THE EAST RIVERSIDE AVALANCHE ACCIDENT OF 1992: ENGINEERING AND SNOW-SAFETY CONSIDERATIONS

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ABSTRACT

A high-intensity snowstorm (>1m snow and >8cm water in 2 days) produced widespread avalanching in Colorado's northern San Juan Mountains during early March, 1992. While the Colorado Department of Transportation (CDOT) was attempting to rescue stranded motorists and close Highway 550 two CDOT employees were caught and buried 40m north of the East Riverside avalanche shed, approximately 8km south of Ouray. One of the employees died. Although Highway 550 is crossed by about 60 avalanche paths, the last six fatalities have occurred at the East Riverside in four separate accidents in 1963, 1970, 1978, and 1992.

The State of Colorado is considering two options to reduce avalanche hazard on Highway 550: (a) an approximately 80m-long northward extension of the existing shed, and (b) hiring two full-time forecasters during the November-April period each season. The shed extension would require a front-end, one-time expenditure of approximately $3,000,000, would decrease the hazard in the East Riverside to less than half the present level, but would only reduce the avalanche hazard over the entire Highway by roughly 5%. Assuming a long-term interest rate of 8% and an amortization period of 30 years, the shed would be financed by a constant annual payment of $266,490. Total "mortgage" cost over 30 years, therefore, would be $7,994,700. The forecast program, including salary, overhead, instrumentation, transportation and other expenses, would cost an estimated $100,000 per year and would reduce the hazard over the entire highway by an estimated 50%. If this annual cost also inflates at an 8% rate over 30 years, the total cost would be $11,328,322. The forecast program, therefore would cost 1.42 times the shed cost over 30 years, but would provide roughly 10 times the hazard reduction.

INTRODUCTION

Highway 550 between Ouray and Durango in Colorado's San Juan Mountains is crossed by at least 60 named avalanche paths and numerous additional unnamed paths and bank slides (Figure 1). Avalanches have been an acknowledged hazard on this transportation route for more than 100 years. A 50km–long reach of this highway south of Ouray contains all of the avalanche terrain and is one of the most seriously exposed sections of highway in North America. A statistical study of avalanche frequency and severity (Armstrong, 1981) concluded by ranking Highway 550 as one of several "high hazard" mountain highways in North America through application of the methods introduced by Schaerer, (1974). This method derives a "hazard index" which can be used to compare relative hazard on different highways or calculate the relative hazard on a single path. A research of historical records (Atkins, unpublished) showed that more vehicles have been caught on Highway 550 during the period 1951–1991 than on all other Colorado highways combined.

Application of Schaerer's hazard index suggests that the East Riverside avalanche by itself accounts for roughly 10–20% of the avalanche hazard on Highway 550. This path (Mears, 1986; Mears, 1990), falls approximately 1,000m to the highway (Figure 2), falling over increasing steep terrain immediately prior to impact. Approximately four–to–six avalanches close the highway in the Riverside area each winter; typically, at least one of these events requires more than one hour to clear from the highway. Because of starting–zone complexity, a tendency to avalanche more than once during most large storms, and for snowpack instability to develop independently of other paths on the highway, the 350m–long section below the Riverside area is the most dangerous on the highway. Although the statistical studies referenced above suggest the East Riverside accounts for no more than 20% of the avalanche hazard on the highway, the last six fatalities have been at the Riverside (3 in 1963, 1 each in 1970, 1978, and 1992).

AVALANCHE CONTROL PRIOR TO 1992/93 WINTER

Control Methods on Highway 550

Avalanche control on Highway 550 has consisted of temporary closure and delivering explosives to starting zones by artillery, avalauncher, and helicopter. The times for closure and control activity were determined as a result of communication with the Colorado Avalanche Information Center (CIAC), observations by Colorado Department of Transportation (CDOT) maintenance personnel, and observations of natural avalanche activity in the area. A full–time, local avalanche forecaster has not been employed and a systematic forecast, closure, and control plan for this area has not been based on the opinion of local snow and avalanche specialists. The CIAC, however, has utilized local storm, snowpack, and avalanche observations in formulation of a regional avalanche forecast which was considered by CDOT.

