Variation of snow cover and extrapolation of RWIS data along a highway maintenance route

Final Report, AURORA Project 2003-05

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Abstract

The success of highway snow control operations can be improved by Road Weather Information Systems (RWIS) with improved snow control. The benefit of RWIS is however limited if the road surface conditions between observing stations cannot be reliably interpolated. This research investigated the variation of snow cover along a maintenance route as related to the terrain and vegetation features of the route. Friction data were collected and used to evaluate variation of snow cover on several maintenance routes in Ontario, Canada. It was found that the periodic structure of friction was correlated to the spacing of roadside terrain and vegetation features. The terrain and vegetation features that affected friction were found to be grouped together spatially in zones that were related to

geomorphologic features and to coincide with terrain shelter conditions. Mean values were found to vary between terrain shelter zones and wind conditions during a storm. These results suggested that snow cover information from RWIS stations could be extrapolated over long distances during low wind conditions but only within similar terrain conditions during periods of high wind.

1. Introduction

Snow accumulation on highway pavements increases the risk of accidents and travel delay during winter months. The risks can be reduced by planning snow control operations with support from Road Weather Information Systems (RWIS).

RWIS use physical measurements of pavement and atmospheric conditions at sensor locations to improve forecasts of frost and snow accumulation on the pavement at the sensor location. Road managers use the pavement-specific forecasts to help schedule plowing, salting and sanding operations, including selection of materials and application rates.

RWIS pavement condition forecasts are limited by the small footprint of measurement devices and their wide spacing along the highway . Extrapolation along a maintenance route may be aided by linear mapping of surface temperatures (Bogren et al, 2000) or by spatial interpolation of meteorological conditions (MDSS,2006) but neither of these approaches addresses variations in snow accumulation within the scale of a maintenance route. Such variations are commonly treated as random events that are predictable only through the experience of highway patrollers.

2. Objectives

The purpose of this study is to investigate the variation of snow cover along a highway during winter storms within the scale of a plow route. Understanding the variance at this scale can assist highway maintainers by:

- Providing guidance in extrapolating surface condition information from an RWIS measuring site to other locations along a highway,
- Locating RWIS stations where road weather conditions are representative of a larger area, and
- Predicting differences in maintenance demand along or between maintenance routes.

3. Approach

Pomeroy and Gray (1995) provide an extensive review of the control of vegetation and terrain on snow drifting and accumulation using physically-based models. The review includes analyses at a variety of scales which can be applied to a highway situation and are illustrated at micro scale in Figure 1.

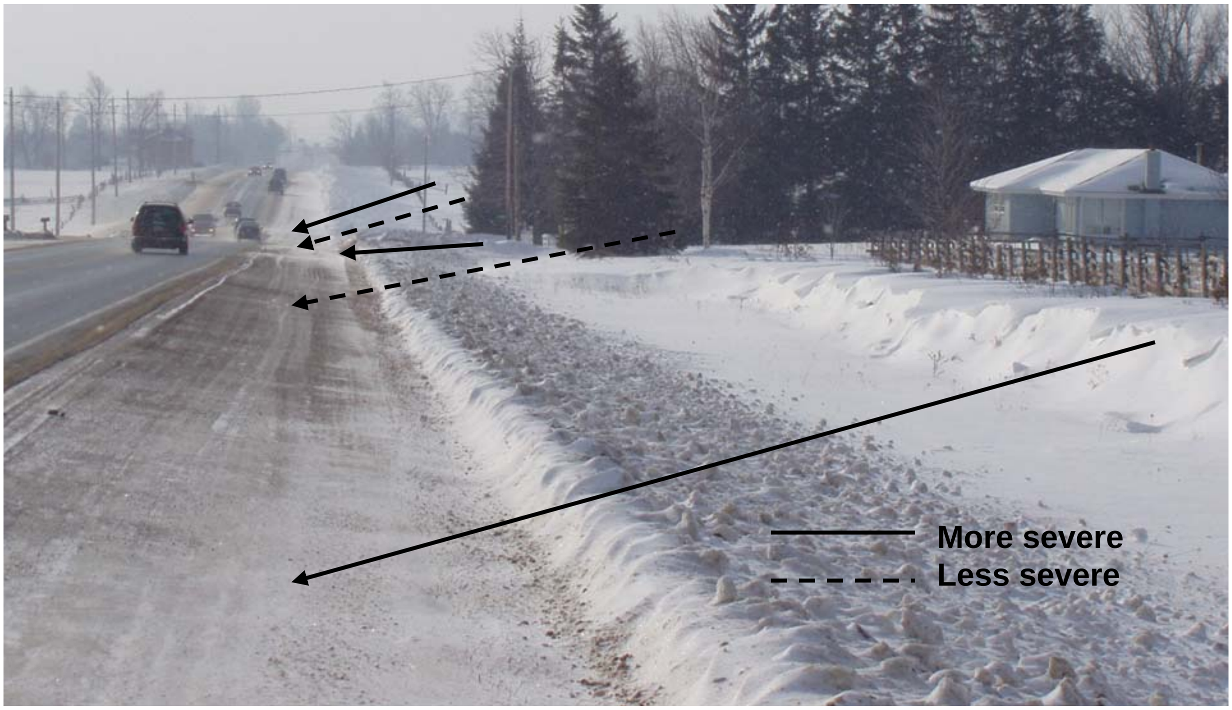

Figure 1. Micro-scale variations in snow drifting related to roadside terrain.

These concepts have been applied to predict snow depth in response to wind speed and snow compaction (Tabler, 2004), topography and vegetation cover (Perchanok, 1997; MTO, 1998).   Perchanok (2002) and Lee et al (2006), demonstrated the additional influence of highway maintenance interventions and initial attempts have been made to model and forecast the snow cover outcomes from all factors, albeit at a scale that does not include within-route variance (MDSS, 2006).

This paper explores the variance of snow cover with meteorological conditions and roadside terrain, and the relationship of roadside terrain to the underlying geomorphologic setting. It is particularly concerned with snow drifting along a plow route and focuses on the following two hypotheses:

1. snow cover during drifting conditions is controlled by roadside terrain and vegetation features and,
2. terrain zones are important factors controlling variance in snow cover along a plow route at the time scale of a winter storm.

