Road Closure to Mitigate Avalanche Danger:

A Case Study for Little Cottonwood Canyon

Gail Blattenberger and Richard Fowles — University of Utah [*]

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Abstract

Avalanche forecasters make decisions to close the Little Cottonwood Canyon Highway to vehicular traffic in the case of avalanche danger. A statistical model improves forecasting performance. Conditions do not vary simply by day as implied in the statistical model, but the development of the snow pack varies substantially among seasons. There are persistent features of a snowpack which affect avalanche danger within

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each season. Forecasters' performance also varies substantially over seasons. This paper attempts to incorporate this feature into an operational method to develop seasonal weights to combine data and expert opinion.

1 Introduction

The Little Cottonwood Canyon road in Northern Utah is a dead-end, two-lane road leading to the Alta and Snowbird ski resorts and is the only road access to these resorts. It is heavily traveled with the daily traffic is greater than 10,000 automobiles on peak days. It is also highly exposed to avalanche danger. One method employed to mitigate the avalanche danger to traffic is to close the highway to vehicular traffic.

Actual decisions to close the road are made by highway avalanche forecasters in the Utah Department of Transportation (UDOT). Previously a model was developed for predicting the occurrence of avalanches crossing the road (**?**). Based on that model, decision rules were developed for deciding when to close the road. In that work the model decisions were combined with information implicit in the actual decisions made by the avalanche forecasters, and the decision rules of the forecasters and the model were given equal weight. However, there was substantial variation in forecasting performance over seasons. In this paper we vary the weights attached to the decision rules to determine if this improves forecasting performance. The weighting method developed is operational. It is inadequate to say retroactively that a particular season was bad and different policies should have been used. The weights here are determined by information available at the time of the decision. They are seasonal in nature.

The focus is on the decision to close the road and not with an assessment of avalanche probability. The decision to close the road is an operationally measurable variable; the probability of an avalanche crossing the road is not. The effect of failure to close the road in the event of an avalanche is not equivalent to the effect of closing the road when no avalanche occurs. This asymmetry is accounted for in the specification of the loss function.

The next section contains a cursory description of the avalanche phenomenon and the process of avalanche forecasting. Section 3 relates to the availability and the nature of the data. Section 4 describes the model specification. Section 5 examines the road closure decision and the development of the loss function employed. Section 6 examines the weighting methods employed and an operational season specific weighting system is developed. Section 7 contains the conclusion.

We wish to make a disclaimer up front that avalanche professionals play a crucial role in the forecasting process. The history of the snow pack and its complex variation are something with which the avalanche professional keeps in intimate contact and the multiple, interlocking facets of this knowledge justify the need for avalanche professionals. The objective of this analysis is to supplement not replace the professional avalanche forecaster.

2 Avalanche Forecasting

It is assumed that many readers are unfamiliar with the avalanche phenomenon. This section is included for the benefit of such readers. Others might skip to the following section. The section focuses on an introduction to avalanches and their forecasting. Data issues relating to this are held off until the next section. To begin with as noted above Little Cottonwood Canyon Highway is in Northern Utah. This is a transitional climate zone. Avalanches have climatic characteristics, and in the continental United States they are roughly characterized as maritime, transitional, and continental. This will be referred to below. The mountains run north-south and the highway goes in an east-west direction. The highpoint of the highway is at the eastern end of the road in the town of Alta. Ski resorts are on the south side of the highway and their slopes are primarily north-facing. Avalanche paths affecting the highway are on the north side of the road and are, for the most part, south-facing slopes. Highway paths are monitored by forecasters at the guard station in Alta. All highway paths are monitored, but the snow study plot and most of the data collection is at the guard station.

Avalanches are complicated phenomena, and snow science and snow mechanics have developed into highly technical fields. Nonetheless many traditional, real-world forecasters have relied almost entirely on a feel for the situation. None rely completely on analytic models. The real world conditions in which avalanche forecasts are made can differ substantially from the laboratory conditions explained in snow mechanics and snow structure science.

Information generally available to forecasters is highly imprecise. This is partly because the information is geographically very local. There are substantial snow differences, for example, between avalanche starting zones and the guard station study plot where snow structure is monitored. In addition, the measurements themselves are imprecise. Two forecasters digging snow pits to appraise snow stability at the same location may come up with differing charts. The data employed by forecasters is fortunately redundant, fortunate because this can compensate for imprecision. The redundancy is well illustrated by a story (?). In the early 1970's four professional forecasters at Red Mountain Pass in Colorado all had similar performances in the accuracy of their forecasts. When questioned subsequently the forecasters listed a combined total of 31 variables they found important in their projections; individually each contributed less than 10 to this total. Each focused on a collection of variables that were comparably accurate. Of the 31 variables, only one was common to all four.