A highway closure policy is an important part of any avalanche–control or hazard–reduction program. Apparently the closure procedure in use during the 1991/92 winter was based heavily on the equipment operator's or maintenance foreman's judgment. The maintenance workers, however, had no access to starting–zone data and therefore had to rely on observed avalanche activity on the highway or upon estimates of storm intensity and duration to arrive at a decision about highway closure. With a major storm in

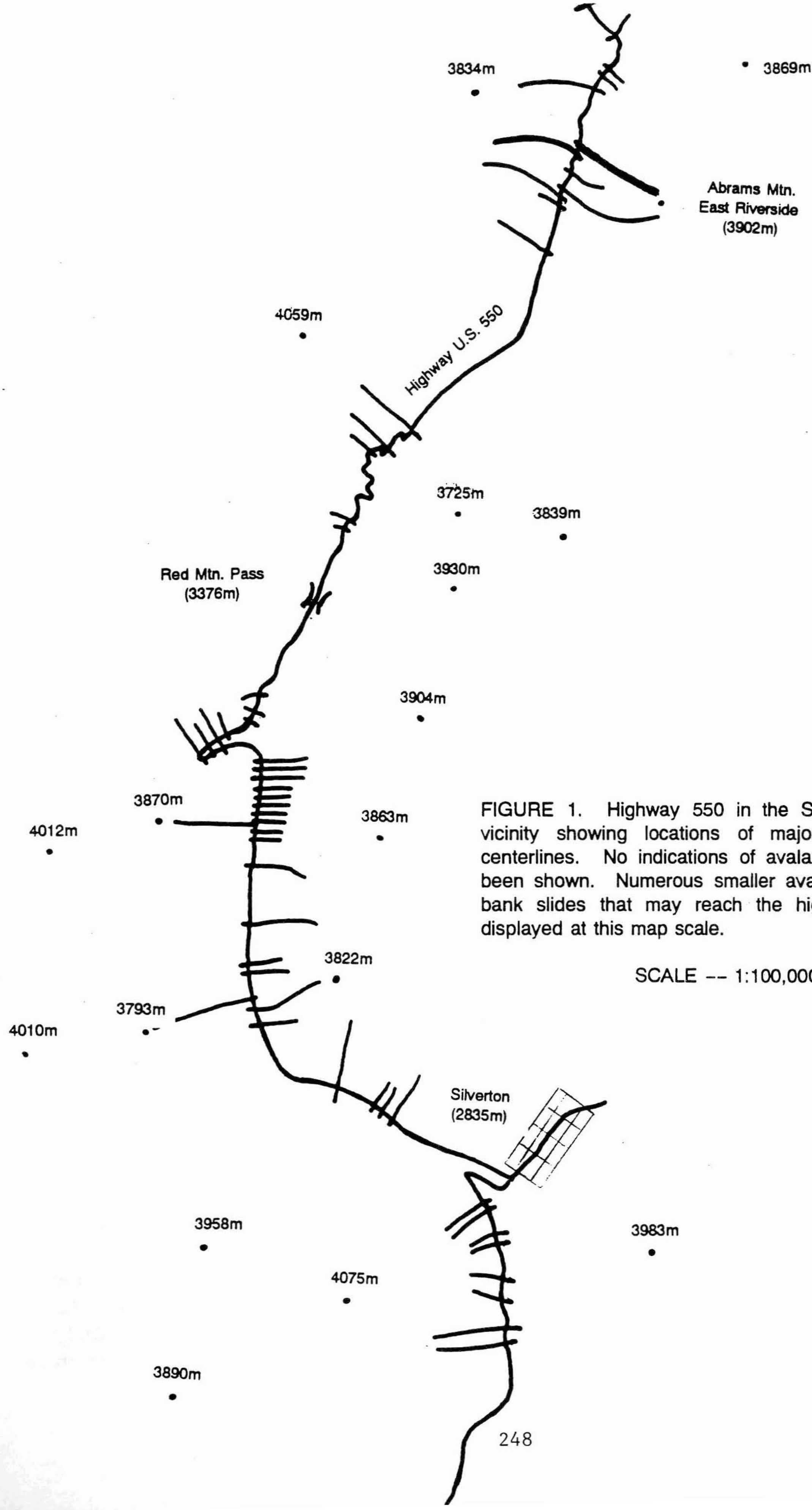

FIGURE 1. Highway 550 in the Silverton, Colorado vicinity showing locations of major avalanche-path centerlines. No indications of avalanche widths have been shown. Numerous smaller avalanche paths and bank slides that may reach the highway cannot be displayed at this map scale.