In order to test these hypotheses, both snow cover, terrain features and other meteorological data along maintenance routes must be collected. Snow cover is however difficult to measure in a continuous and frequent manner along a highway, and direct measurements of variation in space and time during a snow storm are not available. Perchanok (2002) developed an approach to estimating the fractional cover of snow on the pavement using a continuous friction measuring device (CFM), and showed that the friction coefficient (μ) and snow cover fraction are strongly correlated by a relationship such as:

Snow cover fraction=(-.3645 x LnMup) + (.0054 x Vcrit) ,

where LnMup is the natural log of the maximum generated friction (Mup) and Vcrit is the wheel slip speed at which it occurs. Friction between a vehicle tire and pavement decreases as snow cover increases.

As a result, continuous measurements of friction coefficient are used in this study as a surrogate for fractional area of snow cover along the pavement.

3. Data Collection

Friction was measured using a Norsemeter RUNAR Mk1 or ROAR Mk2, variable slip friction trailer (Figure 2). Each traverse of a snow plow route provided measurements at intervals of approximately 30 metres along the road. The RUNAR measured in the left wheel track and the ROAR measured in the lane centre. The variable-slip measuring technique employed by the Norsemeter provides an estimate of the maximum obtainable friction coefficient in successive 29 metre sample footprints.

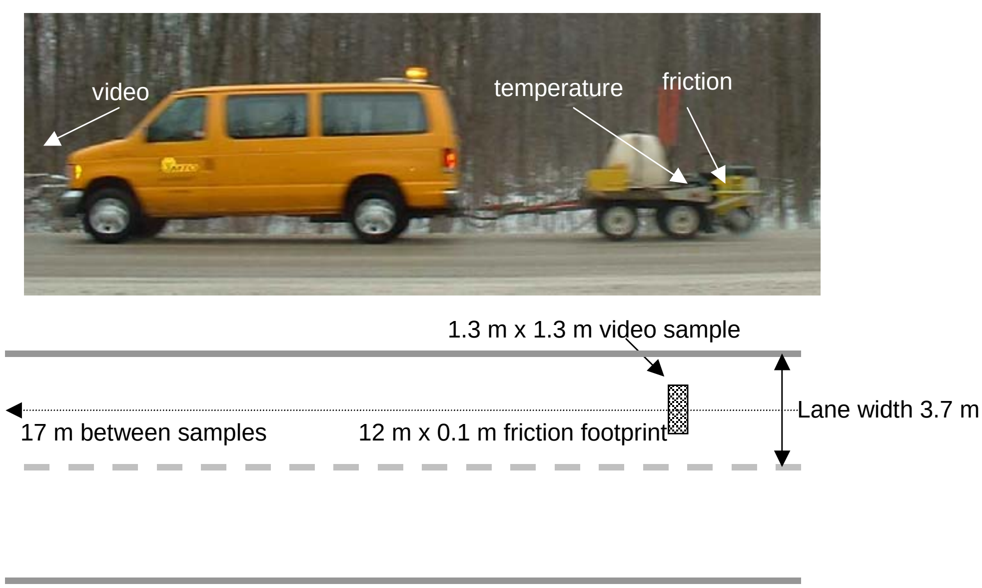

Figure 2. Mobile data acquisition system and sampling characteristics (ROAR Mk2).

Data sets were acquired from three field areas in southern Ontario, Canada:

1) 6 km of Highway 9 westbound and intersecting Highway 4 southbound near Walkerton (Figure 3),
2) 12 km of Highway 21 eastbound, 10 km of intersecting County Road 10 northbound and 10 km of adjoining Highway 6 northbound near Owen Sound (Figure 4), and
3) 14 km of Highway 26 near Barrie, Ontario (Figure 11).

Highways in all of the field areas are serviced according to Ontario Winter Class 2 standards, stipulating that snow is plowed before 1.2 cm of snow accumulate and then on a 1.2 hour cycle and that road salt or winter sand are applied on a 1.8 hour cycle when snow cannot be removed by plowing. Plowing and salting operations were carried out independently by different trucks at the time of this study.

Weather data, consisting of hourly wind speed and direction and daily snowfall, were obtained from the Environment Canada archive for Wiarton, an hourly recording station in the same climatic zone and located 50 to 100 km to the study sites.

4. Terrain Feature Analysis

4.1 Methodology

The first part of the study investigated the influence of roadside terrain and vegetation features on highway snow cover at a local scale during snow drifting events.

The investigation began with a qualitative comparison of terrain and friction features, followed by a quantitative analysis using the frequency domain methods of autocorrelation and power spectra. The autocorrelation function (ACF) is a measure of the correlation of progressively lagged sample points in a stationary series. Its coefficients range from 0 for a random series to 1 for a perfectly correlated series.

The power spectrum measures periodicity in the variance of a data set. It is applied in this study to test the spatial association of variations in snow cover along a highway route with the spatial distribution of roadside features that affect snow cover.

Data for this part of the study were obtained from two field areas. Field area 1 includes level topography with farm fields separated at regular intervals by concession roads and farm laneways. Highway ditches are inhabited by bushes and low vegetation. Intersecting roads or farm entrances are spaced at 200 m intervals along Highway 9 and 1000 m along Highway 4.

Friction was measured in a single traverse of Highway 9 and 4 during a period of strong easterly wind 6 hours after a heavy snowfall.   The wind direction was approximately parallel with Highway 9 and perpendicular to Highway 4 (Figure 3).

Figure 3. Field Area 1; Highway 9 Westbound and Highway 4 Southbound.

Field Area 2 includes irregular glacial moraine topography and drumlin topography (Figure 4). Drumlins are teardrop shaped hills that form sinuous topography with amplitude in the order of 10 m and period in the order of 500 meters. Road construction across drumlin fields requires cut and fill sections of similar dimensions to the terrain scale to avoid excessive longitudinal grades. The drumlin field is characterized by agricultural land use adjacent to valley bottom fills and forest cover on non-arable hilltops. The farm fields are unvegetated in wintertime.

Friction was measured in a single traverse during a period of strong easterly wind approximately 1 hour after a heavy snowfall. It includes an eastbound section of Highway 21 and a northbound section of Country Road 10 and Highway 6.

Figure 4. Field Area 2; Highway 21 Eastbound, County Road Northbound, Highway 6 Northbound

4.2 Terrain Feature Results

Area 1

The westbound and southbound sections of Area 1 exhibit different trends in friction despite a common highway maintenance service class, geomorphologic zone and level topography (Figure 5). The Highway 9 section has low mean friction, suggesting high snow cover while Highway 4 has periodic shifts between high and low friction or snow cover. The highway sections differ with respect to wind orientation; the WB Highway 9 section is parallel with ambient wind while the SB Highway 4 section is perpendicular to the wind.

