Numerical avalanche prediction in Bear Pass, British Columbia, Canada

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Abstract: A numerical avalanche prediction scheme offering prediction rates greater than 70% is under development for the Bear Pass highway operation, British Columbia. A method using one way analysis of variance and canonical discriminant analysis is proposed to identify the principle variables that allow discrimination between avalanche and non-avalanche days. The optimum variable set identified using this analysis may then be used in a discriminant analysis to classify each time period into an avalanche or a non-avalanche day. An analysis is performed using this method for Bear Pass as a whole and also for individual sub-areas defined within the pass. Improvements on classification rates to three out of the four sub-areas are observed compared to the analysis for the whole pass.

Keywords: Avalanche Prediction Numerical Modeling

1. Introduction

The use of computer models in avalanche forecasting is complimentary to traditional forecasting techniques. Computer models provide a useful tool to verify a forecaster's opinion about the prevailing avalanche conditions. In addition, they allow the forecaster to 'test out' possible scenarios by assessing the impact of changes to one or more of the present weather variables.

A numerical prediction model is under development for use at the Bear Pass highway operation, British Columbia, Canada. In this paper, a method for selecting an optimum variable set is proposed, using one way analysis of variance and canonical discriminant analysis techniques.

This paper also investigates the possibility of splitting up the Bear Pass forecasting area into separate sub-areas. The rationale for this is that by separating the pass into areas that are more homogeneous, better discrimination might be possible for individual sub-areas than is possible for the whole pass combined. An operational advantage to this approach is that the forecaster has a more detailed description of where avalanches are being forecasted within the pass.

2. Characteristics of Bear Pass

Bear pass is located on highway 37A between Meziadin Junction and Stewart on the west coast of northern British Columbia, Canada. The area experiences a wet, maritime climate with temperatures moderated by the proximity of the Pacific Ocean. This climate leads to high annual snowfall rates.

The avalanche season runs from approximately mid November to the end of April, however there are paths in the pass that produce avalanches triggered by glacial icefall and these can occur at any time of the year. One of these paths is considered a hazard to the highway. The hazard due to icefall release on this track cannot be forecasted using meteorological and snowpack information and therefore this path is not used in the model.

2.1 Individual areas within the pass

Four distinct areas within the pass were identified on the basis of having avalanche paths of similar aspect, size and start zone elevation.

The Little Bears Area is the area closest to Stewart and contains five east facing avalanche paths on a portion of the highway that runs north south. The Summit Sluffs Area is a small section of short, low elevation avalanche paths approximately in the middle of the pass. This area faces south and is characterized by frequent lower magnitude avalanche occurrences. The South Aspect Area contains the remainder of the avalanche paths on the north side of the highway that face south. These paths are much bigger than those in the Summit Sluffs Area with higher elevation start zones. The North Aspect Area contains the really big avalanche paths on the south side of the highway. Most of these avalanche paths have runout zones that are

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quite a distance from the highway, meaning that only large avalanches running down these paths will impact on the highway.

3. Description of the database

3.1 Weather and snowpack data

The data used in this study consists of manually recorded weather and snowpack measurements from November 1985 to April 2002. The manual weather station in the pass was relocated in 1994, so the database is a combination of records from two different locations. However, the old and the new stations were run concurrently for a period of two years to ensure that the recorded values for the new station were consistent with those of the old.

Variables used in the study are listed in Table 1. It was attempted to introduce memory effects into the model using lagged temperature variables. In this study, these lagged variables are simply the maximum, minimum and present temperature values for two time periods prior to the time period of the observation. Memory is also included with the storm board depth, since snow on this board is allowed to accumulate for the duration of a storm cycle.

Table 1. Variables used in the analysis.

Variable code	Description of variable
MAX_TEMP	Maximum temperature (°C)
MAXT_L2	Maximum temperature - 24 hour lag (°C)
MIN_TEMP	Minimum temperature (°C)
MINT_L2	Minimum temperature - 24 hour lag (°C)
PRES_TEMP	Present temperature (°C)
PREST_L2	Present temperature - 24 hour lag (°C)
LOG_PRECIP_R	Precipitation Rate (cm hr^{-1}) *
NEW_PRECIP	New Precipitation (mm)
PRECIP_TYPE	Precipitation Type *
REL_HUM	Relative humidity (%)
SNOWPACK	Snowpack depth (cm)
LOG_NEW	New snow board depth (cm)
LOG_INTVL	Interval snow board depth (cm)
LOG_STORM	Storm snow board depth (cm)
FOOT_PEN	Foot penetration (cm)
WIND_SPEED	Wind Speed *

*Indicates variables initially in categorical form converted to numerical form.