SCALE -- 1:100,000

progress, snowfall rates exceeding 5cm/hr are possible and strong winds are common. Therefore hazardous conditions sometime develop quickly, possibly before a closure decision could be reached.

Control Methods at the East Riverside

During 1981 and 1984, the CDOT (at that time the "Highway Department"), commissioned studies to investigate avalanche-control options at the Riverside avalanche area. The reliability of *all types* of avalanche control were considered in these studies, including closure, forecasting, explosives, various types of diverting, arresting, and supporting structures, a shed, and a tunnel. A shed was the most cost-effective option for protecting the Riverside area if the objective was to *eliminate* hazard on a portion of the highway. These studies also concluded that a shed approximately 350m long would be required to protect the entire area from *all* avalanches although roughly 80% of the hazard would be eliminated by a structure roughly 135–150m long and 50% would be eliminated by a shed 55m long. Due to funding constraints, CDOT was able to build only a 55m-long shed in 1985. A critical area immediately north of the shed remained exposed to avalanches, some of which fall over a 20m-high cliff onto the highway. Furthermore, in 1984 a major ("100-year") avalanche occurred approximately 40m north of what was to become the north portal, removing portions of a mature forest and increasing avalanche frequency at this location. This avalanche path was the location of the fatality in 1992.

In addition to the shed, CDOT continued to conduct helicopter bombing of the East Riverside and the adjacent West Riverside which descends into the same area. Nearly all of the East Riverside avalanches released during explosive control were contained by the 55m long shed. Several moderate-sized events, however, overtopped the north and south portals.

THE MARCH, 1992 AVALANCHE ACCIDENT

A major late-winter storm reached the northern San Juan Mountains and deposited >1m of snow and >8cm of water during the two-day period of March 4 and 5, 1992. As is often observed, snowfall intensity, wind, and avalanche hazard was far greater on one side of Red Mountain Pass (on the north side this time). Although it was snowing on the south side (Silverton and passes to the south), light traffic from the south continued through Silverton and over the still-open highway toward Ouray 40km to the north on the evening and early morning of March 4 and 5.

At approximately 1 AM, March 5 highway crews decided to close the Pass between Silverton and Ouray. A final traffic "sweep" started at Silverton and found a vehicle stuck in deep snow near the top of Red Mountain Pass. After freeing the vehicle, both CDOT personnel and the two motorists (4 people; 2 vehicles) traveled toward Ouray but were blocked immediately north of the Riverside shed by a small avalanche that had fallen over the cliff about 30m north of the shed. The two motorists and two CDOT personnel took refuge inside the shed and called for a rotary snowplow and two operators to remove debris and enable everyone to proceed to Ouray.

