A QUANTITATIVE ANALYSIS OF AVALANCHE HAZARD ON U.S. HIGHWAY 550, SOUTHWESTERN COLORADO[1]

by

B. R. Armstrong[2]

INTRODUCTION

Avalanches have been a hazard on U.S. Highway 550 for many years. When the Silverton and Red Mountain Railroad traversed much of what is now U.S. Highway 550 from 1886 to the early 1900's, avalanches frequently closed down the line for the winter. Once a wagon road, the Durango-Silverton-Ouray Highway was improved in 1919-20 for automobile use. Historical records document frequent avalanches involving people (B. Armstrong, 1976; 1977). Since 1935, the Colorado Department of Highways has kept the road open in winter, although closures were, and still are, common (B. Armstrong, 1977).

During the period of this study, 1950-1978, traffic on Highway 550 was relatively light. However, since 1978, vehicle traffic has increased by more than 20% (Silverton Standard and the Miner, October 16, 1980). With energy development on the western slope of Colorado, the Four Corners area, and within the San Juan Mountains, traffic probably will continue to increase, exposing more vehicles to avalanche hazard. Considerable research has been done in defining avalanche path locations on U.S. Highway 550, forecasting avalanche events, and examining the San Juan Mountains snow climate (R. Armstrong and Ives, 1976; B. Armstrong and R. Armstrong, 1977; Frutiger, 1964; Miller et al., 1976). This study uses a statistical approach to examine the probability of avalanches covering the highway and the expected numbers of people and vehicles involved.

METHODS

Data for this study came from two sources: Colorado Department of Highways (CDH) data as compiled by the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. and the University of Colorado, Institute of Arctic and Alpine Research (INSTAAR), Snow and Avalanche Project. Colorado Department of Highways data begin in the winter of 1950-51, cover 1951-52, skip three winters, and are continuous from 1956-78. INSTAAR data are continuous from 1971-78. Data examined include number of avalanche events per storm, length of highway covered by avalanche debris during individual storms, frequency of avalanche events reaching the highway by defined path, number of vehicles struck by avalanches, and number of avalanche fatalities. Additional data on average daily traffic volume, during winter, on U.S. Highway 550, from 1970-76, were obtained from Colorado Department of Highways.[3]

Poisson distribution tests are made to determine the probabilities of avalanche activity and damage. Expectancies of moving and stationary vehicles being hit by avalanches are calculated for individual paths which run to the highway, following a method devised by Schaerer (1974), and a hazard index is developed for U.S. Highway 550.

RESULTS

Avalanche Event Data

Avalanches threaten almost a third of the 58 km of U.S. Highway 550 between the town of Ouray and Coal Bank Hill (Figure 1). Along this distance, 93 avalanche paths have run to the highway within the last 100 years. This means that if every avalanche path released and covered a maximum amount of highway, 28% of U.S. Highway 550 from Ouray to Coal Bank Hill would be covered by avalanche debris. This has never been observed to occur. This study examined those paths which have been observed to run to the highway at least once since 1950. Where several adjacent avalanche paths share the same name, they were treated as a single path. This adjusted the total number to 60.

[1] Presented at the Western Snow Conference, April 14-16, 1981, St. George, Utah

[2] USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado

[3] Peterson, C., personal communication; and data from Colorado Department of Highways meeting, July 12, 1978, Denver, Colorado

