The Road Closure Decision in Little Cottonwood Canyon

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Abstract

Statistical models of different types have been used in avalanche forecasting. This paper provides a comparison of several types of models in application to the issue of road closure in Little Cottonwood Canyon. These model performances are contrasted with those of professional forecasters in the canyon who make road closure decisions. A variety of methods are presented which address the issues of statistical modeling and evaluation. A statistical model improves forecasting performance.

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 models were developed for predicting the occurrence of avalanches crossing the road (Blattenberger & Fowles 1994, Blattenberger & Fowles 1995). Based on those models, decision rules were

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developed for deciding when to close the road. It was found that model prediction augmented by the expert information implicit in the forecaster's actual decisions outperformed the historical performance of the highway forecasters. In this paper we briefly describe the data employed in the analysis and the development of the decision criteria employed. We then discuss different types of models which are currently employed in this type of forecasting and contrast their performances.

2 The Data

Our orientation towards the road closure decision rather than simply avalanche activity or avalanche days led to some modification in the data. The variable AVAL is the event of an avalanche crossing the road. Similarly, the loss function described below assesses whether the road is closed when an avalanche crosses it. The variable CLOSE is the event of a road closure. Both of these variables are indicator variables and are operationally measurable constructs, a key requirement of our approach. Unfortunately, the constructs are less precise than expected. The observation unit is generally one day unless multiple events occur in one 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 values CLOSE=(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 in the morning it is only coded as closed within the second of the two days.

Daily avalanche and weather records are available from the 1944-1945 season until the 1989-1990 season from USDA data dates. After 1989-1990 information is available from the UDOT Alta Guard Station. Data used in this study begin with the 1975-1976 ski season. This was done because of the loss function, discussed below. Road closure information was available from Alta Central, the Alta town hall. Unfortunately we do not have information on where the road was closed which would be quite relevant to the loss function. Information regarding avalanche activity was also taken from the USDA tapes and the Guard station records. The variables considered in this analysis include those commonly considered which were available in this case. A specific listing, cursory definitions, and summary statistics are given in Table 1.

3 The Loss Function and The Road Closure Decision

The decision to close the road is made under uncertainty, unless of course an avalanche has already crossed the road. This section discusses the consequences associated with the road closure decision and develops a a decision rule consistent with the historical behavior of the highway forecasters. There are two types of errors a forecaster can make: 1) a Type I error occurs when the road is closed an 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. We previously estimated this at $1,410,370 a day (Blattenberger & Fowles 1994). There are reasons that this figure may be considered large, but it gives an order of magnitude. We dodged the issue of the dollar value of a human life which would be necessary to place a dollar value on a Type II error and instead, designed a loss function which was consistent with the behavior of UDOT forecasters.

Table 2 presents the empirical behavior of UDOT forecasters for historical data. This table illustrates the asymmetry of the data and the asymmetry of the errors made. We believe that these asymmetries reflect the potential losses that decision makers sense.

We assume the highway decision makers wish to minimize the expected losses associated with their actions. The average daily loss 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 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 observable, k is not.

Figure 1 illustrates the road closure decision as a function of an arbitrary value of k. The expected loss function from closing the road and from leaving the road open are both shown. The line with the positive slope is the expected cost of a decision to leave the road open. The decision rule to minimize the expected cost implies an implicit cutoff probability of $k* = \frac{1}{1+k}$, such that the road should be closed for probabilities greater than $k*$ and kept open for lower probabilities. Previously we found a value of $k = 8$ to be consistent with historical performance (Blattenberger & Fowles 1994).

Using this value, we examine the cost associated with decision errors called the realized cost of misclassification (RCM). The loss function employed for this calculation is the one discussed above, with k=8. RCM is computed for three types of statistical models as a function of the cutoff probability and actual events of avalanches crossing the road. Models are fitted on historical data from the 1975-1976 season to the 1991-1992 season and evaluated on two holdout data sets, the 1992-1993 and 1993-1994 seasons. The next section introduces these models.