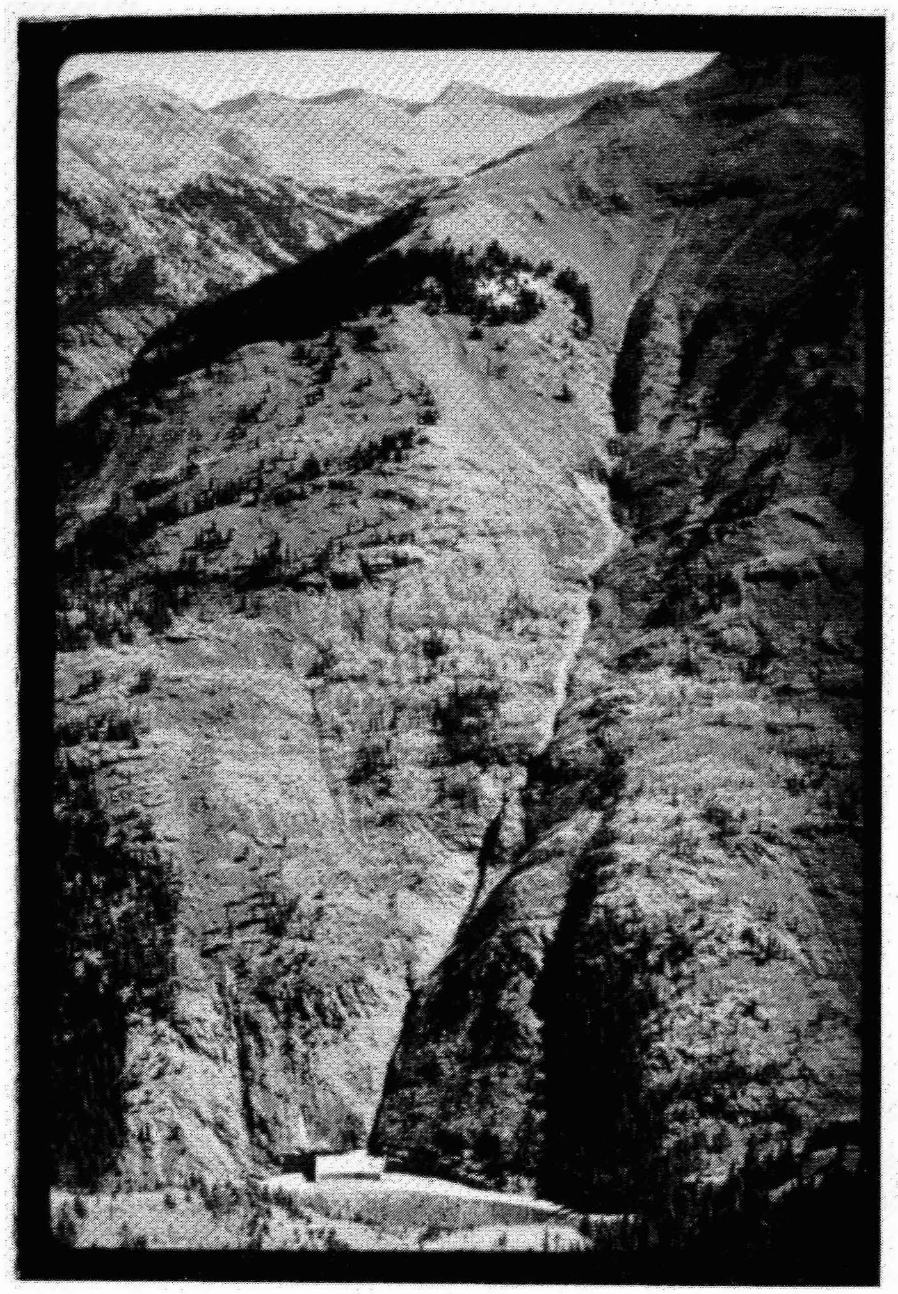

FIGURE 2. The East Riverside avalanche falls approximately 1,030m (3890m - 2860m) from the top of the starting zone to Highway 550. Several distinct starting zones with various exposures to sun and wind produce avalanches as a result of a large variety of snowpack conditions. Approximately 300,000m² of starting zone exists. The fatal avalanche accident of March, 1992 originated below timberline on the left (north) side of the main basin and descended the gully located approximately 40m north of the 55m-long shed (see Figure 3). The present shed reduces the hazard in the Riverside area by an estimated 50%; an 80m shed extension to the north would reduce the hazard by an additional 30%.

While clearing the debris immediately north of the shed, the two CDOT equipment operators went outside the vehicle to replace a tire chain when a large avalanche buried them both (Figure 3). An effective rescue could not be conducted from the shed due to continued heavy snow and extreme avalanche hazard. At approximately 11AM, the four people inside the shed were evacuated to Silverton. One of the buried maintenance workers managed to dig himself through the debris with a flashlight in 15 hours. He then telephoned from inside the shed and was also excavated to Silverton by the San Juan County Sheriff's Department and Rescue Group. The second worker died of hypothermia.

ADDITIONAL CONTROL ALTERNATIVES CONSIDERED

Although highway safety is their primary concern, the Department of Transportation must consider avalanche hazard on U.S. 550 in the context of various highway hazards throughout Colorado, most of which are not related to avalanches. The cost of any type of avalanche-mitigation program or structure must therefore be balanced against the anticipated increase in safety resulting from the particular program. With these considerations in mind, two options are being considered to reduce avalanche hazard on Highway 550: (a) an approximately 80m-long northward extension of the avalanche shed at the East Riverside, and (b) funding, through the CIAC, two full-time avalanche forecasters during the November-April period each year. These options can be compared in terms of costs and hazard reduction.