Variance in the Hwy 9 WB section shows no structure while the Hwy 4 SB section shows a strongly periodic structure (Figure 5, 6), with a variance peak in the order of 50 cycles (Figure 7), equivalent to a mean interval of 1,250 m (Table 1).

The difference in variance structure with respect to orientation suggests that snow cover differences are related to wind exposure, while the similarity between the variance scale of friction (1,250 m) and the spacing of intersecting roads (1000 m) (Table 1) on Highway 4 suggests that snow cover during this period of drifting snow was controlled by the alternating spacing of wind-sheltered areas along vegetated roadside ditches and un-sheltered intersections.

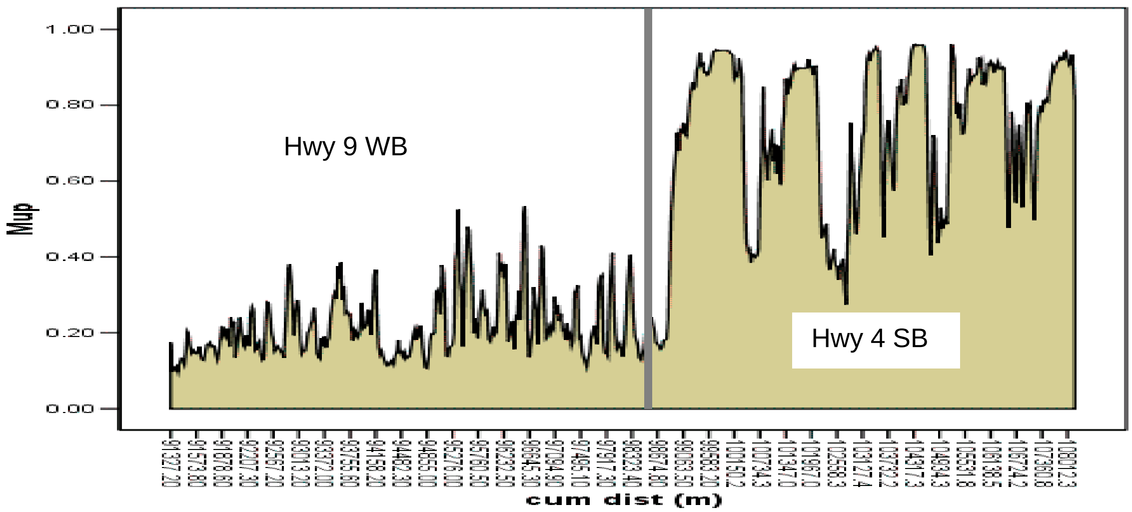

Figure 5. Friction trace for Field Area 1

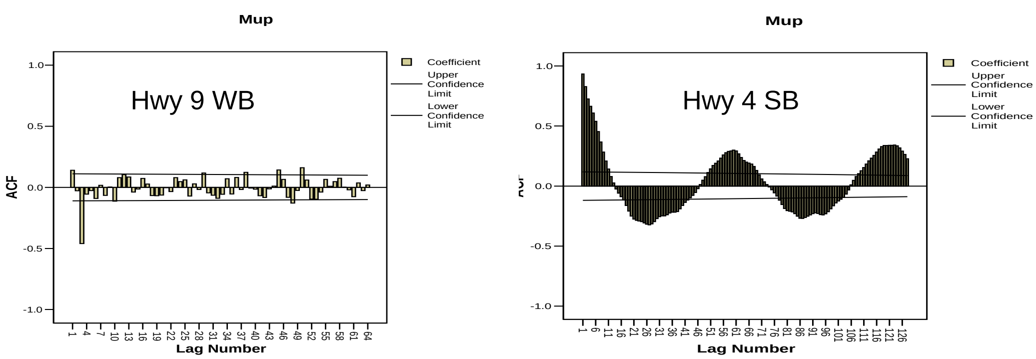

Figure 6. Autocorrelation function of friction, Area 1, March 10 1999.

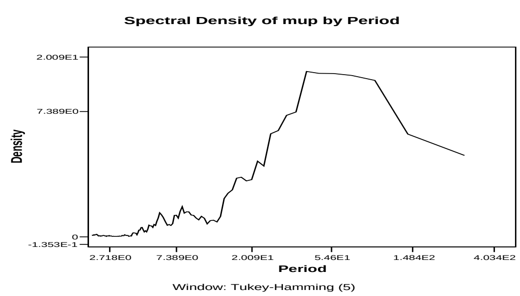

Table 1. Spacing of friction and terrain features

Area	Highway	Friction measurement				Terrain Feature
		n	Sample interval (m)	Spectral period	Interval (m)	Interval (m)
1	Hwy 9	324	26.9	N/A	---	200
	Hwy 4	280	34.2	50	1,250	1000
2	Hwy 21	176	63.5	25	447	500
	CR10	147	61.2	15	600	500
	Hwy 6	191	51.0	N/A	---	---

Area 2

A qualitative analysis in Area 2 compared the friction trace northbound of County Road 10 across the drumlin field with a transect of elevation offset 100 m to the east of the highway. This is the elevation of the surrounding terrain through which the highway is superimposed as opposed to the highway surface. Both data sets are averaged over 150 m intervals along track.

The friction and elevation traces exhibit parallel trends; high friction values are associated with hilltops where the longitudinal profile of the road is achieved by deep cuts through forested areas of high terrain, while low friction values are associated with valley bottoms where the road is on fill sections crossing adjacent farm fields.

