Avalanche Hazard Reduction for Transportation Corridors
Using Real-time Detection and Alarms

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ABSTRACT

Increased travel demand for safe, reliable winter travel on the alpine roads of the Western USA has resulted in an increased hazard to motorists and highway maintenance personnel from snow avalanches. Presented here are configurations for systems that can detect and provide, in real time, warnings to motorists and highway maintainers of the onset of avalanching onto the roadway. These warnings include; on-site traffic control signing and in-vehicle audio alarms for winter maintenance vehicles, as well as notification capability to maintenance facilities and/or centralized agency dispatchers. These Avalanche Detection and Warning Systems are capable of detecting an avalanche-in-progress and use the remaining *Time of Descent* of the avalanche to initiate the on-site alarms. Alternatively, real time knowledge and notification of the onset of avalanching may be used to proactively manage the evolving hazard over an affected length or corridor of highway. These corridors can be several 10's of kilometers in length and may, otherwise, be very remote, low volume rural highways. As a consequence, these systems must be cost effective alternatives to presently available avalanche hazard reduction technology used on highways. Results and experiences from the winters of 1997/98, 1998/99, and 1999/2000 are presented here. An assessment is made regarding the applicability of this technology for

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avalanche hazard reduction and a criteria for site selection for future deployments of such automated natural hazard reductions systems is discussed.

INTRODUCTION

There are a number of factors which, when combined are influencing the growth of avalanche hazard to motorists in North America. These factors include the rapid population growth in the coastal mountains and Rocky Mountain regions of the West. In addition, there continues to be a high demand for winter recreation access from both local and destination tourist populations. In most cases these winter recreationalists access the mountains in private vehicles. These numbers are not small. 8,000 to 12,000 average daily traffic (ADT) counts on narrow, steep mountain roads are common. Congestion is becoming an issue. The value of these activities has increased the requirement for safe, all weather mobility in these regions and is taxing the existing avalanche hazard management as practiced by the various State Transportation Departments (Decker and others, 1997).

Presently, the state of practice for managing avalanche hazards on the winter/alpine roads of the Western United States is avalanche hazard forecasting, often coupled with active control measures (explosive initiation of the avalanches) while the road is temporarily closed. Operations of this style are carried out on roadways in Alaska, California, Colorado, Idaho, Montana, Nevada, Utah, Washington, and Wyoming, as well as in Canada and Europe. This method of temporal avalanche hazard management does not mitigate or decrease the impact of the natural avalanche process, but only seeks to manage its timing and the public's exposure to it.

The method of natural hazard management reported here addresses a new paradigm. Traditionally, hazards such as snow avalanches have been mitigated through efforts to constrain the natural process with constructed works, often at great capital expense or, conversely, as noted above, temporally managing human exposure, while the avalanches are left to run its course. In addition, along rural transportation corridors with low traffic volumes these traditional methods of avalanche hazard reduction either naturally or by artificial initiation with explosives are often too costly to be feasible.

Hence, the goal of this research is to develop and test cost effective, knowledge based systems to assist in managing the hazard to the travelling public and state highway personnel on rural highways during periods when the potential for avalanches is high. This is achieved by monitoring the natural process in real time and responding proactively to the onset or release of an avalanche.

A knowledge based system for avalanche hazard management takes advantage of recent advances in sensor, data handling and automation technology to close roads that are either, one: have, within the last few moments, sustained avalanches onto the road or two: are in the act of avalanching onto the roadway below. The former method has become known as the Corridor Avalanche Management System for automated avalanche hazard reduction, whereas the latter has become known as the Time of Descent Avalanche Management System. The identification of an avalanche event in either the Corridor or Time of Descent Avalanche Management Systems can lead to the actuation of road closure gates and/or timely public and road agency information; including roadside message boards, in vehicle audio alarms, and maintenance and emergency agency notification (See Figures 1 and 2).