4 Statistical Models & Evaluation

Traditionally, the goal of modeling data is to arrive at a mathematical representation of the relationship between an observed response variable and a set of observed explanatory variables. Uses of obtained models might include inferences as to whether or not certain explanatory variables contribute to the response or to discover the nature of such a relationship. Models are often used to estimate the effect on the response variable from changes in one of the explanatory variables. In this paper, the primary goal of development is to arrive at a set of predicting models and to operationally monitor their performance. Part of customary performance evaluation relates to how well data fit the assumptions. Model-data fit is important when optimal models are sought but in fact may be irrelevant to real-world applications of models. This section begins with a quick look at common models and their associated assumptions. We next discuss ways to compare models when forecasts generated by the models exhibit asymmetric errors. The section concludes with a comparison of linear, logit, and nearest neighbors performance for the 1992-1993 and 1993-1994 seasons.

A widely used statistical characterization is that a response variable can be expressed as the sum of two components, a systematic component and a residual or error component. The systematic component is the summary of how the explanatory variables influence the response. Residuals account for any remaining unexplained component. In this section we briefly discuss special statistical assumptions in this framework that arise when the response variable is binary, i.e., the response is observed or not. Usually, it is characterized has having a binomial distribution related to a success probability, p.

One of the simplest and most easily computable models is linear regression. Ordinary least squares (OLS) finds a predictor, $\hat{p}$, based on a linear combination of the explanatory variables that minimizes a function of the discrepancy between the response value and the predicted value. Minimal assumptions are required to use this model although frequently the error term is assumed to be normally distributed. This assumption is only required when inferences about the estimated parameters are to be made. One drawback in using OLS for binary data is that a convenient assumption regarding the constant variance of the error is not valid. A more serious problem is that there is no assurance that the fitted probabilities fall between zero and one. It is important to note that for our purposes in terms of road closure, this is not an obstacle. A fitted probability greater than one simply means, for example, that the data say there is a high probability of avalanche, emphatically so!

The logistic transformation ($log\frac{p}{1-p}$) overcomes this difficulty and also has the desirable property that the fitted probabilities maximize entropy. Entropy is used as a measure of information or uncertainty. High entropy indicates high uncertainty. When inferences are to be made from a distribution (such as close the road) a choice is made to select the distribution which maximizes entropy and yet remains consistent with the constraints implicit in the data. This then employs all the information contained in the data with minimal assumptions. No statistical assumptions are made about the distribution of the residuals.

K-Nearest neighbors (NN-K) is a simple non-parametric classification rule that dates from 1951 (Breiman et. al. 1984). It is related to discriminant analysis but unlike discriminant analysis makes no assumptions that data have a normal distribution. The procedure does requires that a multivariate metric be defined, usually Euclidean distance, and searches over the set of data for the K nearest neighbors to a given point. Probabilities for the response variable can be based on counts of occurrence relative to K. For example, we might find that when looking at a set of 30 nearest neighbors for a given day, avalanches occurred 15 times in that set. Our fitted probability of avalanche for that day would be one half. Limitations of nearest neighbors are that results are sensitive to the choice of the distance function and to how many neighbors should be examined. A more serious objection is that it is an ad-hoc procedure that provides very little information about the nature of the relationship between the response and the set of explanatory variables. An advantage of K-NN is that it provides an easy and intuitive way to generate probabilities with minimal assumptions.

Logit, least squares, and nearest neighbors 30 and 20 RCM results for the first holdout season (1992/1993) are illustrated in Figure 2. The implicit cutoff probability of .111 is indicated by the vertical line. RCM is near the minima at this value for all four models. Figure 2 demonstrates that for this season all models exhibit similar performance. Experts' performance for the evaluation season is plotted as the horizontal line at .202. At their minima, all four models outperformed the experts. It should be noted, however, that the forecasters are making operational decisions whereas the models are historical, although results are based on out-of-sample data.

Figure 3 compares the same models for the 1993/1994 holdout season. Here, OLS is clearly the best model while nearest neighbors do not achieve the RCM performance that the experts did. Seasonal variation in model and expert performance is a common thread that we have found in our research and highlights the necessity for expert judgement and intervention. Ways to merge expert opinion with seasonal varying weights attached to models is introduces in Blattenberger & Fowles (1995) and is a rich field for further research.

