



Center for Weather Impacts
on Mobility and Safety

Effects of Weather on Winter Maintenance Performance

project summary

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RESEARCH PROJECT TITLE

Winter Weather Severity Index
Enhancements

SPONSOR

Minnesota DOT

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MORE INFORMATION

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ABOUT CWIMS

CWIMS focuses on research to find better
and safer ways to travel whenever weather
is a problem.

CWIMS is an Iowa State University
Center administered by the Center for
Transportation Research and Education.

The opinions, findings, and conclusions
expressed in this publication are those of
the authors and not necessarily those of the
project partners.

Objective

The objective of this research was to conduct an independent evaluation of winter maintenance performance indicator and LEM data collection and processing practices. The evaluation sought to establish whether the correct data were being collected and if the appropriate analyses were being conducted on the available data. Appropriate analyses means analyses that are able to identify successes and isolate best practices. Once we can distinguish and measure success, management can reward and encourage it elsewhere.

Problem Statement

To determine the relative severity of winter weather, state transportation agencies (STAs) have used seasonal (the portion of the year when snow is expected) models to measure the weather. Either mild or severe weather would justify less or more effort in fighting winter storms during the year. Some of these models were based on a statistical relationship between the average weather and the severity of fighting the weather, some were based on the relationship between physical properties and the weather, and others were based on educated guesses mixed with scientific theory. None of these approaches allowed for the evaluation of storm severity between storms or severity between locations (e.g., one route compared to another), although such an approach is now being developed at the University of Iowa.

The weather of each region of a state is unique, as are the methods of fighting snow. This makes it important to have both local data and a model that has taken into account local conditions (e.g., traffic volume on the link). With a clearer understanding of the severity of the weather, STAs may be better able to evaluate their performance and react accordingly before the season is over.

Research Description

There were three principal measurement and data issues investigated in this research:

- the appropriate characterization of storm severity,
- the accurate measurement of the important resources (inputs), and
- the accurate measurement of the desired outcome.

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A core business of the Minnesota DOT (Mn/DOT) is removing snow and ice from public roadways. The outcome of this depends on the severity of the winter storm and on the quality and quantity of resources used to perform winter maintenance. Performance is measured by customer satisfaction. Since customer performance cannot be measured following every storm, an indicator—time until bare pavement—is used as a proxy.

Mn/DOT trains each operator to recognize when bare pavement has been achieved. The times are passed from the operator to the truck station manager who then enters the time into a computer terminal. There is a time goal for each roadway classification type. In this analysis, the relative achievement of the goal is the dependent variable. For example, if the objective for a super commuter roadway is three hours, and bare pavement is achieved in three hours, then the performance index (or dependent variable) for the segment becomes one. If bare pavement is achieved after four hours, then the performance index becomes 1.33 ($4/3 = 1.33$).

A mixed linear model was developed to describe the relationship between the performance index and a set of roadway and weather-related covariates. Covariates included weather conditions (e.g., snow and maximum and minimum temperatures), location of the link, and time. This approach allowed for the comparison of the observed performance at a given route relative to the expected performance of all routes at the same time. It also facilitated

the comparison of performance between districts, between storms, or between routes.

After assembling a list of variables potentially associated with performance, a subset was identified that could be measured and for which data would be available within 24–48 hours after a storm. See Table 1.

For the purposes of the statistical analyses, plow route segments were joined to the nearest weather reporting station. The only National Weather Service data used were those reported within 24 hours afterward by the Minnesota Climatological Service. (Several of the weather observing sites are manual, and reporting weather information takes several weeks after the storm [usually by mail]. These data might be used months after the winter season to more accurately define the weather.)

The latest average daily traffic (ADT) counts for the segment were also included. The ADT are average volumes and probably do not reflect the volumes during the actual storm, but the volumes during the storm should be highly correlated with annual average volume.

Roadway routes were grouped into five functional classifications for the purpose of identifying goals for time until bare pavement. Through market research, Mn/DOT found that drivers on lower volume roadways expected longer time until the snow was cleared. The levels of customer expectation and the level of the performance for the goals are listed in Table 2.

