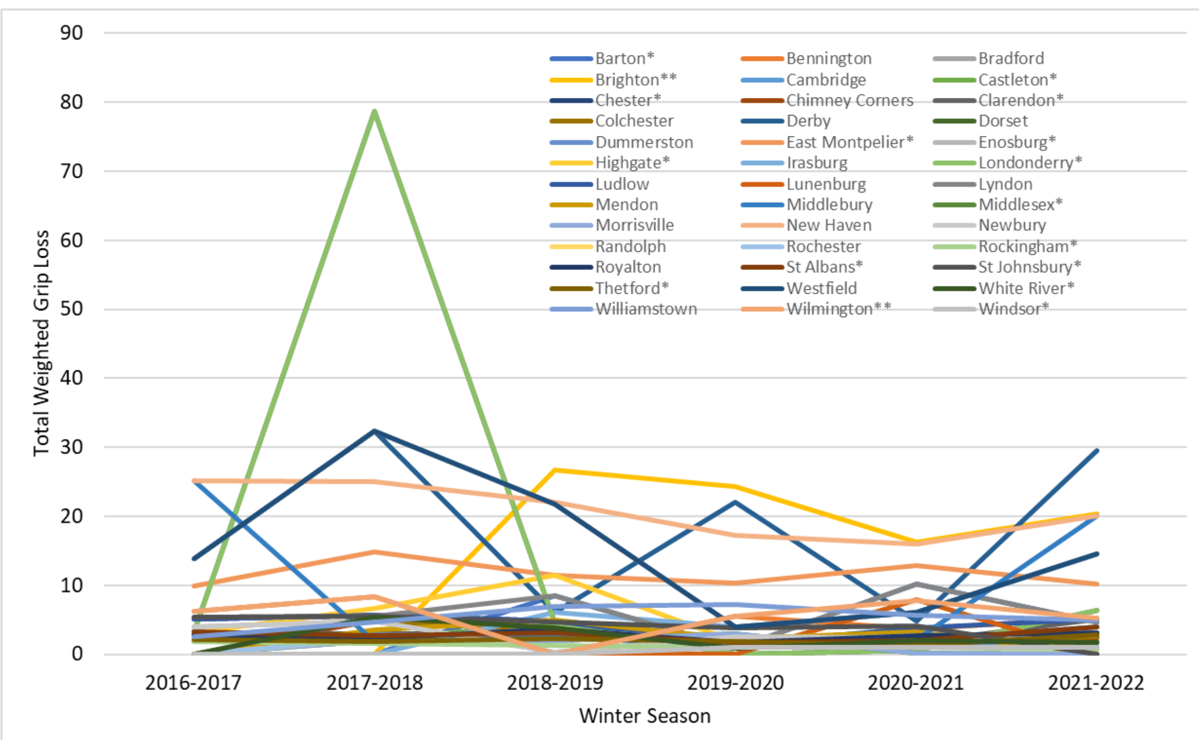
An index value of 100 (no cracking) is evident for nearly 30% of the data, with median values for structural and transverse cracking of 93 and 95, respectively. While there is a significant amount of data, the prevalence of high values, limited range, and skew of the data make it difficult to model. Attempts to transform the variables using traditional approaches (i.e. log-transformations) or unique case approaches (i.e. arcsin(sqrt(x))) did not make a difference. Additionally, modeling an index variable calculated through nested if/then statements with varying expressions introduces artifacts into the model that compromise the results of the analyses.