Avalanche-Shed Extension

The shed extension would require a front-end expenditure of approximately $3,000,000, or a unit cost of $37,500/meter ($11,400/foot). Sheds designed for large avalanche loads in European countries rarely cost more than $15,000-$20,000 per meter, therefore the cost estimate for the East Riverside extension is double the actual costs at many other locations. The high cost at the Riverside probably results from (1) extensive cuts into unstable bedrock, (2) large avalanche loads, (3) inexperience with this type of construction in the United States, and (4) consideration that a major slope failure will increase the cost. The original 55m-long shed cost $2,700,000 in 1985 although the cost was estimated at only $1,650,000 during the construction bids. The increase in cost resulted primarily from design changes due to a large slope failure during excavation of the cliff east of the shed. Various estimates for the cost of the 80m shed extension ranged from $2,000,000 to $5,000,000, with the lower estimates based on experience with sheds in Europe and Canada and the higher estimates based on an inflated unit (per meter) cost of the 1985 structure. The $3,000,000 figure used in this paper *is not* an official Department of Transportation estimate; it is simply my opinion of a reasonable compromise between the various cost estimates, given the physical parameters at the site.

The large "front-end" cost of highway structures can be compared with other, *apparently* smaller annual recurring costs by conducting an annual-cost analysis and summing the annual costs over some amortization or project period. Assuming a long-term interest

FIGURE 3. The East Riverside avalanche shed on March 6, 1992, approximately 36 hours after the accident of March 5. The buried rotary snowplow (accident location), approximately 40m north of the shed, is visible and is still running.

rate of 8% (similar to current 30-year U.S. Treasury bills), and an amortization period of 30 years, the $3,000,000 structure could be financed by an annual "mortgage" payment of $266,490. Over a 30-year period of uniform payments, the shed would therefore cost $7,994,700. The time distribution of annual costs is shown on Figure 4.

The effectiveness of the shed in reducing hazard can be reasonably well-defined because a portion of the highway now exposed to avalanches would be completely protected. Based on avalanche frequency, width, and depth data, the hazard at the Riverside area would be significantly reduced, (the current structure reduces hazard to about 50% of the "no-shed," pre-1985 condition; the extension will reduce the hazard to about 20% of the pre-1985 condition). This means the overall hazard on Highway 550 will be reduced about 5% from the present level.

Avalanche-Forecast Program

An updated avalanche forecast program for Highway 550 would provide weather and snowpack data from local mountain sites and would enable highway closure and avalanche-control methods to be based on local "ground truth" as well as regional weather and avalanche forecasts. Avalanche-forecast programs have proven to be effective at many ski areas, highways, railroads, industrial, and recreation sites throughout the world. Because Highway 550 has one of the most serious avalanche hazards in North America, such a program is justified.

The forecast program costs would consist of the following elements:

a. Salary for two forecasters for the November-April, six-month period, approximately;
b. Vehicle leasing and operating expenses;
c. Telephone and computer connections;
d. Administration by the CIAC;
e. Coordination and travel by CDOT; and
f. Miscellaneous expenses including equipment.

If personnel salaries (both CIAC and CDOT personnel) are multiplied by a factor of two to cover all administrative overhead to the State of Colorado, (pers. comm. J. Siccardi), the annual cost of the forecast program to a taxpayer would be approximately $100,000 per year at today's cost. This $100,000 amount will increase each year because of inflation, even if the program is not changed. An "inflation factor," of 8% is used in this paper. This is identical to the amortization rate used in estimating the avalanche-shed annual cost. The 8% inflation figure is high by today's standards, but would have seemed low 10 or 12 years ago. A long-term prediction of inflation rates is well beyond the scope of this paper and is speculative at best. I have chosen to use the same rate to estimate the shed and forecast program annual costs, as is customary in engineering cost comparisons. Assuming an 8% inflation rate, a $100,000 first year cost, and a 30-year period, the total cost of the forecast program over 30 years is $11,328,322 (Figure 4).