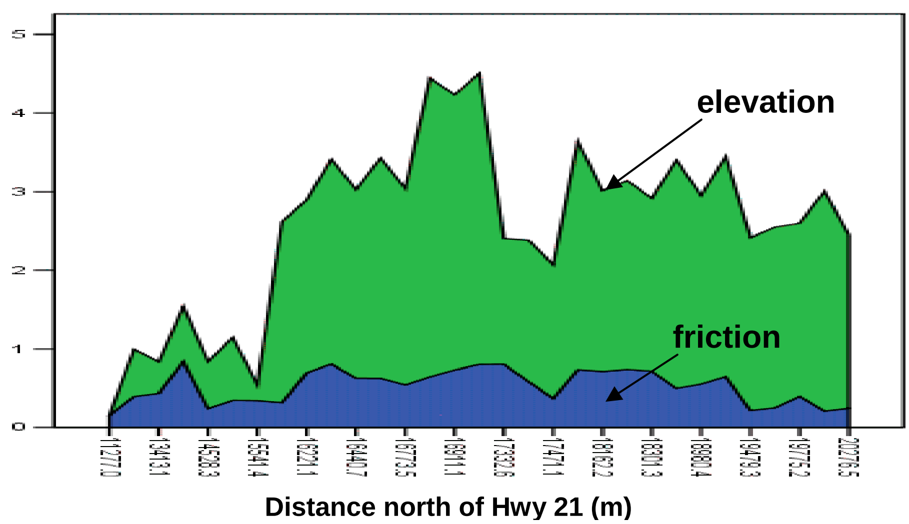

Figure 12. Friction coefficient (blue) and elevation (green) on 10 km traverse of County Road 10 northbound across drumlin field.

The qualitative analysis was tested by comparing the periodic structure of friction power spectra with the scale of terrain features through which the highway passes.

Friction exhibits both moderate variance and persistence on Highway 21 eastbound, high variance and periodicity on County Road 10 northbound, and lower mean and variance with no periodic structure on Highway 6 northbound (Figures 8 and 9). Autocorrelation functions (Figure 8) confirm the periodic structure of friction on Country Road 10 and the random structure on Highway 6.

The periodicities are centred on intervals of 447 and 600 m on Highway 21 and Country Road 10 (Figure 10, Table 1) respectively. This corresponds closely with the longitudinal dimension of drumlins in the surrounding topography in those areas, while the topography at Highway 6 has no drumlins and no periodic structure in its friction trace (Table 1, Figure 2). This supports the hypothesis that the sinuous drumlin topography and related vegetation cover are important local controls on highway snow cover in this area.

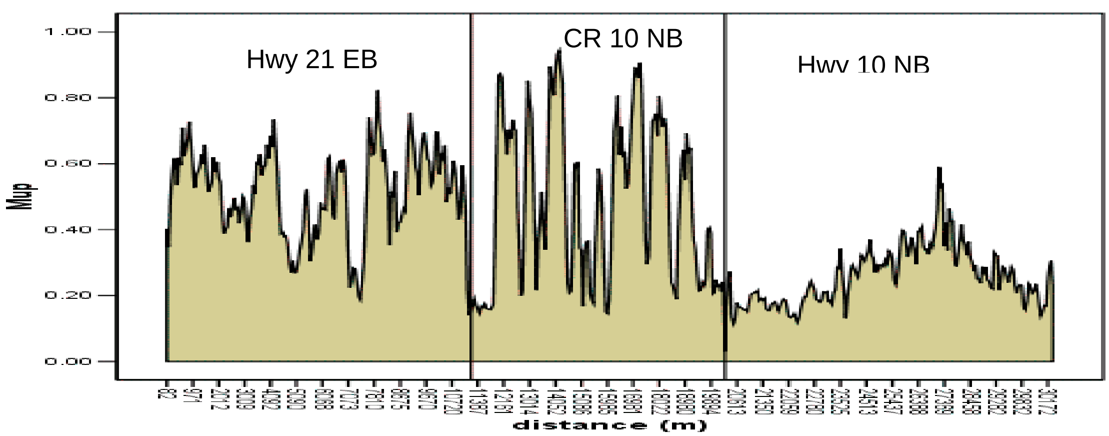

Figure 8. Friction trace for Field Area 2 eastbound and northbound.

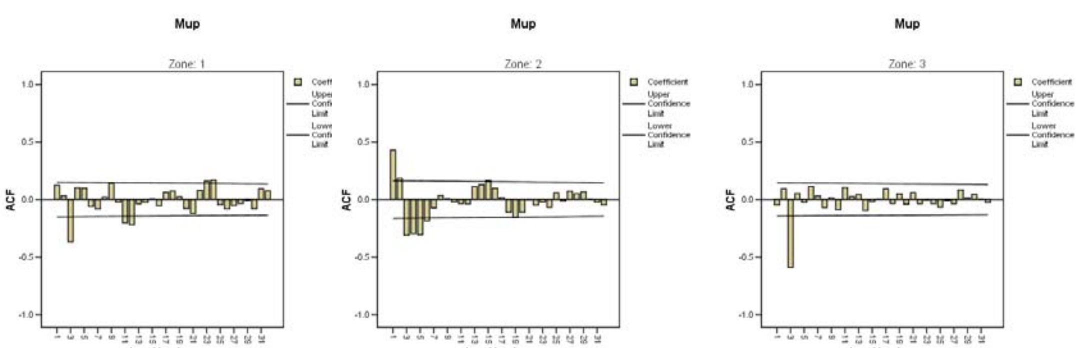

Figure 9. Autocorrelation function of peak friction, Area 2.

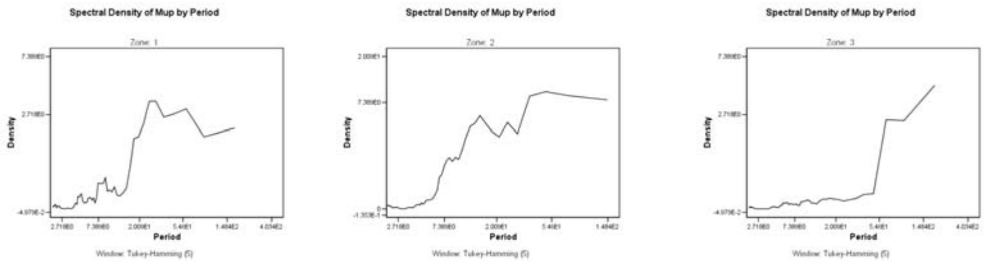

Figure 10. Spectral density function of peak friction, Area 2

5. Terrain Zone Analysis

5.1 Methodology

The second part of the study focussed on comparing the average friction in different terrain zones graphically at a sequence of time intervals through a snow storm in Area 3.

The hypothesis that terrain zones provide a suitable scale for predicting route-wise differences in snow cover was tested using a multiple regression analysis. Multiple linear regression (MLR) is a statistical method that estimates coefficients by which one or more independent predictor variables are related to a dependent, in the form

$Y=a + bX + cY+ \dots$

The coefficients (b,c,…) estimate the linear relationship between each predictor and the dependent, in the presence of other predictors. Standardized (Beta) coefficients estimate the relative influence of each predictor (X,Y, etc.) in relation to other predictors (SPSS, 1999). The Beta coefficient was used to compare the importance of wind speed as a predictor of highway friction between wind-sheltered and un-sheltered highway sections, as a test of the effect of wind shelter on highway snow cover.