Avalanche forecasting is not a quick decision. Hypotheses are tested and revised based on test results and on changing conditions. Characteristics of the snowpack develop over a season. Professional forecasters tend not to take breaks in the middle of a season so they will not lose contact with developments in the snowpack. The multitude of interrelated factors renders a simple forecasting model impossible. The redundancy of the information confirms our emphasis on the implications of the statistical model for decision rather than for estimation or parameter fit. Technical aspects of the avalanche phenomenon are explained in detail in other texts (see, for example, ?), or ?) or ?)). Here we simply point to some facets of the problem.

Avalanches may occur in various forms. Some are minor sluffs [1]. Although these may be deadly to an individual in the wrong location, they are not an important factor in highway closure in this particular situation. Some avalanches are deep slab avalanches transporting tons of snow down the mountain into a runout zone. It is primarily these that threaten this highway. A deep slab avalanche usually, but not always, has three components. On the top there is a cohesive slab of heavy snow. On the bottom there is a bed surface along which the snow slides. The bed surface could be an ice layer resulting from a melt freeze, or even the ground. In the middle there is a weak layer between the slab and the bed surface. In addition, there is usually something that triggers the slide. Ski cuts or temperature changes can precipitate an avalanche. Explosives are used to trigger slides for control purposes, but they are not always effective. None of these features is always present and sometimes these components are difficult to identify in a particular slide.

Avalanche activity is most intensive during storms. Particular storm attributes contribute to the avalanche phenomenon. The depth of the new snow is an obvious feature. This, however, needs to be conjoined with other attributes. The type of snow crystal affects how it will cohere to the old snow

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[1] A minor sluff is small in volume of snow and loose, not cohesive

surface. The density of the snow, in terms of its water content, also affects the hazard. High density snow can cause a slab to form, especially if the density is increasing. A heavy snowfall can trigger an avalanche, particularly following a light snow. Snowfall intensity in inches per hour is another contributory factor: increasing intensity can cause instability. New snow settlement can also contribute to instability, however, the direction of this affect can be ambiguous (**?**). High snow settlement may indicate good bonding with old snow layers but it may also indicate the creation of a heavier slab. Major storms increase highway danger substantially.

Avalanches are not always storm events. The snowpack itself also is very important. A snowpack of sufficient depth covers terrain irregularities that would block or divert a path. In Little Cottonwood Canyon, a 60 cm. base is thought to be a minimum depth for avalanches to occur (**?**). The snow type affects the strength of the snowpack. Snow crystals form in hundreds of identifiable types (**?**) with different strengths, density, and cohesiveness with other snow layers. One finds layers of snow in pits identifiable with particular storms long after the storm occurs. Besides snowfall, surface hoar [2] forms an identifiable weak layer.

Transformations occur over time within the snowpack affecting its strength; it does not remain constant over the season. The most obvious of these is melting: a melt freeze causes a potential bed surface. Transformation in the

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[2] Surface hoar is frost forming on the snow surface. Surface hoar forms when surface air is highly saturated relative to the snow surface. It is common on cool clear nights.

snow crystals also occurs as a function of the temperature gradient from the snow surface to the ground. Increasing air temperature is generally unstable. A warm period can trigger slides.

The climate zone affects the transformations occurring in the snowpack. Maritime climates generally have mild temperatures and high snowfall. Weak layers in the snowpack do not persist over time. Continental climate zones have low snowfall and cold temperatures. This combination results in a high temperature gradient between the ground and the snow surface. The resulting transition in the snow crystals is called depth hoar, a weak layer that can persist for a period of time. It is a notorious culprit in slab avalanches. Little Cottonwood Canyon, located in a transitional climate zone, does experience depth hoar. This paper attempts to examine persistent seasonal effects on the snowpack. In particular, long term temperature patterns and the depth of the snowpack over a long period are singled out.

All of the above conditions must be considered locally. Here by locally, we mean variations even within a slide path, not climatic zones. Temperature and snowfall vary by location and, importantly, snow is transported by wind. Terrain, wind speed, and wind direction determine the location of wind-transported snow. Slabs are often created by wind loading. In addition, the aspect of a slope affects the snow transformations taking place. Major differences exist in perspective between the snow rangers at the ski resorts in Little Cottonwood who principally deal with north-facing slopes, and the highway avalanche forecasters who principally monitor the south-facing slopes affecting the highway.