The database was thoroughly screened for bad and incomplete records. These records were discarded and not used in the analysis.

For most days, there is a morning and an afternoon weather observation (i.e. two records per day). More recently however, only morning weather observations have been collected. For this study, time periods of 12 hours were used. However, if weather observations in the pass continue to be taken only in the morning then switching to time periods of 24 hours may be more appropriate.

3.2 Avalanche occurrence data

Each avalanche occurrence was assigned to one of the 12-hour weather observation time periods according to the date and time of the occurrence. Following McClung and Tweedy (1994), occurrences falling between 1200h midnight and 1200h midday were grouped with the morning weather observations; the remainder were grouped with afternoon records.

Avalanche occurrences were filtered by size for each individual avalanche path. For each path, a minimum size of avalanche that was considered hazardous for the highway was set using the forecasters' expert knowledge of the tracks along the pass. Filtering by size in this way does not necessarily improve the numerical forecasting prediction rates. However, it does give a scheme compatible with the forecaster's prediction objectives.

Avalanche occurrences were also filtered according to the avalanche trigger. After much consideration, the scheme that was used was to include all occurrences from the Summit Sluffs area and only naturally triggered avalanches for all other paths. The justification is that control work on the Summit Sluffs paths is generally done either after paths have already produced avalanches or when avalanches on the paths is considered imminent. In either case, the control work is done using case charges that may be detonated in most weather conditions. Control work in the remainder of the pass is done from an artillery position and using helicopter control missions. These operations are often carried out during weather periods that would not normally produce avalanches. This is especially true for helicopter control missions where fine weather is required for helicopter flights. If such avalanches were included in the record, they might skew the model toward predicting avalanches for fine weather days.

4. Method for variable selection

One way analysis of variance (ANOVA) may be used to test whether the population means differ between two or more groups. The f-ratio is the ratio between the mean square (a measure of between group variance) and the mean square error (a measure of within group variance). The f-ratio will approximate unity for variables that do not discriminate between groups.

Canonical discriminant analysis (CDA) seeks to find a linear combination of the predictor variables, $Z = A_1X_1 + A_2X_2 + ...A_nX_n$, that exhibits the largest difference between group means relative to the within-group variance. The standardized canonical coefficients give information on the relative importance of each variable in the discriminating function.

The proposed method first uses ANOVA to select variables that show a significant ability to discriminate between groups. CDA is then performed on the selected variables to gain more information on the relative importance of each variable and on possible interactions between variables. Prior to performing CDA a test of homogeneity of the variance-covariance matrix must be performed (e.g. Hotelling-Lawley trace). Special attention must also be paid to avoid collinearity through the inclusion of redundant variables. This may be assessed through an analysis of the covariance matrix.

4.1 Classification functions

Once the optimum variable set has been identified, discriminant functions can be built allowing each 12-hour period to be classified as either an avalanche period or a non-avalanche period.

The prediction ability of the model may be assessed by analyzing the classification rates. Realistic classification rates are only achieved if the functions are tested using an independent data set not used in the construction of the functions.

5. Comparison of classification rates

The method described above was applied to the whole pass and to the individual areas within the pass (described in section 2.1). Classification rates for each area are given in table 2.

Table 2: Classification matrix (for independent testing data sets) by area.

Area	Sample Size	Classification Rates (%)		
		Avalanche	Non-avalanche	Overall
Little Bears	130	78	77	78
Summit Sluffs	171	78	80	79
South Aspect	273	77	71	74
North Aspect	224	64	76	70
Whole Pass (all areas)	465	73	72	72

The model for Bear Pass as a whole gives a classification rate of 72%. Three out of the four individual areas perform better than this. The Summit Sluffs Area is the best with an overall classification rate of 79%. This is expected, since the Summit Sluffs Area represents the most homogeneous area within the pass. The lower overall classification rate of 70% for the North Aspect Area is also understandable, given the nature of the high magnitude avalanches in this area running on paths with complicated terrain.

6. Conclusions

A robust statistical method is presented for determining the combination of variables that gives the optimum ability to discriminate between avalanche periods and non-avalanche periods. When this method is applied to Bear Pass as a whole, the optimum variable set allows a discriminant model to be built which yields a 72% overall success rate.

There is some justification in dividing the pass into smaller areas, as prediction rates for all areas except the North Aspect area improved when this division was made. This does come however at the expense of reducing the sample size and so it may be that the resulting model is less robust than when all areas are included.

The next stage in the project will be to compare the prediction rates from the discriminant analysis with those from a nearest neighbours analysis.

7. Acknowledgement

Doug Wilson of the Ministry of Transportation is thanked for imparting his extensive knowledge of the Bear Pass highway operation and for identifying the individual areas within the pass.

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