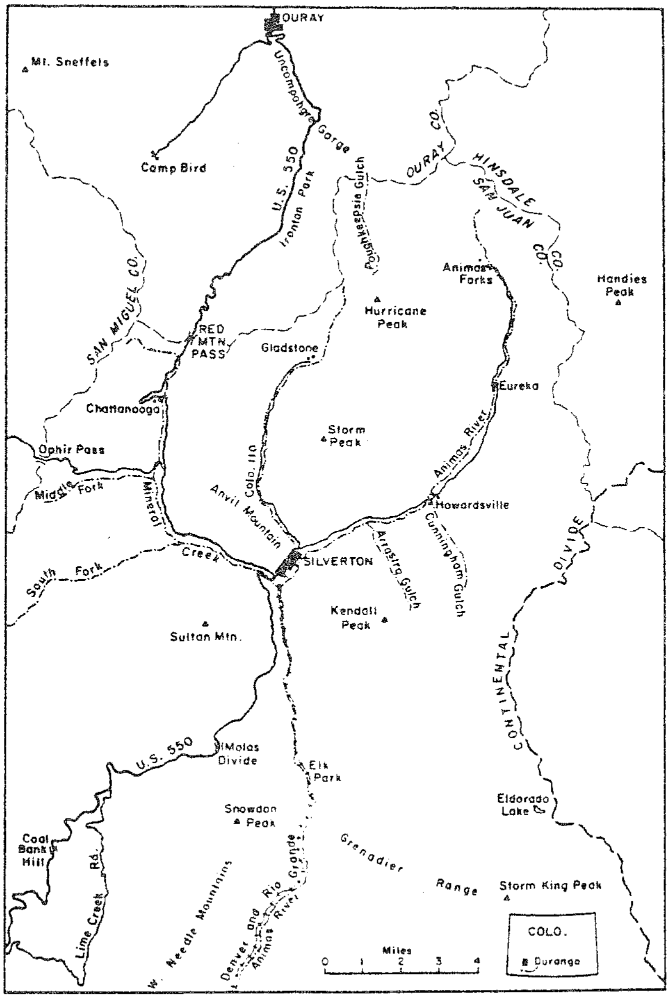

Figure 1

Location map of U.S. Highway 550, southwestern Colorado

Table 1 shows length of U.S. Highway 550 covered by avalanche debris during seven winters, 1971-78. This is computed by summing the length of highway covered by all avalanches during each winter. During both the winter of 1971-72 and 1974-75, avalanche debris covered more than 3 km of highway. However, this table does not give any indication of avalanche frequency per storm. During 1971-72, more than half of the yearly total of avalanche debris came during one storm. In contrast, the winter of 1974-75 had numerous storms, but in terms of avalanche debris on the highway, none approached even half the magnitude of the December 26-27, 1971 storm. To examine hazard probability, more detailed data are required.

Table 1
Length (m) of U.S. Highway 550 covered by avalanches and average snow depth (m)--natural and artifical events.

WINTER	Total length covered	Average length per event	Average depth
1971-1972	3,712	52	1.8
1972-1973	2,594	22	1.4
1973-1974	1,698	28	1.5
1974-1975	5,032	39	1.7
1975-1976	2,652	31	1.7
1976-1977	120	40	0.6
1977-1978	2,964	28	1.1

Probability of Avalanche Damage to Vehicles on U.S. Highway 550

The probability that none, one, or more moving vehicles would be hit by avalanches on the highway during one winter is calculated. Table 2 lists numbers of vehicles and people involved in avalanches on the highway from 1951-78, (no data available for the winters of 1952-3 through 1954-5).

Table 2.

Avalanche encounters with vehicles and people on U.S. Highway 550, 1951-1978

	People				Vehicles			Other		Path
Winter	caught	buried	injured	killed	caught	buried	damaged	buildings	misc.	name
1951-1952										
30 Dec.						1	1			East Riverside
1955-1956										
25 Jan.						1	1			Cement Fill
1956-1957										
8 Jan.						1				Champion
27 Jan.		3				1				Barstow
27 Jan.									1	Water Gage
1957-1958										
14 Feb.									1	Guadalupe
1958-1959										
9 Feb.						2				Blue Point
1961-1962										
8 Jan.						1				Brooklyns
1962-1963										
3 Mar.		3		3		1	1			East Riverside
1967-1968										
19 Dec.		3				1	1			East Riverside
19 Dec.						1				East Riverside
1968-1969										
25 Jan.		1								Brooklyns
1969-1970										
2 Mar.		1		1		1	1			East Riverside
10 April		1	1			1				Harley Short
26 April		1	1			1	1			Mother Cline
1970-1971										
26 Nov.						1				Brooklyns
1971-1972										
26 Dec.	3				1					Benny Long
1972-1973										
7 May	1				1					Champion
9 May	1				2					Silver Ledge Mill
1973-1974										
18 Dec.	2				2					Mother Cline
5 Jan.	1	1			1	1	1			Brooklyn G
9 Jan.	1				1					East Lime Creek
16 Mar.	1				1					Champion
4 April	1				1					Mother Cline
1974-1975										
9 Jan.	1	1			1	1				Brooklyn F
25 April	1	1	1		1	1	1			Mother Cline
1975-1976										
9 Feb.	32	3	1		10	10	5			Brooklyn M
9 Feb.	1				1					West Lime Creek
1977-1978										
10 Feb.	1	1		1	1	1	1			East Riverside
20 Feb.									4	West Guadalupe
29 Mar.					1	1	1			Brooklyn B