Current State of Avalanche Detection and Warning Systems

Avalanche detection systems are not unique. The first such domestic avalanche detection system was designed in the mid-1950's and implemented by Ed LaChappelle and Monty Atwater in Alta, Utah. The detection system consisted of trip wires (provides an on/off signal with the requirement that it be manual reset after an avalanche) placed in the avalanche path. The data was communicated via Radio Frequency (RF) telemetry to a stripped wall paper recorder, where personnel could monitor avalanche activity remotely (Personnel communication from with E. LaChappelle, 1998). This concept was further developed to prevent train derailments. These detection systems, implemented in Europe and Canada, consisted of wires along the tracks, which are broken, when snow or rocks hit the rails. Sensors have included cables with trip switches, radar, vibration, sound sensors, and photoelectric barriers (McClung and Schaerer, 1993). Many of these systems lack an automatic reset feature. Thus requiring personnel to enter the hazardous area when the avalanche hazard is high or greater. Railroad employees were required to reset or even rewire the system after every alarm. Recently, researchers and technicians in Switzerland have designed a remote avalanche warning system. This warning system consists of Doppler Radar, force measurements of cables, and geophones. Data is recorded in real time and is communicated automatically to warning lights and public phone systems (Gubler, 1996). At Rogers Pass, British Columbia, Canada, transportation officials are implementing an Avalanche Track Monitoring System (ATMS). This system provides real time monitoring of avalanche activity. The monitoring system is suspended from a cable tensioned between two fixed points on either side of the avalanche track. During the passage of an avalanche the ATMS is tilted and sends a signal, which is received by a radio or datalogger (Statham and others, 1996).

CORRIDOR AND TIME OF DESCENT AVALANCHE MANAGEMENT SYTEMS

Corridor Avalanche Management

The Canyon Creek section of Idaho State Highway 21 passes through a hazardous corridor consisting of numerous avalanche paths (See Figure 3). Fifty-six avalanche paths cross the highway in the 14-kilometer (9 miles) section between mileposts 96 and 105. The average frequency which any particular avalanche hits the highway ranges from 0.03 to 2.5 occurrences per year (Unpublished data from D. Bowles, 1988).

Travel along this corridor is hazardous to the motorist and especially maintenance section personnel. The Idaho Transportation Department (ITD) estimates a 0.20 probability that a moving car will be hit in any given year (Unpublished data from D. Bowles, 1988). Notwithstanding, SH 21 is a popular roadway, providing the most direct route between the winter recreation areas of Sun Valley, and Boise, the state capital and major population center, to the west. In addition it is the most direct route to Boise from the communities of east central Idaho. Historical traffic counts show an ADT of fifty-six vehicles per day during the six winter months (Decker and others, 1997). Highway maintenance and emergency management agencies are in need of near real time notification of the onset of the avalanche process in this remote corridor. There is neither electrical power or telephone service in this corridor. Presently, maintenance section personnel must patrol and monitor this hazardous section of roadway to learn of the onset of avalanching and if there is avalanche debris on the road. With this knowledge in hand, action to close the road may be taken. Maintenance crews must then travel the corridor under very high hazard and close the road manually.

The numerous avalanche paths effecting the SH 21 corridor require that the hazard of the entire corridor be addressed. However, the monitoring of all fifty-six-avalanche paths within the corridor by the installation of sensors at each avalanche track is cost prohibitive, especially when considering the relatively low ADT traffic volumes. Hence, installing avalanche event sensors at an avalanche path, which avalanches frequently, provides a level of confidence on the behavior of the remaining avalanche paths whose avalanche characteristics are indicative of the other, un-instrumented paths along the corridor. Of course, the addition of avalanche detection installations in additional avalanche paths would continue to increase the confidence level on the corridor as a whole.

A frequency analysis (Unpublished data from D. Bowles, 1988) of each avalanche path indicated several such potential “indicator” avalanche paths. With the assistance of local maintenance section personnel the avalanche path at milepost 96.92 was chosen in 1996 as the best indicator of eminent avalanche activity along the entire corridor. The frequency of avalanche path 96.92 is 2.5/year.