A final factor to be considered is control activity. Control activity is roughly categorized as active or passive in nature. Passive control includes building control structures which, in Little Cottonwood Canyon, amounts to the bypass road between Alta and Snowbird on the south side of the canyon. Regulation of the structure and location of new building sites is passive control. Road closure is also termed passive control. Active control is direct action to trigger avalanches, including ski cuts and explosives. This active control tests the snow stability and in unstable conditions releases avalanches under controlled situations.

3 The Data

Two key variables describe closure of the road, CLOSE, and the event of an avalanche crossing the road, AVAL. Both are indicator variables and are operationally measurable constructs, a key requirement to our approach. Unfortunately, the constructs are less precise than expected. The observation unit is generally one day unless multiple events occur in a day; these appear in the data as multiple observations. The occurrence of an avalanche or, for that matter, a road closure is a time-specific event. It may happen, for example, that the road is closed at night for control work with no avalanche. It is then opened in the morning and there is an avalanche closing the road. Then it is reopened and there is another avalanche. This then represents three observations in the data with corresponding data values ROAD = (1,0,0) and AVAL = (0,1,1). An uneventful day is one observation. If the road is closed at 11:30 at night and opened at 7:00 the following morning it is coded as closed only within the second of the two days. Daily avalanche and weather records are available from the 1944-45 season until the 1989-90 season from United States Department of Agriculture (USDA) data tapes. After 1989-90, information is available from the UDOT Alta Guard Station. The data used in this study begin with the 1975-76 ski season. This was done because the loss function, discussed below, regarding the road closure decision is affected by the traffic which has substantially increased since that time. Road closure data is also less available in earlier years. Road closure information was available from Alta Central, the Alta town hall. Many aspects of the avalanche phenomenon are not captured in the data; the modeling effort is restricted by the available data.

Weather and snowpack information, obtained from the USDA tapes, were compared to guard station time profiles for consistency. These variables all pertain to measurements taken at the Alta Guard Station. One variable obtained from this data is TOTSTK or total stake. This is the maximum depth of the snowpack on a particular day. This was converted to a measure TSTK60, the total stake greater than 60 cm. to reflect the work of Perla (1970). The variable INTSTK, interval stake, defines the amount of snowfall in inches on a particular day. In addition INTSTK1, INTSTK2, and INTSTK3 specify the value of INTSTK lagged one, two, and three days respectively. This gives information on the snowfall history. DENSITY is defined as the ratio of the water content of the new snow to INTSTK. [3] RELDEN is the ratio of the density of the snowfall on the most recent previous day of snow to the density of the snowfall on the second-most recent previous snow day. This is an attempt to reconstruct the layers in a snowpack. The days compared may represent differing lags depending on the weather. A value greater than 1 suggests layers of increasing density. SETTLE specifies the fraction of new snow settlement in a 24 hour period. When no settlement occurs the value is 1. When wind increases the total stake by more than the new snowfall the value of SETTLE is truncated to 1 because this variable is intended to measure the phenomenon of settlement, not wind. CHTEMP measures the change in the minimum temperature over a 24 hour period. SWARM (**?**) defines the sum of the degrees above freezing of the maximum temperature over a four-day period. This gives an indication of the occurrence of a warm spell. Finally, NAVALLAG (**?**) gives the number of reported avalanches in paths affecting the road on the previous day. [4] The presence or absence of recent avalanche activity is an indicator of snowpack stability.

Figure 1 is a sample daily time profile as used by the DOT for the major

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[3] The concept of density generally relates to volume. Since the new snow can be thought of as relatively homogeneous and water surely can, density can be measured as a ratio of inches of water content to inches of new snow. A normal value of this variable is 0.1 or 10%.

[4] **?**) have employed an interaction term taking the sum of the avalanches weighted by size. The size measure which they use is the Canadian measure. The size measure available here is the American measure which is less appropriate. However, a similar adjustment might be relevant here.

meteorological variables for January 1993. [5] The top line measures TOTSTK, vertical bars represent INTSTK and water content or INTSTK multiplied by DENSITY (multiplied by 10 for scaling). The water content bar is consistently smaller than the INTSTK bar reflecting the occurrence of "Utah powder." The triangles represent the number of avalanches on paths crossing the road. The lower graph shows the maximum and minimum temperatures. Descriptive statistics for the data are given in Table 1. [6]

Notably missing from this dataset are measures of snowpack stratigraphy. Monthly snowpit data was available for the period in question. Snowpits are undoubtedly useful to the forecaster to learn about the snowpack, but snowpits at the Alta study plot are not reflective of conditions in the starting zones, and monthly information is not sufficiently current. **?**) found snowpits of minimal use in forecasting avalanche occurrence. She devised a method of coding pits which identified slabs, weak layers, and bed surfaces. These are not identified in the conventional methods of coding snowpit data. Consequently, we did not code or use the snowpit data.