The field area was classified subjectively into terrain zones on the basis of shelter and orientation to the prevailing westerly wind (Figure 11, Table 2):

Zone 1: forested, level former glacial lake bed
Zone 2: rolling, dissected glacial moraine
Zone 3: level, bare fields with highway trending northwest, and
Zone 4: level, bare fields with highway trending southwest.

Friction was measured during 9 successive traverses in each direction over a 12-hour period during a major winter storm. The period included heavy snowfall with light winds and light snowfall with strong winds from the northwest.

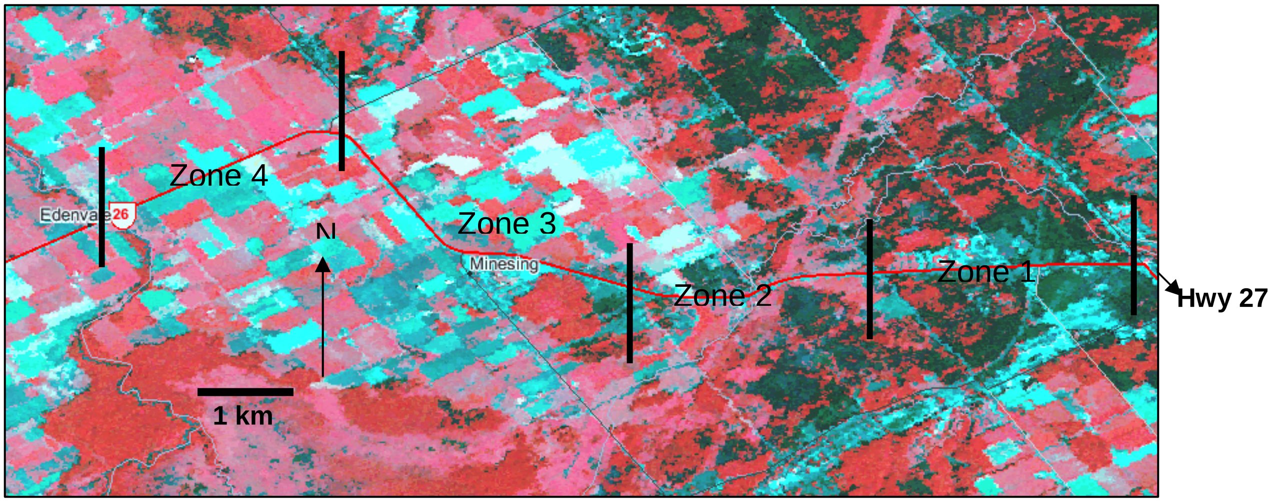

Figure 11. Terrain Zones in Field Area 3 (false-colour satellite image).

Table 2. Wind Shelter Zones, Area 3

Zone	Heading	Shelter	Location (m from Hwy 27)
1	EW	Sheltered	0-3000
2	EW	Partial shelter	3001-6000
3	NS	Exposed	9001-10,000
4	EW	exposed	10,000-14,000

4.2 Terrain Zone Results

The variance structure of friction through the winter storm is represented by traverses #1, 3 and 9 (Figure 12). Traverse 1, under conditions of heavy snowfall and light winds, exhibited low mean friction with periodic spikes across all zones, and stationary trend. Traverse 2, under conditions of moderate wind, exhibits non-stationarity, with highest mean and variance in Zone 1, and decreasing mean and variance to Zone 4. Traverse 9, under high wind conditions, exhibits high mean and low variance in zones 1 and 2, and low mean with moderate variance in zones 3 and 4.

speed and times of salt application (Figure 13). Plowing was independent from and more frequent than salting. The trends in friction through the storm varied by terrain shelter condition; friction increased consistently in Zones 1 and 2 through most of the storm. Zone 4 exhibited uniformly low friction except immediately following some salt applications, while the trend in Zone 3 was intermediate between zones 2 and 4.

Mean friction was plotted by traverse in each terrain zone along with hourly wind Mean values did not differ significantly by zone during the initial period of snowfall with low wind speed, while differences between zones are apparent during periods when wind speed exceeded 10 kph. Friction responded to each salt application in Zones 1 and 2, less in Zone 3 and still less in Zone 4. This suggests that friction along the entire route is a single population under low wind conditions but not under wind conditions conducive to drifting.

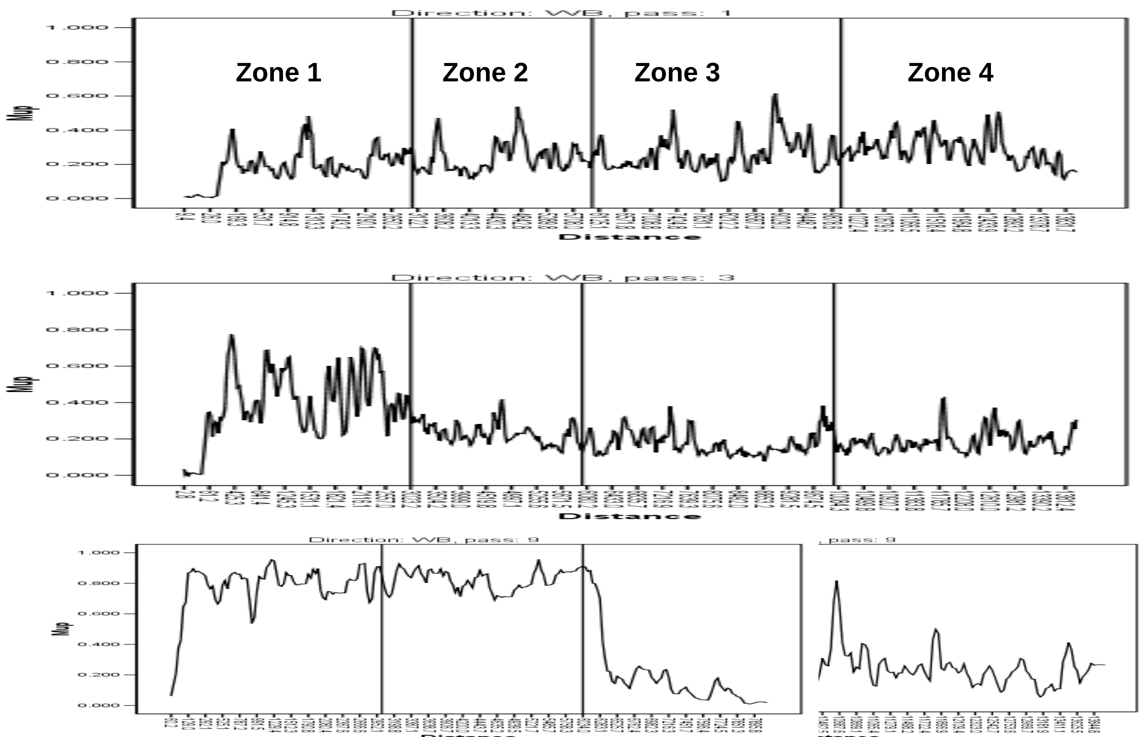

Figure 12. Friction traces for Traverses 1, 3 and 9 in Zones 1-4 of Field Area 3.