In Table 3, a Poisson distribution ($\lambda = 1.56$) is compared to observed data of encounters between avalanches and vehicles and judged acceptable using a Chi-square test for goodness of fit (Moroney, 1951). Based on the fit to the Poisson distribution, the probability that no vehicles will be hit by avalanches during a winter is 21%. Conversely, there is a 79% probability that at least one vehicle will be hit ($1-P(o) = 79\%$). Return intervals for individual events were calculated from:

$$T = \frac{1}{p} \qquad (1)$$

where T = return period (years) and p = probability (Haan, 1977). The probability that one vehicle will be hit per year is 32%, or one vehicle each 3 years. Probability for two vehicles is similar, with 26% and a return period of 3.9 years. These Poisson values should be taken only as estimates of probability. In addition, this test does not differentiate between moving and stationary vehicles. Another test for determining expectancy of encounters between avalanches and vehicles is illustrated by Schaerer (1974).

Table 3
Probability of moving vehicles being hit by avalanches, on U.S. Highway 550, in one winter, using a Poisson distribution.

	Number of vehicles hit per winter						
	0	1	2	3	4	5	6
probability values	.2101	.3278	.2555	.1329	.0518	.0162	.0042
probable frequency expected in 25 years	5.25	8.19	6.39	3.32	1.30	.40	.11
actual frequency in 25 years	10.00	6.00	5.00	2.00	0.0	0.0	2.00
$\chi^2_{(6)} = 5.9$ (P = .5)							

The Avalanche Hazard Index

Schaerer (1974) calculated the degree of avalanche hazard for several highways in British Columbia, Canada. Hazard is defined as the probability of avalanches inflicting damage to vehicles and occupants, and is a function of: size of the avalanches, frequency of avalanche occurrences, number of avalanche tracks, length of highway exposed, volume of traffic, and speed of traffic. Schaerer defines encounter probability as the probability of a vehicle, moving or stopped, being in the track of an avalanche at the same time an avalanche runs across the road. Following Schaerer's technique, the first step was to calculate the expected number of moving vehicles hit by avalanches per year, by using the following equation for each path:

$$Em = \frac{ADT\cdot(L+D)}{V\cdot 1000\cdot 24}\cdot F = 4.2\cdot 10^{-5}\cdot\frac{ADT}{V}(L+D)F \qquad (2)$$

where,

Em = expected number of moving vehicles hit by avalanches, per year
ADT = average daily traffic volume (cars/day)
V = average speed of the traffic (km/hr)
L = width of the avalanche = average length of highway covered by the avalanche (in meters)
D = average stopping distance (in meters) on a snow-covered road, for a vehicle with the speed V
F = frequency of avalanche occurrence, average number of avalanches per path crossing the highway per year.

For U.S. Highway 550, the ADT figure used was 675 vehicles per day. Because of much greater summer traffic than winter traffic, this number is one-half of the mean annual value for average daily traffic on U.S. Highway 550 from 1970-76.[4] The average speed used was 40 km/hr, with a stopping distance of 30 meters.[5] A relatively low average speed was used, because traffic moves slowly on U.S. Highway 550 during storms, when the roads are usually snow-packed and visibility is limited. Considering the nature of the highway, its narrowness along much of the mountainous section, and the number of curves, actual speeds might be less than 40 km/hr. L is taken from data for 1951-78 and is the mean length of highway covered by each avalanche path. Frequency (F) is calculated using natural and artificial avalanche event data from 7 years of detailed observations, by the INSTAAR project and the CDH, during 1971-78. In the cases of paths with infrequent activity, the longer, but less detailed record, 1951-78, is used.

