On probabilities of avalanches triggered by alpine skiers. An empirically driven decision strategy for backcountry skiers based on these probabilities.

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Abstract: This paper gives a decision strategy for backcountry skiers based on empirical probabilities. They are the result of a logistic regression model based on data of avalanche events and forecasts in Tyrol within three seasons (1999-2002).

Keywords: avalanche danger; decision strategy.

1 Introduction

In Austria, most fatal snow avalanche accidents are caused by skiers or snowboarders. 79 avalanche accidents (17 fatalities) were reported during the winter of 2001/02. 16 out of 17 these fatalities were caused by alpine skiers or snowboarders. By far the highest number of accidents took place in Tyrol (2001/02: 47 accidents/ 12 fatalities). However, it is rather difficult to predict the risk (=probability) of avalanche events on a backcountry ski slope under given conditions. About 10 years ago, the mountain guide Werner Munter suggested a quantitative method in order to estimate the risk of avalanche events. Assuming that the variables

- danger levels from the local avalanche information service (low=1 to very high=5),
- incline of the slope (three classes from flat to steep),
- aspect of the slope (north, south) and
- skiers behaviour

have an influence on the risk, he calculated a quantity which he calls "remaining risk". On the base of this quantity, he developed a strategy for backcountry skiers whether to go or not to go on a skiing tour (stop if "remaining risk" is larger than 1, see [1]). But Munter's quantity cannot be understood as a probability of avalanche events. Moreover, there is no empirical evidence for his method because he does not take skiing incidents without avalanche accidents into account ([2]). At least, it is necessary to include some information on frequencies of skiers on slopes under specific conditions.

2 Statistical models

In Rothart and Pfeifer (2003), we present an approach which seems to be the first one where results on probabilities of avalanches triggered by skiers have been given. This consists in modeling the counts y_i of avalanche events in each class of incline and aspect for days i with avalanche reports from the Tyrolean avalanche information service (Lawinenwarndienst Tirol).

$$\log(y_i) = \texttt{LWS} + \texttt{NEIG} + \texttt{EXPOS} + \texttt{WOENDE} + \texttt{TOURV}$$

Beside danger level `LWS`, incline of slope `NEIG` and aspect of slope `EXPOS`, we took the qualitative variables skiing conditions `TOURV` and day of the week `WOENDE` into consideration. There is some evidence that frequencies of skiers on slope strongly depend on weather and snow conditions and on the days of the week (weekend, working days). We used accident data and avalanche forecasts in Tyrol within the seasons 1999-2002 reported by the Tyrolean avalanche information service (497 days of observation). However, because avalanche accidents are expected to be rather rare this simple Poisson model shows strong underdispersion. To overcome this misspecification we proposed the following statistical models (see Pfeifer and Rothart (2004)):

- Zero inflated Poisson models (**ZIP**): The observations y_i are expected to be drawn from a mixture of a Bernoulli and Poisson distribution.
- Zero altered Poisson models (**ZAP**): The observations y_i are expected to come from mixture that is zero with probability one in the first component and a truncated Poisson in the second component.

Using this models for counts with extra zeros seems to increase the goodness of fit of the Poisson model. The predicted probabilities are slightly lower than in the Poisson case. However, for the purpose of getting predicted probabilities there is no essential difference between specially built Poisson models and the logistic model in the following.

2.1 Logistic Model

In this approach, we propose a logistic regression model for reasons of simplification (no vs. one or more accidents as dependent variable for days i with avalanche reports from the Tyrolean avalanche information service), in order to estimate the probabilities **p** in question. As mentioned before, the variables `WOENDE` and `TOURV` are taken into the model in order to control effects due to different backcountry skier frequencies.

$$\text{logit}(\mathbf{p}) = \texttt{LWS} + \texttt{NEIG} + \texttt{EXPOS} + \texttt{WOENDE} + \texttt{TOURV}$$

Table 1 gives the estimated parameters of this logistic model.

	Value	Std. Error	t value
(Intercept)	-7.2283515	0.6393772	-11.3053003
LWS	0.9116466	0.1781101	5.1184440
NEIG	0.8324917	0.1464717	5.6836361
as.factor(EXPOS)	-0.5777892	0.2153850	-2.6825877
as.factor(WOENDE)	0.4006435	0.2147187	1.8658994
as.factor(TOURV)2	-0.1226823	0.2903134	-0.4225857
as.factor(TOURV)3	-0.9364877	0.3808698	-2.4588132

Table 1: Estimated parameters of the logistic regression model

Figure 1 shows the distribution of the predictions (=probabilities) of the logistic model fitted to the avalanche data.