Plots of friction and wind speed through the storm period suggest that drifting snow associated with high winds had little influence in forested zones but quickly reversed the effects of winter operations in exposed areas, and that differences among zones become progressively greater during periods of high wind.

A regression analysis was applied to Zones 1 and 4 to test this hypothesis. Zones 2 and 3 were not included in the analysis because Figure 13 suggests there are transitional between 1 and 4.

The regression compared the influence of predictor variables between Zone 1 which is sheltered from wind and Zone 4 which is exposed to wind. Coefficients were predicted through the origin to standardize the analysis to a common, snow covered condition. The model provided a moderate explanation for friction in Zone 1 and a good explanation in Zone 4 (Table 3).

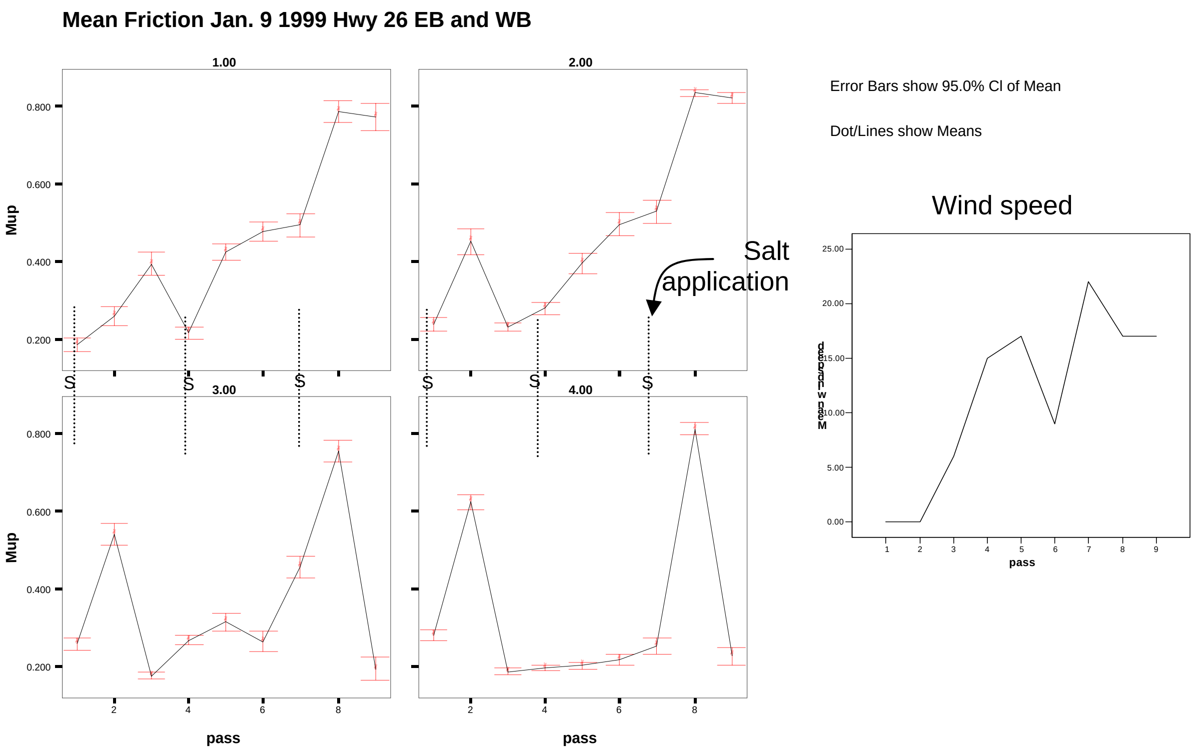

Figure 13. Mean friction, wind speed and times of salt application for 9 Traverses in Zones 1, 2, 3 and 4, Field Area 3, January 9 1999.

Coefficients in both zones (Table 4) indicate that friction increased with the passage of time since salting (ET Salt), and decreased with the passage of time since plowing (ET Plow), and with increasing wind speed (WS). This is consistent with the physical hypotheses that:

1. melting of snow by road salt is a progressive process that begins whe the salt is applied
2. snow cover decreases instantaneously with plowing and then increases progressively with ongoing snow fall
3. accumulation of snow due to drifting increases with wind speed.

Standardized (Beta) regression coefficients allow comparison of the relative influence of predictive variables between zones. Wind speed was the weakest of the three predictors of friction in Zone 1 (B=-.450) while it was the strongest (B=-.745) in Zone 4.   This suggests that highway snow cover is relatively unaffected by wind conditions in wind sheltered zones and is strongly affected by wind conditions in exposed zones, and therefore that snow cover varies with terrain shelter conditions during storms with drifting snow.