Expected encounters for individual paths are calculated and listed in Table 4. Because average number of avalanches per path per year (F) is part of the equation, the expected encounters for more active paths are high. For example, the Mother Cline path (069) shows a Em of 0.275, meaning that 0.275 vehicles would be hit by avalanches per year, or that once in 3.6 years, a moving vehicle would be hit at the Mother Cline. Data from Table 2 show that the Mother Cline from 1951-78 was observed to hit five vehicles, a frequency of five incidents per 25 years, giving a return period of 5.0 years, fairly close to the calculated Em. The Bennie Long path (014) caught one vehicle in 25 years, giving a return interval of 25 years. The return interval from the calculated Em is 20 years. In the case of the East Riverside path, the observed return interval is shorter than the calculated: observed, 4.2 years and calculated, 5 years. These examples show cases where return intervals from observed data and derived from the calculated Em are close. This is not always the case. At the Champion path (144), three vehicles have been caught, giving a return interval of 8.3 years; the calculated Em of 0.06 gives a return interval of 16.7 years, double the observed value. To compare the calculated Em values with observed data, all highway incidents are used. This could be misleading, because for many of the incidents, it is not known whether the vehicles were moving or stationary. However, in general, values calculated using eq. 2 approximate observed values to the extent that they may be applied as indices. Limitations of using this method are analyzed later.

Expected encounters for traffic stopped under avalanche paths are also calculated. Schaerer notes that most avalanche accidents on roads occur because traffic has stopped in the path of avalanches. The most frequent reason for stopping is when an earlier avalanche has already deposited snow on the highway. Vehicles then are exposed to subsequent avalanches in the same or adjacent tracks. This is particularly relevant on U.S. Highway 550 in the case of the East Riverside avalanche (064). Of the six recorded fatalities, all occurred after the avalanche had released once and the victims were stationary or moving slowly under the path when it released a second time. Probability of recurrence of fatalities is described in the next section.

Using Schaerer's average figure of 0.15 for the probability (Ps) of another avalanche occurring at the same or adjacent site, Ew is calculated from:

$$Ew = Ps \cdot F \cdot N \qquad (3)$$

where,

Ew: expected number of waiting vehicles hit by avalanches per year
Ps: 0.15
F: average number of avalanches reaching the highway per year

$N = \frac{L}{15}$: number of potential vehicles in the avalanche path.

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[4] Peterson, C., Colorado Department of Highways, personal communication
[5] Schaerer, personal communication

Table 4.
Hazard index for U.S. Highway 550 by damage classes

Damage Classes: R-2 Sluffing

Path No.	Path name	$\bar{L}$ (m)	F (yr)	Em	Ew	(Em+Ew)
001-004	Anvil-Pit	30	.2	.01	.06	.07
011-12	Barton North and South	18	.2	.01	.04	.05
013	Blackburn	35	.4	.02	.14	.16
014	Benny Long	85	.6	.05	.51	.56
062	East Riverside South	11	1.3	.04	.14	.18
063	East Riverside Left	15	3.9	.12	.59	.71
066	North Emergency Phone	9	.6	.02	.04	.07
067	Cliff	15	.4	.01	.06	.07
068	Dunsmore	9	.9	.02	.08	.11
070	Silver Point	46	1.3	.07	.60	.67
071	Jackpot	27	.3	.01	.08	.09
091	King	15	.2	.01	.03	.04
092	Twin Bridges	30	.2	.01	.06	.07
093	Barstow	38	.2	.01	.08	.09
094	Idarado	30	.4	.02	.12	.14
096	Blue Willow	15	2.1	.07	.31	.38
097	Blue Point	22	13.3	.49	1.00	1.49
098	Snowflake	46	.6	.03	.28	.31
099	Fence	24	.3	.01	.07	.08
143	Harley Short	35	.6	.03	.21	.24
152	Deer Creek North	18	.3	.01	.05	.06
155	Henry Brown	14	1.6	.05	.22	.27
156	Coal Bank	61	.2	.01	.12	.14
157	Coal Creek, East	14	.3	.01	.04	.05
158	Coal Creek, West	20	.9	.03	.18	.21
159	Engineer Mt. A	24	.2	.01	.05	.06
063	E. Riverside Right	11	.6	.02	.07	.08
			TOTAL			6.44
			x weight(w)		w=2	12.87