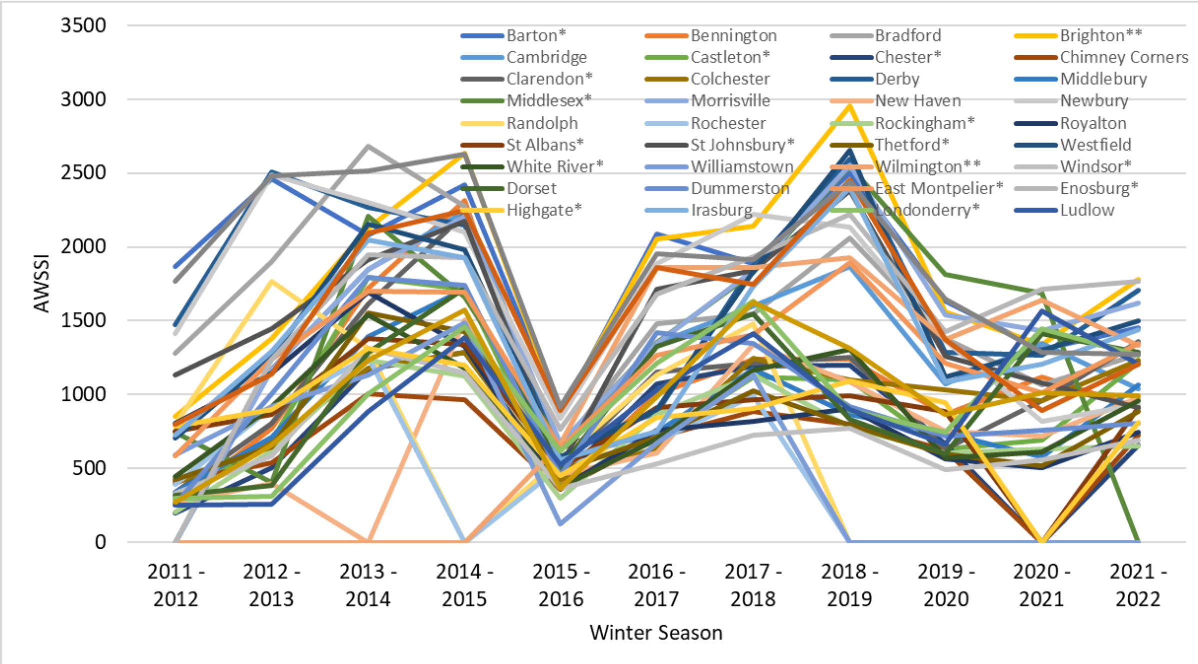
For the rutting and IRI index variables, their distributions show a significant left-skew, albeit to a lesser degree than the cracking indices, making them more difficult to model. For these variables, however, the raw measurements are available and are better suited to including in a regression model. Therefore, these index variables were omitted from the analysis.

The composite index was calculated using the other index variables, indicated by high correlations with all index variables between 0.7 to 0.8. Inclusion with any other index variables may then result in multicollinearity within the model. Based on these findings, all index variables were omitted from the modeling analysis.

3.5 Historical Data Summary

This project also consisted of the calculation of the weighted Grip loss performance measure for the last 6 winter seasons, along with the winter severity and winter maintenance costs for the last 11 winter seasons. All data is reported by VTrans parent garage for consistency. This data was delivered electronically but is also illustrated in Figure 2.