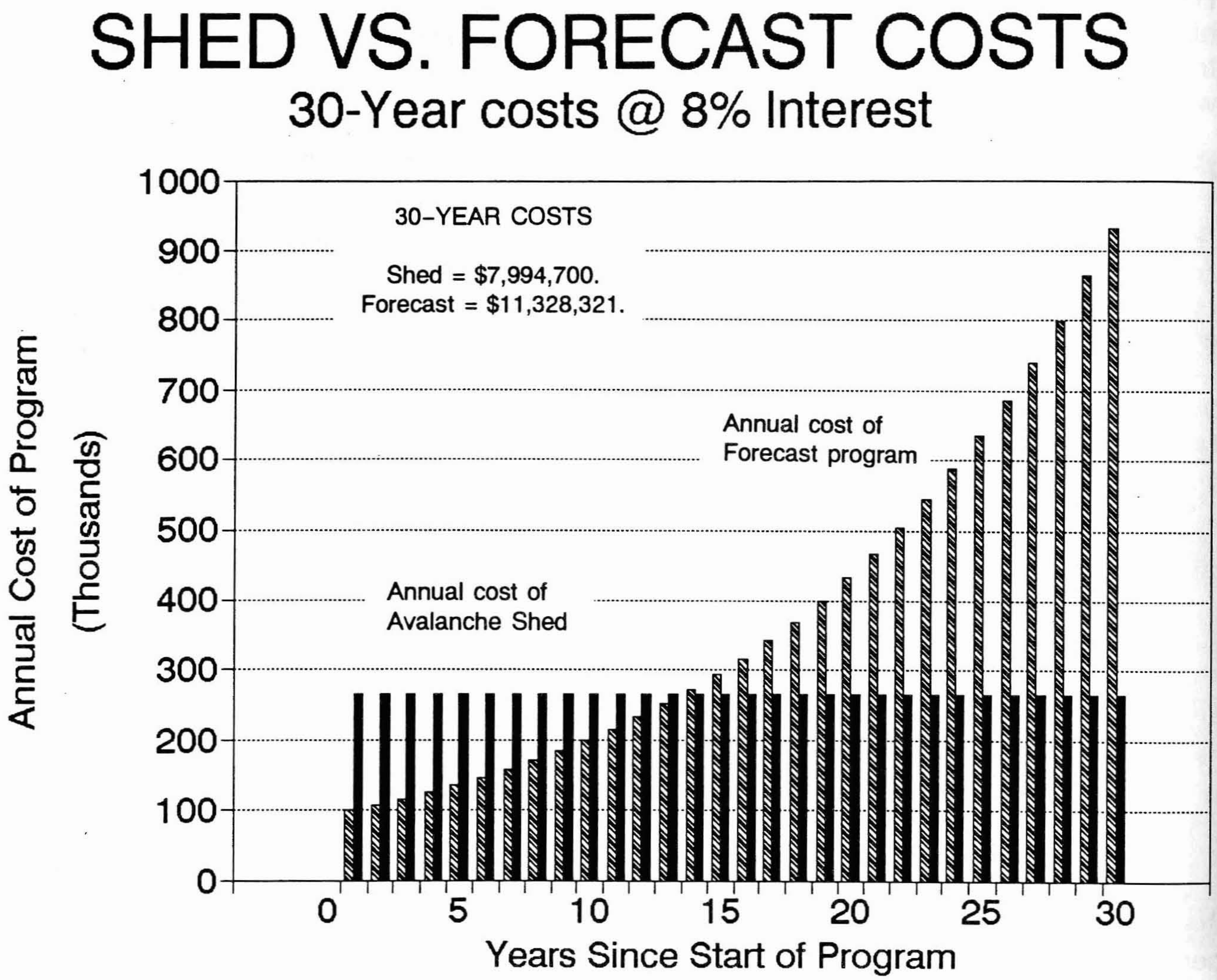

FIGURE 4. Comparative costs of an updated avalanche forecast program for Highway 550 vs. cost of a shed extension. Both costs assume an 8% interest rate (or 8% inflation rate) over a 30-year period. The annual capital recovery cost of a shed ($266,490) is shown as black bars; the forecast-program cost, assuming a $100,000 first-year cost, is cross hatched. Total shed cost over 30 years is $7,994,700; forecast cost over 30 years is $11,328,321. Therefore, over a 30-year period the forecast program costs 1.42 ($11,328.321/$7,994,700) times the shed cost. The forecast program, however, may provide about ten times the protection on Highway 550.