Also missing are a variable indicating the temperature of the snow below the surface and variables for the wind speed and direction. The temperature variable is available only at the Snowbird study plot which is on the wrong side

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[5] This graph was produced by the Snowlink program of Judd Communications.

[6] Avalanche data has been partitioned into three categories (**?**) and (**?**). These categories are stability factors, snowpack factors, and meteorological factors. All three of these categories are found in our data although, as is common, the best data is of a meteorological nature. By meteorological data we are referring to observations concerning the present moment. These variables include INTSTK, DENSITY, CHTEMP, SWARM and SETTLE. Snowpack variables are limited to TSTK60 and stability variables are limited to NAVALLAG.

on the canyon. Wind speed and direction are also not consistently available. We are working on developing these series by combining several data sets.

The data are surely not optimal. A relevant question is if they are informative for real-world decision making. The imprecision and redundancy of the data channel our focus to the decision process itself.

4 The Model Specification

Model specification is a binary outcome model. The variable to be explained is the indicator variable AVAL. The model generates probabilities of avalanche occurrence. These probabilities are based on functions of explanatory variables from an estimation set. Results from logit and simple linear formulations are presented in this paper. The logit form generates probabilities constrained to fall between zero and one, the linear form can generate values outside this interval. [7]

A random sample of half of the observations formed the estimation dataset. [8] We used random sampling from the entire dataset to obtain observations from all of the seasons. As noted above, developments in the snowpack within a season isolate certain impacts to be season-specific. Isolating the sample and forecast periods by season could induce season-specific biases. Our objective was to measure overall impacts. 218z Faced with specification ambiguity and

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[7] Generalized qualitative response models based on the exponential generalized beta density of the second type (EGB2) were also considered (?). The logit is a special case of the EBG2 density. Results are available from the authors.

[8] Some observations were subsequently deleted making the division slightly different from exactly one half, 1614 and 1619.

data redundancy, we considered several sets of models, each differing in terms of direct and interactive effects of the set of explanatory variables. In our final specification, we included only the main effects, not interactions. This equation basically said that it avalanches when it snows, a result commonly reported (National Research Council 1990, or Fohn, Good, Bois, & Obled 1977 or Bovis 1977) but not very informative. [9] We then supplemented our variables with one quasi-interaction term, INTSTK * DENSITY. This is termed a quasi-interaction term because of the way that DENSITY was defined. Based on this definition INTSTK * DENSITY is the water equivalent of new snow measured in inches of water, a commonly used variable. The final specification includes DENSITY, INTSTK, and DENSITY * INTSTK.

Model specification was simple. First the specification was selected on the basis of data consistency across the estimation and forecast periods. This led us to omit any interaction terms from the specification. This does not imply that there are no interaction effects, but that they are not simple and not revealed in a consistent manner in the historical data. Interaction terms seemed to lead to overfitting of the data. Second we wished the specification to be pragmatic and simple, conforming to accepted principles of the avalanche phenomenon presented in Section 2. Details regarding the exact specification are available on request.

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[9] Even based on this equation, this work remains distinct from others because of its decision focus.

5 The Loss Function and the Road Closure Decision

Since it is not known when an avalanche will occur, the decision to close the road is made under uncertainty. This section discusses the consequences associated with road closure decision making and develops criteria for evaluating statistical models used to assist decision makers. It begins with the decision maker's loss function and focuses on two types of errors: 1) a Type I error occurs when the road is closed and an avalanche does not happen, and 2) a Type II error occurs when an avalanche happens and the road is open.