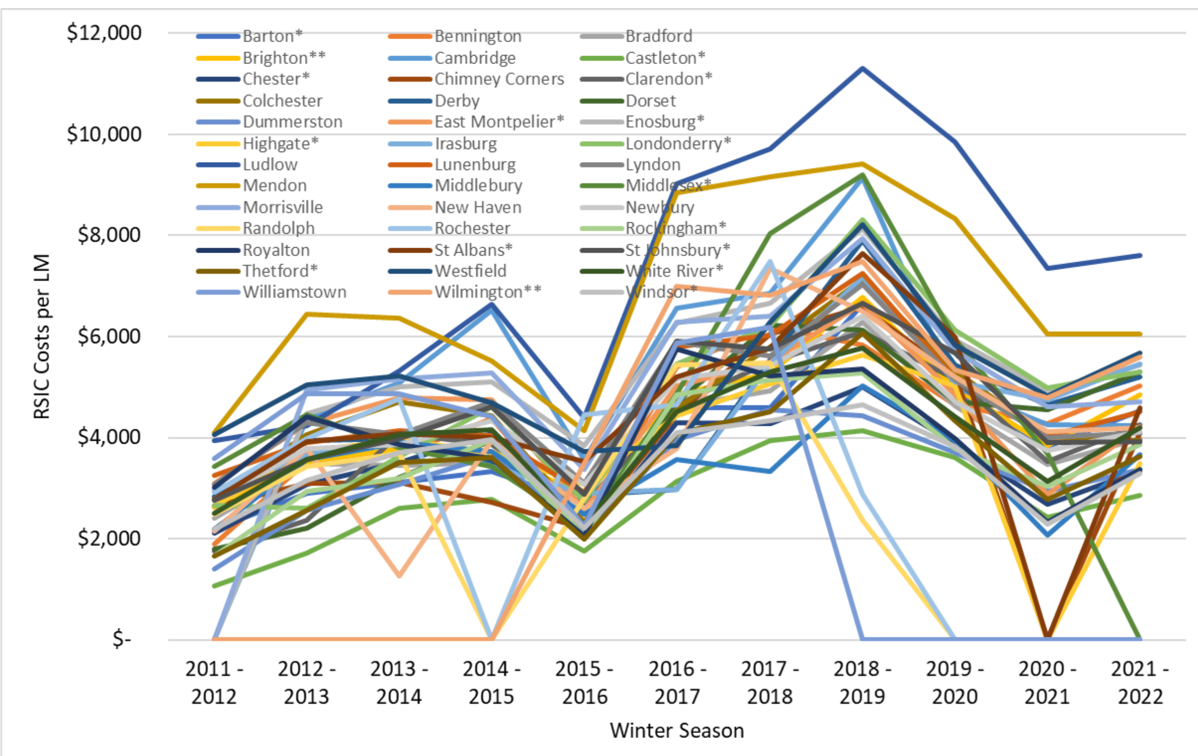


Figure 2 Historical Weighted Grip Loss (top), Winter Severity (middle), and Winter Maintenance Cost (bottom) by Garage

Asterisks near the garage name indicate one or two satellite garages that support winter maintenance for that service area. However, costs are attributed to the parent garage in the MATS.

4 Methods

Simple and multiple linear regressions were used to analyze relationships in this study. In each case, the dependent variable is the winter maintenance cost, and independent variables represented winter severity and pavement quality. The strength of the models was assessed by each model's R-squared value and the contributions of the individual independent variables was assessed by their p-values. To account for varying spatial scales, the team modeled the relationships statewide and then by the newly-established regional level. Although the plow route spatial scale is also available for all of the data, it is not considered reliable due to reporting inconsistencies in the MATS data, and sparseness of weather stations in the NOAA data. The exploration of varying spatial scales served to parse the data – the statewide analysis includes all of the data, whereas the regional analysis cuts the dataset into thirds.

Pavement quality data is of course only available on an annual basis and is in fact only collected in the non-winter months. Therefore, the pavement quality data (IRI and rut depth) for a given summer season were assigned to the previous winter season, to represent the worst case for pavement quality likely seen by winter maintenance crews that winter. Since the relationship between pavement quality and RSIC cost was expected to be less prominent than the relationship between winter severity nad RSIC cost, this analysis was held until after the temporal and spatial scales had been explored. This approach would allow the analysis of pavement quality to take advantage of the optimal spatial scales found in the previous modeling. Pavement quality variables were included with winter severity variables but also alone, to determine if a positive relationship is still present without consideration of weather. Table 1 summarizes the regression models created for this analysis, in terms of the independent variables included. Table 2 summarizes the spatial scales used in the regression models.

Table 1 Independent Variables Used in Multiple Regression Models

Variable	A	B	C	D
AWSSI	+	+		
IRI	+	+	+	+
rut depth	+	+	+	+

Table 2 Spatial Scales Used in Multiple Regression Models

Spatial Scale	A	B	C	D
Statewide	+		+	
regions (3)		+		+

5 Results and Conclusions

All pavement quality analyses were conducted at the seasonal level. Pavement quality measures (IRI and rut depth) were aggregated, assigned to their responsible garage, and regressed against the garage's seasonal RSIC costs. All independent variables were standardized. Models were created with and without AWSSI at the statewide and snow-region geographies. Results of the multiple regression models A and B are provided in Table 3, and the results of models C and D are provided in Table 4.