The effectiveness of an avalanche forecast program is also speculative. Forecasting is not a well-ordered science, but has been described as "a mix of deterministic treatment for snow and weather parameters and inductive logic to reach actual forecast decisions" (LaChapelle, 1980). Such a program is highly dependent on the skill of the forecaster, and the effectiveness of the communication with CDOT. A skilled forecaster, if given complete control over highway activities and all the data necessary to make a forecast may argue that the hazard could be reduced by as much as 90% over the current "no forecast" case. In contrast, some may argue that all the necessary data cannot be obtained, and that timely control and highway closure will rarely take place. Furthermore, the forecaster may misjudge conditions or possibly not be available when necessary. This person may argue that hazard can only be reduced by 10%. Most people would agree that the hazard reduction would be somewhere between 10% and 90%. As a reasonable compromise, I have assumed that a well-conducted forecast program will result in a 50% hazard reduction.

Shed and Forecast Programs Compared

The estimated costs and relative hazard reduction of an avalanche-shed extension and the proposed updated forecast program are compared in Table 1.

TABLE 1. Avalanche-Control Options:
Shed Extension and Forecast Program Compared

Control Option	30-Year Cost	Hazard Reduction	Unit Cost
Shed Extension	$7,994,700	5%	$1,598,940
Forecast Program	$11,328,321	50%	$226,566

Note: "Unit Cost" is cost *per percent* of hazard reduction.

Table 1 demonstrates that even though a forecast program is 1.42 times ($11,328,321/$7,994,700) more expensive than a shed extension, the "unit cost" of the forecast program is 7.06 times ($1,598,940/$226,566) more effective in reducing avalanche hazard over the *entire highway*. This 7.06 figure is qualitative, as discussed below. However, the forecast program would probably be less effective in reducing hazard at the East Riverside than over the remainder of the highway, because of the terrain complexities and other unpredictable aspects of the East Riverside path.

DISCUSSION

Uncertainties reduce the accuracy of the numbers presented in Table 1, and are discussed below:

a. The East Riverside may actually be more than "10–20%" of the highway avalanche hazard. The method used for calculating hazard (Armstrong, 1981; Schaerer, 1974) is somewhat subjective. The fact remains than all of the last six avalanche fatalities have been at the East Riverside.

b. The "hazard–reduction" estimates for the forecast program are clearly speculative.

c. The cost estimates provided in this paper may be incorrect.

The relative effectiveness of shed extension vs. forecast reliability was presented as numbers in this paper. The forecast program is shown, by simple calculations to be "7.06 times as effective" as a shed extension in reducing the overall hazard on Highway 550. Although it was presented in the form of a quantitative ratio, it must be interpreted as a qualitative assessment only. A more meaningful statement would be to say only that the forecast program would probably reduce avalanche hazard over the entire highway more than a shed extension at the East Riverside.

Many decisions made by Department of Transportations throughout the United States are based on engineering or economics considerations. In the example presented in this paper, the decision maker *knows* that six people have been killed at the East Riverside and *knows* that a shed will prevent a recurrence of avalanche deaths at this location. The decision maker may also assume that the shed will be designed according to the best available engineering principals and avalanche–dynamics analysis; appropriate safety factors will be applied and the structure is unlikely to fail. Furthermore, the public also knows that people have been killed at this location and will be aware that something "concrete" is being done at an obviously dangerous area.

The same decision maker may have only a limited understanding of the terrain, weather, and snowpack factors that contribute to avalanche hazard and may believe the forecasts to be speculative or inaccurate. The true effectiveness of a forecast program cannot be quantified, as discussed above. Furthermore, unlike a shed, a forecast program cannot be seen by the public. The public may feel that such a program is not working if even a single person is caught or killed by an avalanche.

CURRENT CDOT AVALANCHE–REDUCTION PLAN FOR HIGHWAY 550

As this paper is being written (September, 1992) the Colorado Department of Transportation is proceeding with both avalanche–control options discussed in this paper. The new avalanche–forecast program is intended to be in place for the 1992/93 winter.

Survey, geotechnical and civil engineering, and avalanche-loading analyses have begun on the shed extension with the hope of awarding a construction contract in 1993.

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