R-3 Light Snow

Path No.	Path name	$\bar{L}$ (m)	F (yr)	Em	Ew	(Em+Ew)
009	Lower Cement Fill	40	.2	.01	.08	.09
030	Cemetery	30	.2	.01	.06	.07
061	Slippery Jim	52	.3	.02	.16	.17
069	Mother Cline	46	5.1	.27	1.00	1.27
082	Ironton	15	.04	<.01	.01	.01
087	McIntyre Gulch	24	.08	<.01	.02	.02
088	Galena Lion Gulch	12	.04	<.01	.01	.01
095	Willow Swamp	61	2.1	.14	1.00	1.14
100	Silver Ledge Mine	64	1.3	.09	.83	.92
101	Rockwall	64	4.6	.31	1.00	1.31
102	Silver Ledge Mill	98	1.0	.09	1.00	1.09
103	Porcupine	91	1.0	.09	1.00	1.09
138-9	Gladstone, North and South	24	.2	.01	.05	.06
142	Peacock	30	.4	.02	.12	.14
147	Waterfall	34	.4	.02	.14	.15
148	Springs	15	.4	.01	.06	.07
149	East Lime Creek	122	1.4	.15	1.00	1.15
150	West Lime Creek	104	1.1	.10	1.00	1.10
153	Deer Creek, South	37	.4	.02	.15	.17
154	Swamp	18	.1	<.01	.02	.02
						10.04
					w=4	40.16

R-4 Deep Snow

Path No.	Path name	$\bar{L}$ (m)	F (yr)	Em	Ew	(Em+Ew)
010	Cement Fill	61	1.0	.06	.61	.67
015-028	Brooklyns	58	12.4	.77	1.00	1.77
060	East Guadalupe	122	.06	.01	.07	.08
064	East Riverside	38	4.1	.20	1.00	1.20
074	West Riverside	30	.5	.02	.05	.07
075	West Guadalupe	91	.1	.01	.09	.10
104	Eagle	50	3.4	.19	1.00	1.19
105	Telescope	61	2.4	.16	1.00	1.16
106	Muleshoe	50	.9	.05	.46	.51
140-141	Jenny Parker North and South	30	.3	.01	.09	.10
144	Champion	26	1.4	.05	.36	.42
145	Deadwood	8	.1	.00	.01	.01
146	King Mine	30	.08	.00	.02	.03
						7.31
					w=10	73.15

Hazard Index = $\sum_{R2}^{R4} w(Em+Ew) = 126.181$

L is the average length (in meters) of highway covered by the avalanche. Average length of road occupied by one waiting vehicle is 15 m. A value of 10 meters was used in the Avalanche Task Force Report; Schaerer is now using 15 meters.[6] Schaerer's Ps value is an average based on terrain, weather conditions that would produce avalanches, and how frequently the road is patrolled by road maintenance staff. In the Avalanche Task Force report, the probability of occurrence of subsequent avalanches was assumed to be 0.15 for most major British Columbia highways (Schaerer, 1974); this value is used here.

Schaerer found that the expected number of waiting vehicles (Ew) hit by avalanches is three to six times higher than those for moving traffic (Schaerer, 1974). For several of the high frequency avalanche paths, calculated Ew values were greater than one. These numbers were cut off at one. Using the Ps value of 0.15 may be responsible for the high Ew values. This and other assumptions are described in the Discussion section. Results from Table 4 show that this difference ranges from three times to an order of magnitude higher for Ew.

Avalanches are then classified according to their effect on traffic, in order to calculate the hazard index for the highway. The four classes are:

R1 Snow Dust:	Snow dust or windblast only; no significant deposit of snow on the road. The conditions would be similar to that in a blizzard, where drivers could lose control.
R2 Sluffing:	Frequent small bank avalanches or sluffing; the snow deposit would be across the width of the highway at the maximum. The individual avalanches would be small, but many of them could occur during an avalanche cycle, and, in time, a car could be buried.
R3 Light :	Avalanches go beyond the highway, and deposit snow, usually dry, between 0.3 and 1.2 m deep; cars could be pushed over the highway, but not buried. Heavy trucks would be buried with their wheels covered, but usually not damaged or moved.
R4 Deep Snow:	Avalanches would deposit snow averaging deeper than 1.2 m on the highway; vehicles could be buried or swept off the highway and damaged when falling over a steep slope (Schaerer, 1974).