References

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Table 1: Descriptive Statistics of Variables Considered

Variable	Min	Median	Mean	Max
Total stake in inches	0	68	67.46	150
Total stake over 60 cm. (in cm.)	0	112.7	114.7	321.0
Interval stake in inches	0	0	3.08	42
Weighted average of interval stake - 4 days	0	4.5	7.51	62
Density of new snow	0	0	.044	.90
Ratio of density of two previous snow days	.09	.99	1.07	5.75
Sum of degrees above freezing for 4 days	0	12	19.99	127.00
Settlement of new snow	0	1.	.80	1.
Water content of new snow	0	0	.28	3.80
Change in minimum temperature	-36	0	.026	31
Minimum temperature	-35	18	16.96	46
Maximum Temperature	-12	33	32.78	65
Wind Speed	0	9	10.21	55
Road Closure	0	0	.10	1.
Number of avalanches lagged	0	0	.52	31
Size of avalanches lagged	0	0	1.31	72

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

	Avalanche Activity	
Decision	Avalanche Occurs	No Avalanche Occurs
Close Road	84	253
Do not Close Road	54	3004

Figure 1

The Road Closure Decision

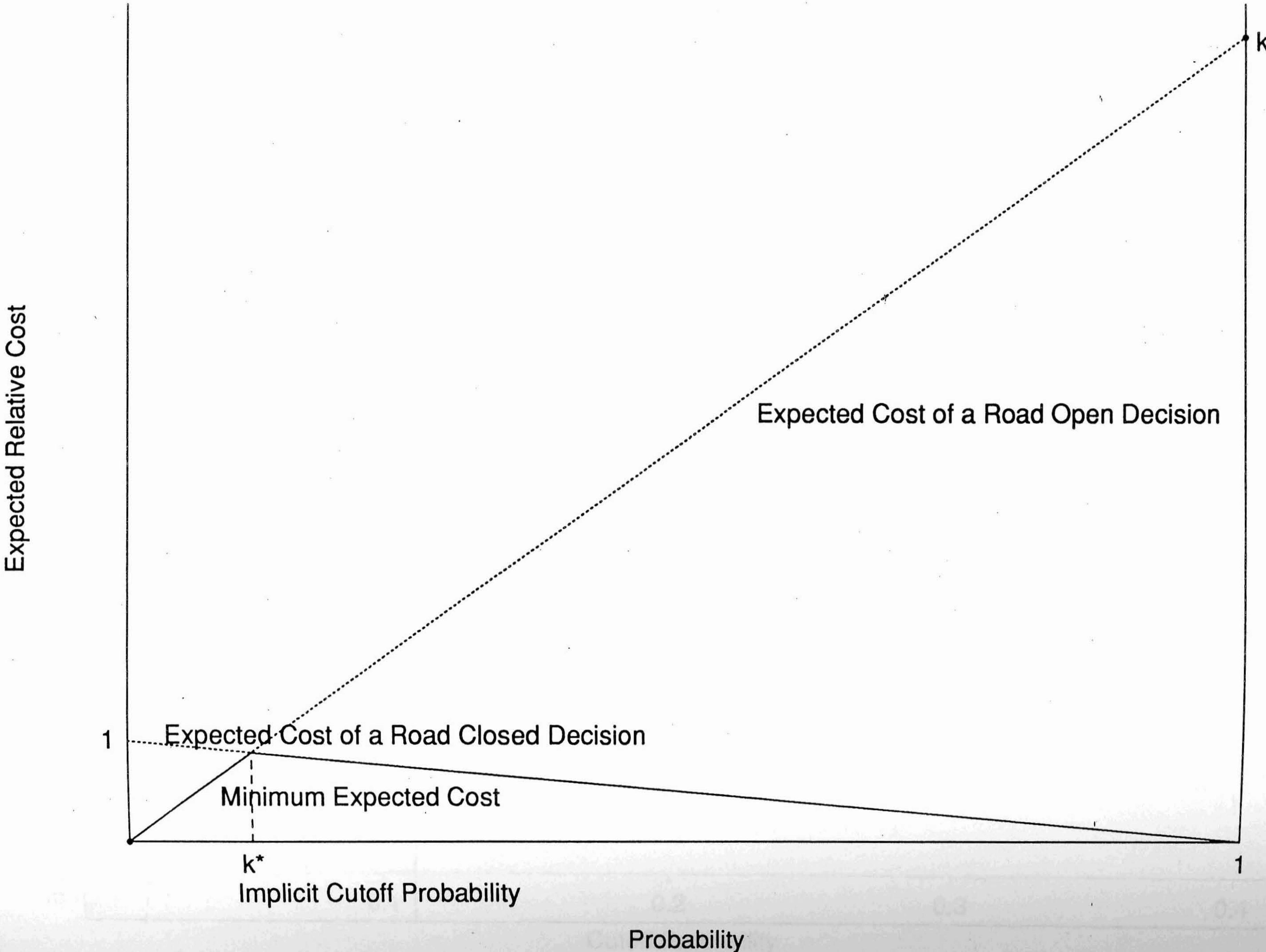

Fig 2

Model Performance for the 92/93 Season

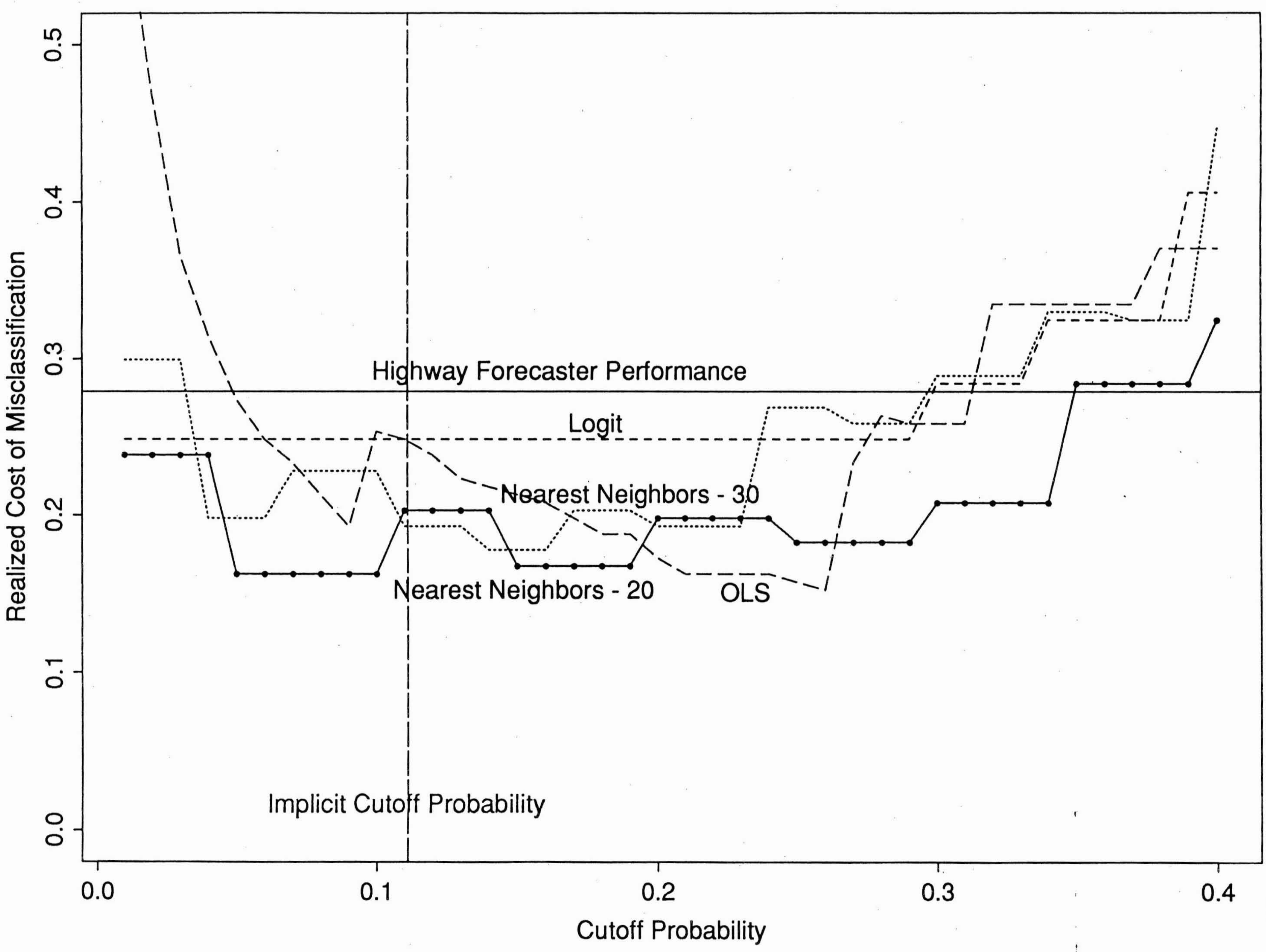

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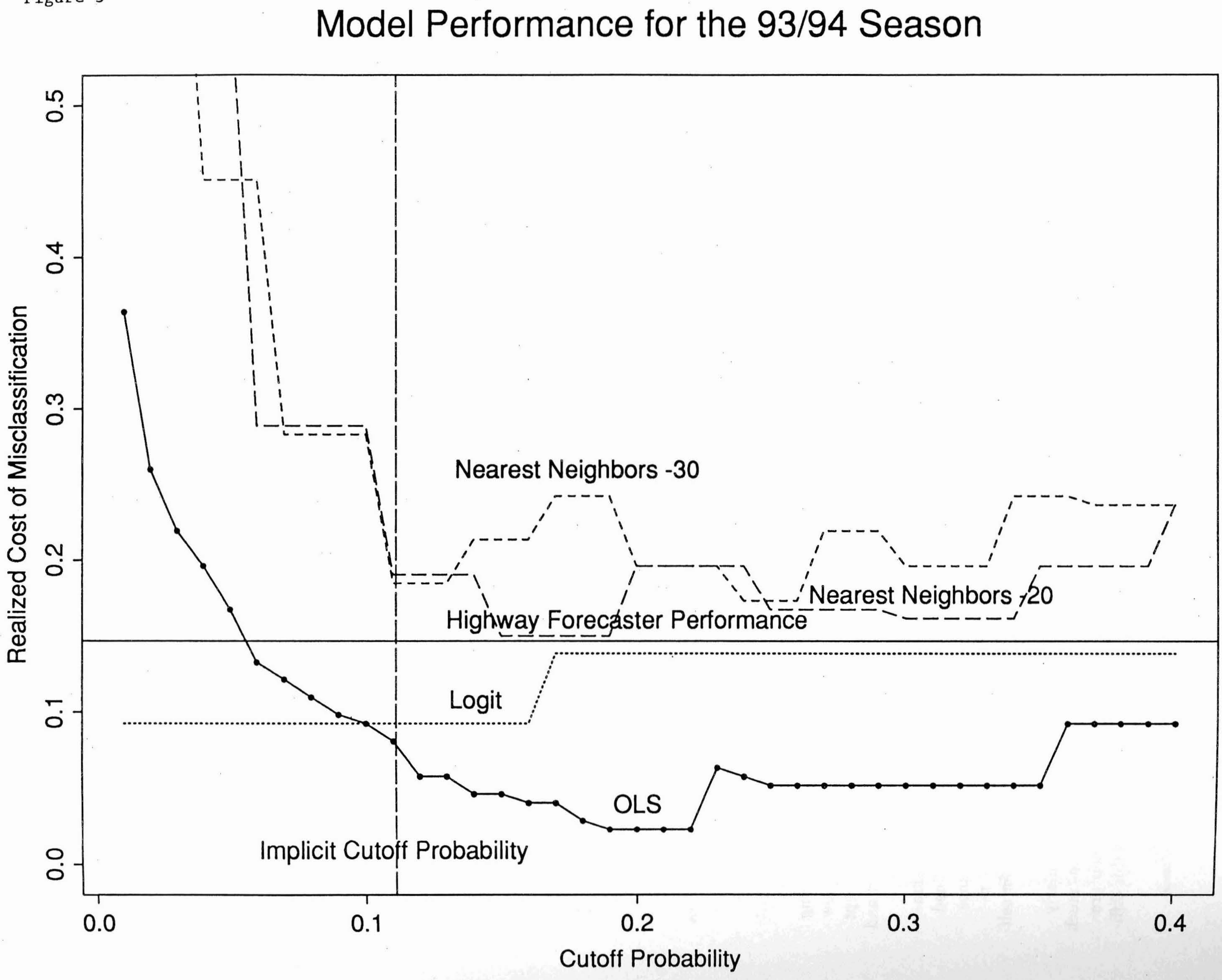
Figure 3



Model Performance for the 93/94 Season
Realized Cost of Misclassification
0.0
0.1
0.2
0.3
0.4
0.5
Cutoff Probability
0.0
0.1
0.2
0.3
0.4
Nearest Neighbors -30
Nearest Neighbors -20
Highway Forecaster Performance
Logit
OLS
Implicit Cutoff Probability