Table 1. Variables

Index variables	Variable definition	Type of variable	Variable
District	Geographical location of observation	Classification	District _i
Storm of the season	1,2,3, ...	Classification	Storm _j
Volume	Average volume on roadway/1000	Continuous	Volume _{ijk}
Performance relative to goal	Actual bare lane time/goal	Continuous	Y _{ijk}
Route orientation	Route is E-W or N-S	Integer variable	EW _{ijk}
Snow quantities	Amount of snow at nearest NWS site	Continuous	Snow _{ijk}
Wind speed	Maximum wind speed at nearest NWS site	Continuous	Wind _{ijk}
Maximum temperature	Maximum temperature record by nearest NWS site	Continuous	Tmax _{ijk}
Minimum temperature	Minimum temperature recorded by nearest NWS site	Continuous	Tmin _{ijk}

Table 2. Route classification

Route classification	Traffic volume	Goal
Super commuter	More than 30,000	3 Hours
Urban commuter	10,000–30,000	5 Hours
Rural commuter	2,000–10,000	9 Hours
Primary	800–2,000	12 Hours
Secondary	Under 800	36 Hours

We fitted a mixed linear model to performance indexes, provided by Mn/DOT, that correspond to seven statewide storms that occurred in the winters of 2005 and 2006. The specific form of the proposed model is as follows:

$$y_{ijk} = \beta_0 + \beta_1 * district_i + \beta_2 * volume_{ijk} + \beta_3 * EW_{ijk} + \beta_4 * Snow_{ijk} + \beta_5 * Wind_{ijk} + \beta_6 * T \max_{ijk} + \beta_7 * T \min_{ijk} + S_j + \epsilon_{ijk} \quad (1)$$

The model in (1) is known as a *mixed linear model* because it includes fixed and random effects among the covariates. In the model, y_{ijk} denotes the log-performance index of the k-th route segment in the i-th district, j-th storm, β_0, \dots, β_7 are regression coefficients

associated with the fixed effects in the model, ϵ_{ijk} and S_j are random variables, and

$$\epsilon_{ijk} \sim N(0, \sigma_\epsilon^2) \text{ and } S_j \sim N(0, \sigma_S^2) \quad (2)$$

The independent variables—district, orientation of segment, and storm—are categorical variables rather than continuous variables such as temperature and snowfall depth. The estimated model is shown in Equation 3.

$$\hat{y}_{ijk} = 0.8875 + \beta_{district} - 0.0347 * volume_{ijk} + 0.03719 * EW_{ijk} + 0.07381 * Snow_{ijk} + 0.003638 * Wind_{ijk} - 0.05677 * T \max_{ijk} + 0.03679 * T \min_{ijk} \quad (3)$$

To confirm whether the assumption of normality for the response variable is plausible and to investigate whether important variables may be missing from the model, we carried out an analysis of the estimated residuals from the model. Figure 1 shows the residuals plotted against the predicted response variable (top left panel), the distribution of the estimated residuals (top right panel),

a quantile-quantile (Q-Q) plot of the residuals (bottom left panel), and a box plot of the residual distribution (bottom right panel). The residual plot shows no trend or unexpected behavior, and that, as expected, the residuals are approximately normally distributed, with zero mean, suggesting that the proposed model fits the data well.

Key Findings

A comparison was made to all known performance indicators. Researchers concluded that Mn/DOT should keep their current indicator—time before bare pavement is regained.

Researchers also concluded that the performance data must be timely, accurate, and accessible to management