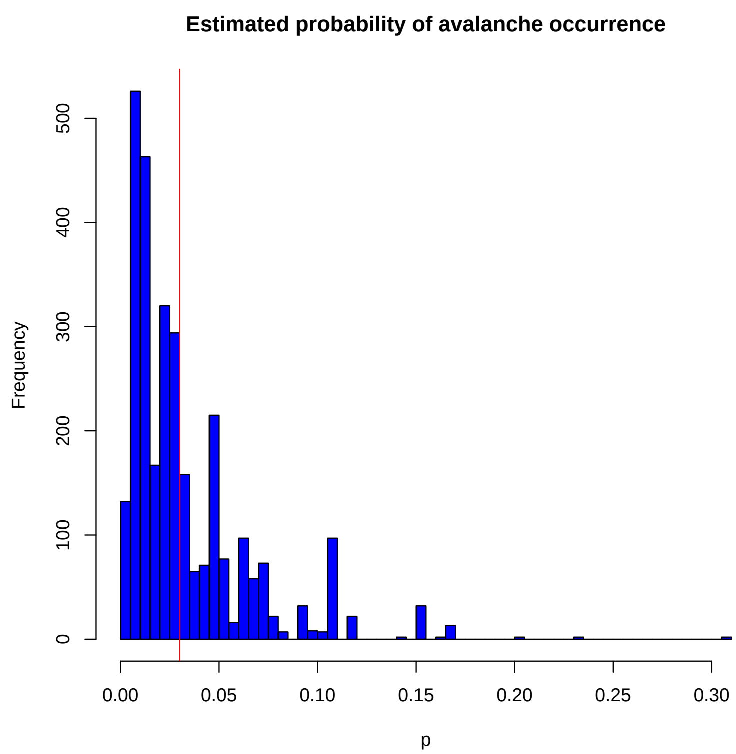

Figure 1: Histogram of estimated probabilities and cut-point for decision stop/go

3 Decision strategy

Further on, we try to establish a decision strategy for backcountry skiers based on empirical/statistical arguments. We have to fix a limit probability p^* which represents the cut-point for the decision whether to stop or to go. If the probability triggering an avalanche is smaller (higher) than p^*, then the backcountry skier would decide to go on the tour (to stop the tour). We choose this cut-point in such a way: For given p, calculate the 2×2 contingency table based on the variables avalanche occurrence yes/no and decision stop/go and quantify the dependence measure $\chi^2(p)$. Identify $p*$ in such a way that maximizes the function $\chi^2(p)$, $0 \leq p \leq 1$. As a result of this we get the cut-point p^* where the dependence between the variables avalanche occurrence and decision stop/go is a maximum. The vertical line in Fig. 1 indicates this point p^* (equal to 0.03) in our case.
Finally we are able to suggest the decision strategy depending on the variables danger level, incline of the slope and aspect of the slope in Figs. 2 and 3. The rows represent the three classes of the slope incline and the columns represent five classes of danger level. The meaning of the colours of the boxes is the following:

- green (go): relative frequency of predicted cases where to stop is equal to zero;
- yellow (attention): relative frequency of predicted cases where to stop is smaller than 50%;
- red (stop): relative frequency of predicted cases where to stop is larger than 50%.

4 Conclusion

For the purpose of obtaining acceptance from the avalanche research community, we tried to give an empirically driven decision strategy for backcountry skiers using rather simple statistical techniques. Our proposal is more or less comparable to Munter's method. But the aspect of the slope seems to be not that important as widely believed (if we notice the higher predicted cases in the yellow boxes of Fig. 3). Finally we recommend to do additional research (count data based on a random sample instead of qualitative data) in order to get more precise information on the frequencies of backcountry skiers on slopes.

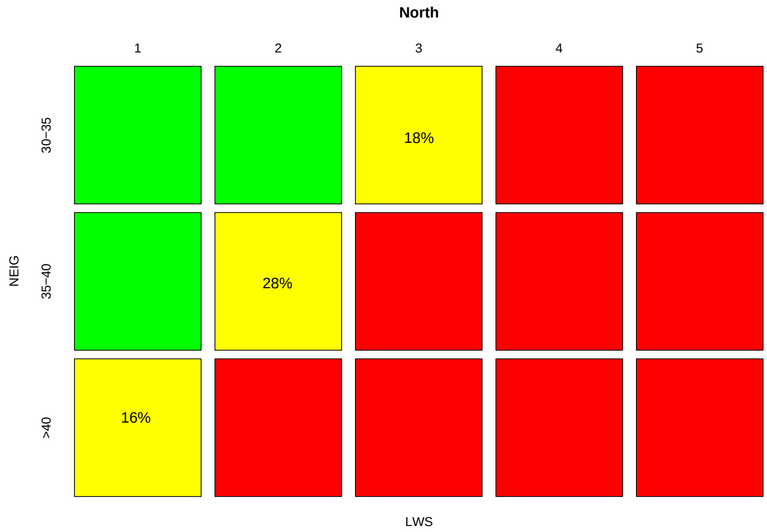

Figure 2: Decision strategy in the northern sector dependent on the danger level and the incline of the slope (go/green, yellow/attention and stop/red)

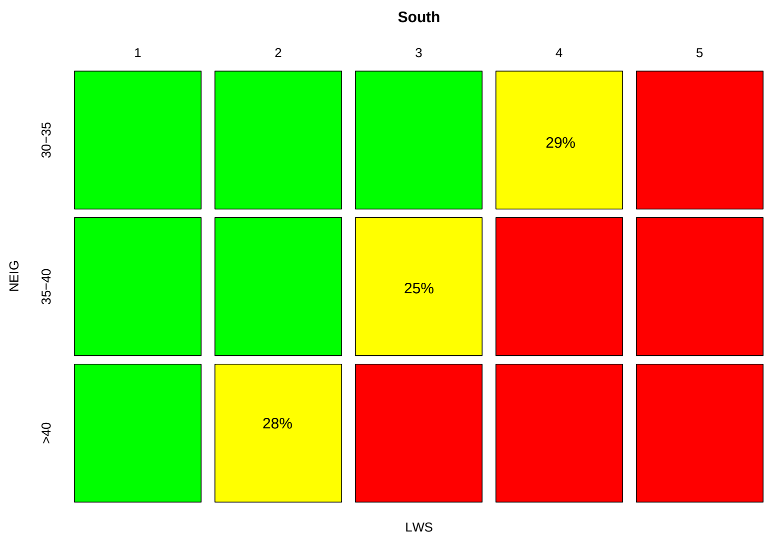

Figure 3: Decision strategy in the southern sector dependent on the danger level and the incline of the slope (go/green, yellow/attention and stop/red)

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