Most avalanches which threaten U.S. Highway 550 deposit snow directly onto the road, so the R1 class is not used in this study. Table 4 lists avalanche paths in Classes R2-R4. The Em and Ew values of each class of damage are multiplied by a weight (w), and the products are summed. The weight is an expression of the cost and consequences that could result from an accident (Schaerer, 1974). Weights used are:

R2 Sluff $w = 2$
R3 Light Snow $w = 4$
R4 Deep Snow $w = 10$

The sum of the products is the hazard index.

$$\text{Hazard Index} = \sum_{R2}^{R4} W(Em + Ew) \qquad (4)$$

The hazard index (Schaerer, 1974) is an indication of how dangerous the avalanches are which affect the highway. Schaerer uses the hazard index as an indicator to determine degree and types of avalanche control. The British Columbia Avalanche Task Force rating of avalanche hazard and consequences for avalanche control is:

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[6] Schaerer, personal communication

Hazard	Hazard Index	Consequence for avalanche control
very low	less than 1	no action necessary
low	1 to 10	avalanche warning and occasional closure
moderate	10 to 100	avalanche control at selected sites, closure
high	greater than 100	full control

The calculated hazard index for U.S. Highway 550 is 126, putting this highway in the high hazard group. Snoqualamie Pass, on Interstate 90, in Washington State, has a hazard index of 44, putting it in the moderate hazard category. Of the 26 British Columbia highways examined in the Avalanche Task Force study in 1974, only three are in the high hazard category. Rogers Pass, on the TransCanadian highway, between Revelstoke and Golden, B.C., while not detailed in that study, has a hazard index of 174, although this figure would be 335 if paths which are passively controlled with snowsheds were counted (Schaerer, 1974).

Probability of Avalanche Fatality at the East Riverside

Because the East Riverside is the only avalanche path on U.S. Highway 550 to take any lives, a final analysis has been made using the East Riverside avalanche path data alone. A Poisson distribution is used to estimate the annual probability of none, one, two, or three fatalities occurring at the East Riverside (Table 5). Since 1950, five people have been killed at the East Riverside. The time period used is 28 years. While three years of data are missing, newspaper records and personal communication would probably have mentioned any fatalities. Because none were reported during this period, the time period was considered to be continuous.

As seen in Table 5, there is a 15% probability during one winter that a fatality will occur at the East Riverside. From estimated return intervals, the probability for one fatality per winter is 6.7 years; for two or more fatalities, 71 years. These return intervals are slightly longer than observed: one or more fatality per year, 9.3 years. Schaerer's method of determining return interval gives a recurrence of once in 5 years, very close to that derived using Poisson data. This means that, based on existing data and assuming no significant climatic change or increase in traffic, at least one life is likely to be lost in an East Riverside avalanche once every 5 to 10 years.

Table 5
Probability of avalanche fatalities at the
East Riverside path, U.S. Highway 550, in one winter,
using a Poisson distribution.

	Number of fatalities per winter			
	0	1	2	3
probability values	.836	.150	.014	.001
probable frequency expected in 28 years	23.4	4.20	0.40	0.028
actual frequency in 28 years	25.00	2.0	0.0	0.1

$\chi^2_{(3)} = 0.67$ (P = .85)

DISCUSSION

Two methods have been used to analyze avalanche hazard on U.S. Highway 550: the Poisson distribution and the hazard index of Schaerer. Return intervals and probabilities derived from these methods should be considered as index values or guides to assessing the hazard from avalanches along U.S. Highway 550. The use of the Poisson distribution requires little discussion, because it merely smooths the data before estimating probabilities.

Expected encounters for moving and waiting traffic, at specific avalanche sites, calculated by Schaerer's method, should be considered only as approximate indices. Expected encounters for moving vehicles correlate well with observed events. However, the figures for traffic waiting under, or adjacent to, high frequency paths showed Ew values that reach or exceed one, indicating that one or more waiting vehicles could be expected to be hit. These figures are unrealistic. Which variable in the Ew equation is responsible for giving these high values--the frequency data, the average length of highway covered, or the Ps value--is not known.