Table 3. Regression Model Summary

Zone	R	R Square(a)	Adjusted R Square	Std. Error of the Estimate
1	.739	.547	.546	1.04041
4	.914	.835	.835	.59037

Table 4. Regression Coefficients

Zone	Variable	Coefficients			t	Sig.	Correlations		
		Unstandard-ized		Stand-ardized			Zero-order	Part-ial	Part
		B	Std Error	Beta					
1	**ET plow**	**-.512**	**.019**	**-.975**	**27.3**	**.000**	**-.658**	**-.629**	**-.544**
	WS	**-.052**	**.003**	**-.450**	**15.5**	**.000**	**-.463**	**-.417**	**-.309**
	ET Salt	**.315**	**.021**	**.656**	**14.8**	**.000**	**-.463**	**.402**	**.296**
4	**WS**	**-.080**	**.002**	**-.745**	**44.6**	**.000**	**-.803**	**-.781**	**-.507**
	ET plow	**-.362**	**.010**	**-.721**	**35.4**	**.000**	**-.747**	**-.704**	**-.403**
	ET Salt	**.194**	**.011**	**.433**	**17.2**	**.000**	**-.694**	**.435**	**.196**

Dependent Variable: LnMup
Linear Regression Through the Origin with Stepwise Entry
ET plow: elapsed time since plow pass (hours)
ET salt: elapsed time since road salt application (hours)
WS: wind speed (km/h)

5. Terrain Classification Analysis

5.1 Methodology

The hypothesis that terrain shelter zones associated with different snow drifting susceptibility are related to underlying topography was tested using a Two-Step Cluster analysis. Cluster analysis is a method of breaking a data set into groups on the basis of one or more objective measures

Two-step cluster has the additional advantage of objectively selecting the number of clusters to represent differences in the data set. It is suited to classification of categorical data where groupings or numbers of groupings are not known a-priori (SPSS, 1999). It was applied to analyze the spatial association between the subjective terrain shelter zones (Table 2) and individual, local scale features that were hypothesized from the Terrain Features analysis to control wind shelter and thus snow drifting across the pavement (Table 4) .

A database of each feature class was compiled comprising observations at 200 metre intervals along each side of the highway (Chak, 2000). The database for the NW side of the highway was used in this analysis because that was the prevailing wind direction during the winter storm.

The clustering procedure assigned each 200-metre observation to an objectively defined group based on the similarity of assemblages of four feature classifications.

Table 4. Terrain Feature Classification, Area 3

	Terrain Feature Attributes			
Class	Grade	Crossing	Elevation	Vegetation
1	level/elevated	driveway	lowland	Open
2	road cut	road	neutral	Hedge
3		Railway	upland	Bush
4		culvert		forest
5		bridge		

5.2 Terrain Classification Results

The cluster analysis assigned each observation point along the route to a group that was objectively defined by a similar assemblage of classes on each terrain feature. Three clusters were defined (Table 5). Comparison of the group assignment of each 200 metre sample point with its subjectively defined wind shelter zone (Figure 14) shows a close correspondence between objective cluster groups and subjective shelter zones; Cluster 1 correlated very closely with the forested terrain zone, Cluster 3 correlated closely with the exposed terrain zone, and cluster 2 corresponded with the partially sheltered and exposed zones (Zone 2 & 3). Comparison of attribute importance in the cluster analysis suggests that forest cover is the primary attribute of Zone 1, while Zones 2 and 3 differ by grade and elevation; Zone 3 is primarily level and unforested while Zone 2 has variable grade and elevation associated with irregular terrain (Figure 15).

This analysis supports the hypothesis that individual terrain features controlling snow accumulation on highway surfaces during winter storms occur in clusters of spatially contiguous zones that are related to underlying terrain-forming factors or geomorphology.

Table 5. Cluster Distribution

Cluster	N	% of Combined
1	48	28.6%
2	51	30.4%
3	69	41.1%
Combined	168	100.0%

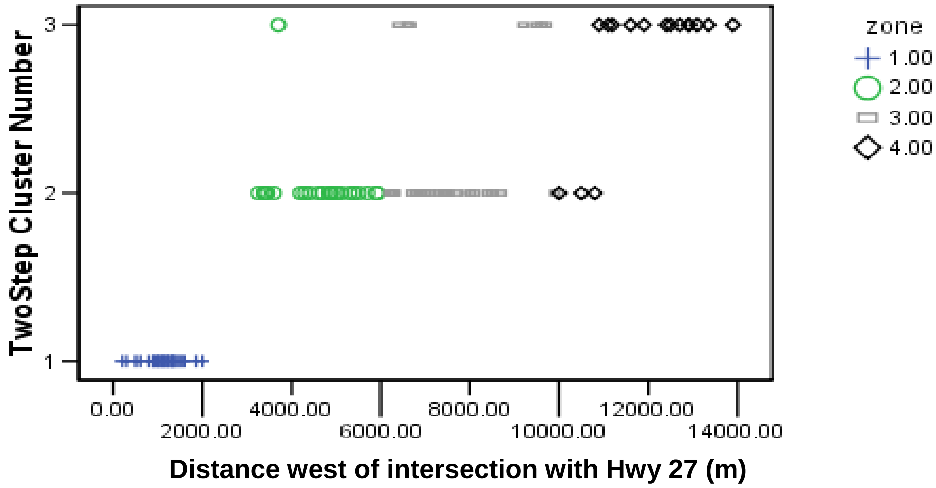

Figure14. Relation of Terrain Feature Clusters to Terrain Zones with increasing distance west of Highway 27.

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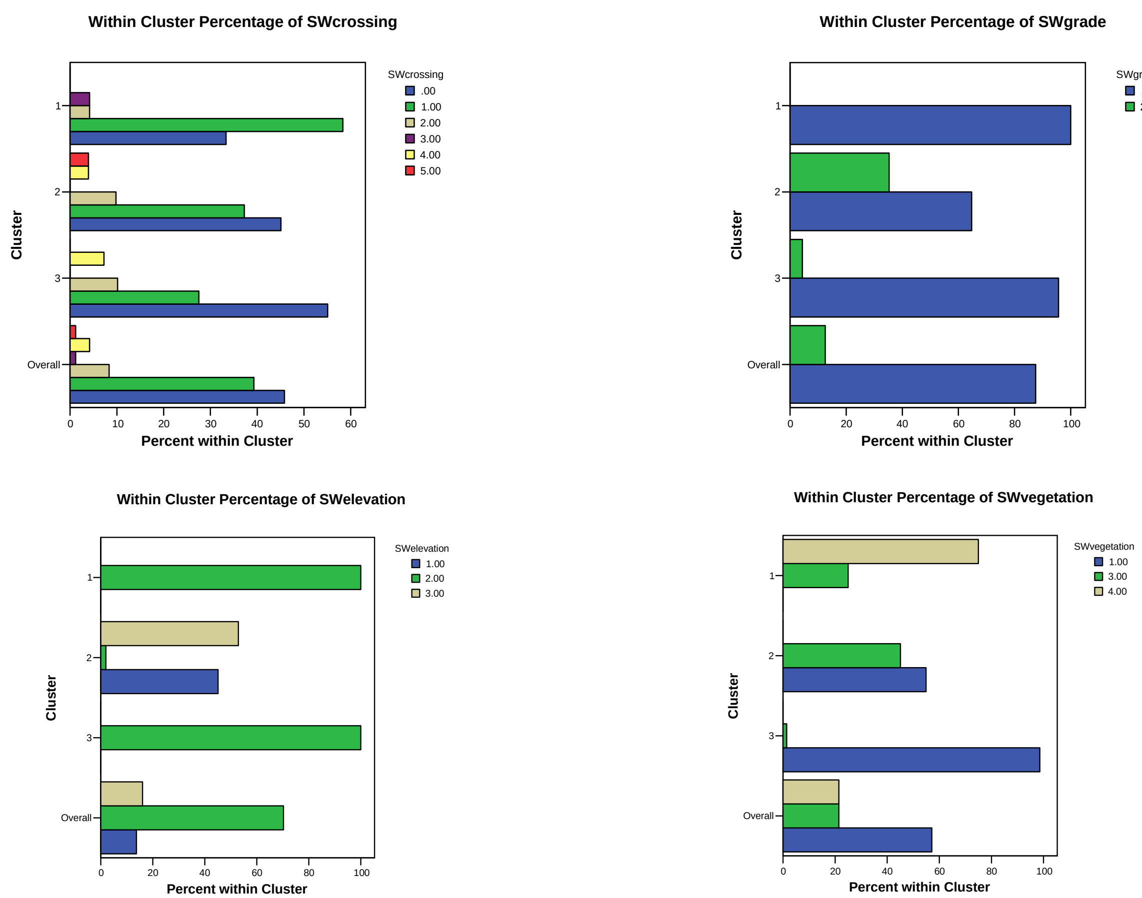