Table 3 Results of Multiple Regression Models A and B

	Statewide		Northeast Snow Region		Northwest Snow Region		South Snow Region	
Variable	**coefficient**	**p**	**coefficient**	**p**	**coefficient**	**p**	**coefficient**	**p**
Intercept	614084	0.00	513674	0.00	750681	0.00	625270	0.00
AWSSI	146927	0.00	141363	0.00	173523	0.00	200885	0.00
IRI	12648	0.47	99285	0.00	-12599	0.83	-11382	0.56
Rut depth	97076	0.00	21422	0.40	79879	0.10	74644	0.00
R^2 (Adj R^2)	**0.35 (0.34)**		**0.45 (0.44)**		**0.25 (0.22)**		**0.41 (0.40)**	

Table 4 Results of Multiple Regression Models C and D

	Statewide		Northeast Snow Region		Northwest Snow Region		South Snow Region	
Variable	**coefficient**	**p**	**coefficient**	**p**	**coefficient**	**p**	**coefficient**	**p**
Intercept	614084	0.00	604524	0.00	748857	0.00	527978	0.00
IRI	56167	0.01	110902	0.00	113800	0.05	-4555	0.85
Rut depth	43243	0.03	-17883	0.57	-10823	0.83	64184	0.03
R^2 (Adj R^2)	**0.10 (0.10)**		**0.13 (0.12)**		**0.06 (0.04)**		**0.06 (0.05)**	

The model of RSIC cost and seasonal winter severity alone with all statewide data resulted in an R^2 of 0.37. The first model with pavement quality variables in the top left corner of Table 2 includes rut depth and IRI in that same model, causing the fit to degrade to 0.35. The IRI is not significant in the model, considering a threshold for p values of 0.05, but rut depth is significant, and its coefficient is comparable to that of AWSSI. For the same model with only data from the Northeast snow region, the fit improves to 0.45, but this time rut depth is not significant and IRI is significant. The coefficient of the pavement quality variable is comparable to that of the AWSSI. For the same model with only data from the Northwest snow region, neither of the pavement quality variables is significant, and model fit is poor. For the model of the South snow region, the rut depth is again significant, and the fit is improved, but the size of the coefficient for rut depth is very small relative to the coefficient for the AWSSI and the model intercept. These results overall suggest that poor pavement quality, as indicated by increasing roughness and rut depth, does cause RSIC costs to be slightly. However, the effect of pavement quality on RSIC cost is very small and inconsistent relative to the AWSSI as a measure of winter severity. Inconsistencies may be due to regional differences in the pavement quality or the ability of the AWSSI to accurately indicate winter severity.

For the models without AWSSI, both IRI and rut depth are significant for the statewide using a threshold for p of 0.05. Regionally, the significance of the pavement variables varies with each model. IRI is significant for the Northeast snow region, but rut depth is significant for the South snow region. However, the very poor model fits for these models indicates that the contribution of pavement quality to the models of RSIC cost is very small, and potentially negligible.

This study investigated the relationship between RSIC costs, weather severity and pavement quality. Consistent with the expectation that RSIC is costlier when winter weather is more severe, the team found a strong relationship between RSIC cost and winter severity. Multiple regression models indicated that poor pavement quality may lead to increased RSIC costs, yet these effects are small relative to the contribution of winter severity. Pavement quality (rut depth and roughness) and its relationship to RSIC effort is subtle and complex. The statewide and regional models created in this paper take advantage of the larger sample size available for this resolution and the inconsistency of RSIC cost data at the plow route level. However, the true relationship seems to be affected by the priority level of the roadway, and its corresponding functional class. Higher-priority roads are generally of a higher functional class and are kept at a higher level of pavement quality. Therefore, the effect of pavement roughness and rut depth is more difficult to discern along plow routes serving high priority roads, or within districts that primarily serve high-priority roads. Lower-priority roads, which tend to be of lower functional class, do not require intensive RSIC but are also not kept in as good a condition with respect to roughness and rut depth. So, for plow routes or districts with a higher percentage of low-priority roads (like the Northeast snow region in Vermont), the relationship between pavement quality and RSIC cost is more evident whereas it seems to be more difficult to discern in the Northwest snow region, where more high-priority roads are located. Further research is needed into the combined relationship between RSIC cost, pavement quality, and RSIC priorities served by the route, garage, or district to learn more about how these variables are related.

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