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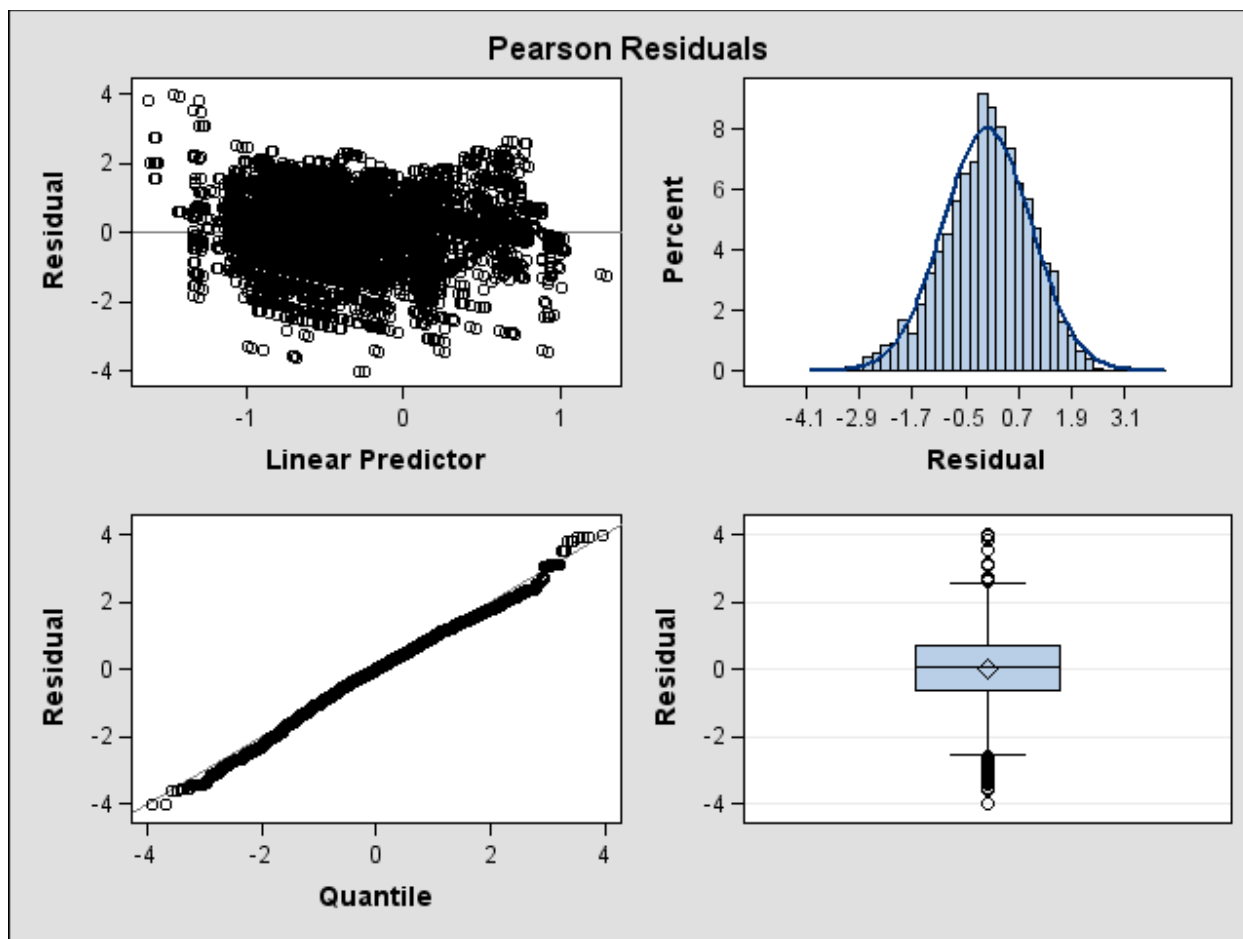


Figure 1. Residual analysis of model (1)

personnel. This would require Mn/DOT to generate rules for data coding, delivery, timeliness, and distribution. After reviewing weather severity indices, the researchers believe that Mn/DOT should find an index that is more appropriate to Minnesota and can take current weather conditions (rather than seasonal weather conditions) into account.

The most important relationship estimated is between measurable weather parameters and performance. Because electronic data on weather variables are immediately available, severity can be measured between storms and between geographic locations immediately following a storm. In most cases, the data used were available within 24–48 hours following a storm. This allows the DOT to make a rather quick assessment of the impact of the storm on the performance of road cleaning crews throughout the state.

The model developed used only one year of data. Clearly more data covering more years is required before propos-

ing a model to be used operationally. However, even the current fitted model can provide a benchmark for measuring the weather's impact on snow and ice operations. Furthermore, only after the model is put into operation will we be able to determine whether model predictions coincide with experience.

Our work demonstrates that, at least for the seven storms considered here, performance is statistically associated with weather and roadway characteristics.

Implementation Benefits

Performance can be accurately forecasted using readily available weather data. In fact, the model permits individual post-storm analysis, which in turn permits adjusting the operations of road-cleaning crews to improve performance before the winter season is over. This has the potential to increase the overall efficiency of the DOT relative to a simple year-end analysis.