Figure 15. Distribution of Terrain Feature Attributes by Terrain Cluster

6. Conclusions and Discussion

This study has shown that friction, which is highly correlated with snow covered area of a highway surface, varies along a highway maintenance route, and that the structure of its variance is controlled by the interaction of roadside terrain with drifting snow. Susceptibility to snow drifting is related to roadside vegetation and topographic features and that in turn is related to the morphology of the surrounding terrain.

Snow cover is not uniform within the spatial scale neither of a weather system nor even at the scale of a plow route, but varies at the scale of roadside terrain zones and individual terrain features that control snow drifting within the zones.

The local control of drifting on snow cover implies that estimates of snow cover that are based on data from Road Weather Information Systems can be interpolated with confidence within similar terrain zones but cannot be interpolated to dissimilar terrain zones, even when those are located within a short distance of the observing station.

The application of friction measurements as a surrogate for snow cover provides new opportunities to analyse fine detail in the spatial pattern of snow accumulation. It allows a detailed understanding of factors controlling snow cover from the micro scale of individual terrain elements to the meso scale of terrain zones to the macro scale of highway routes.

This study shows that snow cover varies at a scale of 10^2 metres in response to individual terrain or vegetation elements and that these elements cluster in terrain zones at a scale of 10^3 metres in response to geomorphologic setting.

Variation between zones is determined by the interaction of terrain zones with storm conditions.

Friction measurement also provides access to frequency domain analysis methods that have not been applied previously to highway operations or to snow cover mapping. In this study the spectral signature of friction along a plow route was used to identify the influence of terrain elements on snow cover and to discriminate terrain zones by their influence on snow cover during calm and windy conditions. This line of analysis may conceivably be expanded to predict trajectories of snow cover under characteristic progressions of storm conditions to predict local differences in demand for winter maintenance operations or for road salt. Frequency domain analysis of friction measurements has been previously applied to analysis of pavement texture under summer conditions (Rado, 1994).

The trends in mean friction in zones with different wind exposure showed that snow cover measured at a single measuring footprint of 30 m length is representative of snow cover over a maintenance route of 30 km length during periods of low wind speed, but is not representative during periods of higher wind speed that are associated with drifting snow.

The spatial association of variance in friction with roadside terrain features indicates that bias can be introduced in characterizing snow cover in one terrain class from an RWIS station located in a different terrain class.

7. References

Bogren, J., T. Gustavsson, M. Karlsson and U. Postgard, 2000. The impact of screening on road surface temperature. Meteorol. Appl. 7, 1-8 (2000).

Chak, D., 2007. Collecting Landscape Data Using Global Positioning System. Internal Report to Research and Development Branch, Ontario Ministry of Transportation, Toronto, May 2000.

Chapman, L.J. and D.F. Putnam, 1973. The Physiography of Southern Ontario, 2nd Ed., U. of Toronto Press

Fu., L, R. Sooklal and M. Perchanok, 2006. Effectiveness of Alternative Chemicals for Snow Removal on Highways. Transportation Research Record No. 1948, Transportation Research Board, U.S. National Academies, Washington, 2006.

MDSS National Laboratory Consortium, 2006. The Maintenance Decision Support System Project (MDSS), Prototype Release 4.0, System Description Version 1.1. Federal Highway Administration, Road Weather Management Program, February 13, 2006.

MTO, 1998. "Design and Maintenance Procedures to Minimize Impacts from Drifting Snow on Highways - Provisional Guidelines", Report MAT-98-01, Research and Development Branch, Ontario Ministry of Transportation, Downsview, October 1998.

Perchanok, M., 1997. "SNOWDRIFT Environmental Modelling System: An Independent Implementation of SHRP Study Results", International Roads Federation World Congress, Toronto, June 1997.

Perchanok, M., 2002. Patchiness of Snow Cover and Its Relation to Quality Assurance in Winter Operations, World Road Association-PIARC Winter Road Congress, Sapporo, Japan, January 2002.

Pomeroy, J.W. and D..M. Gray, 1995. Snowcover; Accumulation, Relocation and Management. National Hydrology Research Instititute Science Report No. 7, Environment Canada, Saskatoon.

Rado, Z., 1994. A study of road surface texture and its relationship to friction. PhD Dissertation, The Pennsylvania State Universtiy.

SPSS, 1999. Statistical Package for the Social Sciences, Base 9.0 Applications Guide, SPSS Inc., Chicago, 1999.

Tabler, R.D.2004. Effect of Blowing Snow and Snow Fences on Pavement Temperature and Ice Formation. *In:* Transportation Research Circular Number E-C063. Sixth International Symposium on Snow Removal and Ice Control Technology (June 7-9, 2004, Spokane, Washington). Transportation Research Board of the National Academies. Pp. 401-413.