The decision to close the road has significant economic implications. When the road is closed, the resorts suffer substantial monetary losses. An average traffic day was 5,710 cars in the 91/92 season and high traffic days exceeded 10,000. [10] There was an average of 2.6 persons per car of whom 2.5 were skiers. Residents accounted for 40% of the skiers and non-resident skiers 60%. Resident skiers spent, on average, \$19/day and non-resident skiers spent \$152/day. [11] This implies a road closure cost of \$ 1,410,370 a day. There are reasons to contest this figure but it is a ballpark number. For example, all or almost all of the skiers staying in accommodations up the canyon are non-resident. Thus, more than 40% of the car traffic is resident. Non-resident skiers with accommodations in the valley do not spend the entire \$152 in the canyon. Road

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[10] Utah Department of Transportation (1992)

[11] Feldsted & Hochman (1991).

closure may occur in bad weather or on light traffic days. These factors would tend to diminish the estimate. On the other hand road closure frequently occurs after the storms on high traffic days. At the same time non-monetary costs have not been included which would raise the estimate.

Costs associated with the failure to close the road in the event of an avalanche are potentially enormous. Death, disability, and property destruction are possible consequences of a Type II error and although the valuation of life and loss due to incapacitation is more subjective than the loss of resort revenue, these costs are certainly real. In fact, escalation of litigation due to erroneous decisions has become a primary concern for avalanche forecasters, motivating better record keeping including statistical data on snow and weather conditions.

Table 2 shows the decision makers' closure decisions for 3233 observations in the entire data set. In the sample, there were 295 total errors. Approximately 18 percent of those errors were of the Type II variety – failure to close the road and an avalanche occurred. The remaining errors were Type I – closure of the road when an avalanche did not occur.

The table illustrates the asymmetry of the data events and the asymmetry of the errors made. We believe these asymmetries reflect both the physics of the avalanche phenomenon and the asymmetry of the losses that decision makers sense. We dodge the issue of the dollar value of a human life and attempt to design a loss function that is effectively consistent with the historical record of UDOT forecasters performance.

We assume the decision makers wish to minimize the expected losses associated with their actions. The average daily loss of the UDOT forecasters is assumed to be of the form of the asymmetric loss function:

$$Loss = k * p + q \tag{1}$$

In this equation p represents the fraction of the time that an avalanche crosses the road and it is open; q represents the fraction of the time that an avalanche does not cross the road and it is closed. The term k is a scale factor representing the relative cost of a Type II versus a Type I error. Both p and q are empirically observable, while k is not. The decision rule to minimize expected loss implies an implicit cutoff probability, k* = $\frac{1}{1+k}$ such that the road should be closed for probabilities greater than k* and kept open for lower probabilities. In previous work, we found a value of k=8 to be consistent with the historical performance of the highway forecasters (**?**).

To evaluate model performance we examine a measure of the cost associated with decision errors, called the realized cost of misclassification or RCM. We determine the RCM for each model as a function of the cutoff probability selected. Logit and linear model RCM results are illustrated in Figure 2. The implicit cutoff probability associated with k=8 of .111 is near the minimum for the linear model. The functions are not necessarily at their minima at this value of because the graphs are of the observed not the expected results. The functions are jagged because as the cutoff probability is raised the road is opened more. More Type II errors are observed and less Type I errors are observed. These changes, however, vary with the fitted values of the model. Information in Figure 2 reflects only the forecast data set. Experts' performance in the forecast set is graphed in Figure 2 as the horizontal line at .202.

Figure 2 shows that the linear model exhibits reasonable RCM performance for cutoff probabilities within the range of .07 to .15 and typically outperforms the logit model. For both models, the hypothetical rule is too conservative for low cutoffs, closing the road too frequently, and at high cutoffs, the models suffer the consequences of excessive Type II errors. Both statistical models, at their minima, actually outperform the professional forecasters in terms of misclassification costs. It should be noted, however, that the forecasters' are making operational decisions whereas the models are historical, although out-of-sample.

6 Weighting

Statistical decision models can provide substantial gains to lower misclassification costs. This section examines the potential for additional benefits when statistical information is combined with expert opinion in an operational context. Unfortunately, available information reflecting forecasters' judgments about the likelihood of an avalanche crossing the road is reflected only in a dichotomous variable: either they closed the road or not. Assuming the forecasters are calibrated, probabilities of avalanche activity can be imputed based on data from the sample period. Based on these data, the forecaster's daily probability of an avalanche crossing the road when the road is closed is $P_{expert}(AVAL|CLOSE) = \frac{44}{170} = 0.2588$ and the probability of an avalanche crossing the road when it is open is $P_{expert}(AVAL|OPEN) = \frac{25}{1444} = 0.0173$. These values can be used with generated probabilities from the model to form the combined daily probabilities of avalanche activity.