The frequency data (F) were tabulated using both natural and artificial avalanche events. It could be argued that the inclusion of artificial events biases the sample towards high frequencies for controlled avalanche paths. However, it can also be argued that had the paths not been controlled, many would have run during a subsequent storm as natural events. The argument for artificial release of avalanches is that while they may run more frequently, the magnitude of the event is smaller than a natural release. Thus in eq. 2 the L values would be greater for natural events than for artificial events. To totally eliminate all artificial events imposes an unfair bias toward a lower frequency, including artificial events does the opposite. A coefficient could be determined that would correct downward the frequencies of the controlled avalanche paths. Reducing the frequencies would reduce the Em and Ew values and would lower the overall hazard rating. However, counting only natural events would increase the L values and could counteract the decreased F values. This is a difficult problem to resolve, and more research is needed to determine if, how, and by how much, frequencies of controlled avalanche paths should be corrected.

Following Schaerer's method, a Ps value of 0.15 is used. Because some of the Ew values are so high, an independent estimate of Ps from observed data, ranging from 0.03 to 0.05, may be more appropriate. Recalculated Ew values based on a Ps of 0.04 were much lower. Whether these reflect a more realistic number is not known. Here too, more research needs to be done. Research at the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, on joint frequency of avalanches at adjacent avalanche paths should give an indication of what a realistic range is for Ps. Individual Ps values could be calculated from this range, based on terrain and road maintenance policies. However, the purpose of using Schaerer's method was to compare U.S. Highway 550 with other hazardous highways; to do this, the same parameters had to be used.

The hazard index is calculated based on several assumptions. First, it assumes that the average daily traffic volume (ADT) of 675 is a reflection of the actual numbers of vehicles traveling U.S. Highway 550 during hazardous periods. Although the ADT number might be low compared to recent traffic estimates by the CDH (about 900 over the winter according to the Silverton Standard and the Miner, October 16, 1980), the ADT figure represents an average over the study period (1950-78) and balanches out the low traffic volume during the early part of the period. Increasing traffic would increase the expected number of encounters. Data from the U.S. Forest Service, Recreation Management Information System (RIM), Rocky Mountain Region, show that in San Juan County, from 1973-76, the numbers of cross-country skiers tripled, from 1,100 to 3,600.[7] As this trend continues, and more people involved in recreation and mineral development use U.S. Highway 550, the hazard to travelers will increase proportionately.

A second assumption is that, as noted by Schaerer, traffic would move freely during avalanche periods, drivers would ignore the hazard, avalanche debris on the road would be removed in a short time, and traffic would again move freely. While it is possible for all these conditions to exist on U.S. Highway 550, it is unlikely, because the highway is usually closed after the first avalanches block the road. Drivers commonly ignore the hazard, however, and traffic close to already-run avalanches usually waits in place instead of moving to a safe location. Thus, both the calculations and experience show that the hazard to waiting vehicles will be much greater than the hazard to moving vehicles.

Other assumptions are: (3) that it is valid to combine natural and artificial events in the frequency value (F) in eq. 2, and (4) that the Ps value is representative for U.S. Highway 550. Some of these assumptions are questionable, and all require further research to substantiate the results of this study. Additional factors which should be considered in calculating a hazard index for U.S. Highway 550 are: (1) the ratio of avalanche-prone highway to total length of highway, and (2) road surface conditions (i.e., snow-packed) in calculating stopping distance (D) in eq. 2.

[7] Trogert, N., U.S. Forest Service, Denver, Colorado, personal communication

CONCLUSION

Based on the method of the British Columbia Avalanche Task Force, U.S. Highway 550 can be classified as a high hazard route. However, additional research could produce values which would alter and possibly lower the hazard index from high to moderate. Therefore, the calculated probabilities and the hazard index value should be considered only as index numbers in assessing future control and closure policies for U.S. Highway 550. These statistical methods can be applied to any avalanche-prone highway to determine degree of hazard, given data on avalanche frequency and other readily determined parameters.

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