A question is how to best weight these values and is discussed in a rich literature (see, for example **?**), **?**), and **?**)). For our purposes, weighting had to be operational. It would not be appropriate to retrospectively examine when the model did well relative to the experts and weight accordingly. The method we selected was based on simple weighted averaging of model and expert, a heuristic that is not unreasonable, especially when there exists a correlation between the input sources ((**?**) and (**?**)) or when the exact statistical model is not known (**?**).

Avalanche forecasters face weather conditions that vary substantially from season to season. These seasonal changes may lead to significant expert RCM variability between seasons. This is apparent when looking at Figures 3 and 4. Figure 3 plots the observed RCM performance of the experts by season. Their worst seasons were 83/84 and 92/93. Figure 4 plots the difference between the experts' RCM performance and the linear model's performance at our implicit cutoff probability of .11. Higher values correspond to better model performance compared with that of the experts. In season 87/88, for example, the experts and the model achieved about the same RCM performance while in season 84/85 the experts outperformed the model. In many seasons, the linear model outperformed the experts with the largest gain in 92/93, the season the experts did their worst. These results are viewed from a post hoc perspective and do not provide a basis for developing operational seasonal weights.

We account for seasonal inconsistency in RCM performance by linking it to seasonal snowfall and temperature variability. Time varying weights are formulated in an operational manner by examining how daily total snow depth, minimum temperature, and snow depth multiplied by minimum temperature deviate from historical averages for corresponding days. Weights were computed using thirty day moving averages of the difference between daily data and long run corresponding daily averages. [12] Quantiles of the moving average differences formed the basis of the daily weights, scaled to fall between .3 and .7, with weights set to .5 for the first 30 days of each season. [13] When the snowpack, temperature, or product is above average, more weight is given to the statistical model. At below average values, the experts are given more weight. [14] Figures 5 and 6 show the variation in the seasonal moving averages for snow depth

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[12] Recall that the experts have significant daily weather data, extending back to 1945.

[13] Following Blattberg & Hoch (1990) we chose only moderate weighting values, keeping close to the 50% model and 50% expert rule.

[14] We also computed symmetric difference weights. The directed difference weights produced marginally better results. These are available from the authors.

and temperature across the seasons. These are referenced against the moving average for the entire data period (heavy line).

Realized costs of misclassification based on weighted model and experts are shown in Figures 7A, 7B, and 7C (for stake, temperature, and interaction (stake times temperature) weighted models). The scales are the same to aid comparison. All RCM's are computed at a cutoff probability of .11. Stake weighted (Figure 7A) and temperature weighted (Figure 7B) models achieve virtually identical results, with worst performance in season 81/82. In comparing these two models, there is a slight edge in favor of the stake weighted model. The best performing model is the interactive weighted model (Figure 7C) which does not do badly in the 81/82 season. These results demonstrate that by combining statistical information with expert judgement, RCM performance gains are realized across the seasons at the implicit cutoff probability. Similar gains are also realized over a broad range cutoff probabilities over the entire forecast set. This is demonstrated for the weighted interactive model in Figure 8. RCM performance for the combined model is plotted along with that of the linear model alone. As in Figure 2, the highway forecasters' performance is graphed at the horizontal line, RCM=.202.

7 Conclusion

This paper illustrates the advantages of using statistical analysis to improve road closure decision making. The role of expert judgement is highlighted, and model performance is enhanced when expert opinion is merged with statistical information. Model and expert performance vary substantially by season. The paper develops an operational way to weight expert opinion that overcomes the inconsistent seasonal performance of the forecasters.

The paper focuses attention on real world decision making and not theoretical values of avalanche probability. Consistent with decision theory, an explicit loss function is employed to study the costs of erroneous decisions. The actual function is arbitrary but reasonable and in accord with decision theory.

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Table 1: Descriptive Statistics

Name	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
TOTSTK	0	43	68	67.5	93	150
INTSTK	0	0	0	3.08	4	42
DENSITY	0	0	0	0.0440	0.0833	0.9
RELDEN	0.093	0.725	0.979	1.09	1.25	5.75
SETTLE	0	0.6	1	0.805	1	1
CHTEMP	-36	-4	0	0.0251	5	33
SWARM	0	1	12	20.0	31	127

Table 2: Summary of Avalanche Occurrence and Road Closure Decisions for Entire Sample

	Avalanche Activity	
Decision	Avalanche Occurs	No Avalanche Occurs
Close Road	81	243 (error)
Do Not Close Road	52 (error)	2857