The avalanche path at 96.92 drops 255 vertical meters at a consistent 36-degree slope. The starting zone has an East-Northeast aspect, and includes an area of 1.4 hectares. A typical avalanche from this path entrains 4,200 cubic meters of snow, burying 18.5 meters of highway 4.5 meters deep (Decker and others, 1997).

Ten meters above the roadway, in the avalanche path, a 1.91 cm in diameter cable is strung across the avalanche path, about 2.5 meters above the ground, anchored to steel posts imbedded in concrete. Hanging from the cable is three weighted wire ropes. On these wire ropes sensors are attached. The sensors are tilt switches, epoxied inside galvanized steel pipes. The impact of an avalanche causes the steel pipe to pivot and coupled with the dynamic motion of the wire rope causes the tilt switch to reach an angle of 90 degrees, thereby closing the circuit. Data produced by the sensors is stored and logged by a datalogger/controller. The datalogger/controller contains a program that identifies threshold values indicative of the tilt switch closures. When these threshold values are met or exceeded the datalogger/controller can potentially initiate a call, via radio telemetry to an ITD central dispatch office in Boise and maintenance facility in Lowman (~45 miles to the west) advising of the onset of avalanching in the Canyon Creek corridor. When this information is relayed to maintenance personnel they can initiate timely inspection, closure and/or rescue on the highway.

In the summer of 1998 a second avalanche path at mile maker 100, on Idaho SH 21, was identified as an additional site for avalanche detection sensors. The avalanche path at mile maker 100 drops 1,820 vertical meters at a consistent 34-degrees. The starting zone has a Southeast aspect, and includes an area of 13.0 hectares. The resulting avalanche affects 61 meters of highway. The frequency of avalanche path 100 is 1.5/year (Unpublished data from D. Bowles, 1988).

Sensors and data acquisition systems were installed at mile maker 100 in the fall of 1998. The system is identical to the site at 96.92, however, six sensors monitor avalanche path 100, as opposed to three at mile maker 96.92.

The Corridor Avalanche Management System provides ITD maintenance personnel the ability to monitor, in real time, the avalanche conditions in Canyon Creek. Hence, allowing for a more efficient and safe management of winter maintenance manpower and equipment resources over the entire SH 21 corridor, as opposed to concentrating a significant amount of time and manpower on the relatively short section of roadway affected by avalanche hazard. In addition, this system has the potential to limit the exposure of maintenance workers and road users to the avalanche hazard.

Time of Descent Avalanche Management

14 Kilometers (9 miles) south of Jackson, Wyoming in Hoback Canyon along US Highway 189 is Cow of the Woods, an avalanche path with a consistent 35-degree slope and a north aspect. This avalanche path creates a hazard to the travelling public (Figure 7), but more specifically to the Wyoming Transportation Department (WyDOT) removing avalanche debris. Cow of the Woods has a return period of ~12.0/year (WyDOT record books). Due to the fact that the Cow of the Woods avalanche path has multiple and separate starting zones, it is possible for it to avalanche several times during a single winter storm cycle. WyDOT maintenance personnel have been struck by avalanches while cleaning debris off the highway from recent, previous avalanche.

The Time of Descent Avalanche Management System is designed to detect an avalanche in progress while instantaneously triggering an alarm system to warn travelers via flasher lighted road signs and maintenance personnel via audio in-vehicle alarms of the onset of an avalanche. This system has a unique characteristic that it alarms the drivers in their trucks in real time, hence providing them with a ~10-12 second warning prior the arrival of the avalanche at the roadway.

Of importance to the success of this system is the location of the sensors. The sensors must be located to detect avalanche events that will effect the highway. If the sensors are placed too high in the avalanche track, the signal and alarms will be activated for avalanches that do not reach the highway. Also, sensors located too low in the avalanche track present a timing issue (lights and alarms being activated without sufficient warning time).

The locations of the sensors are dependent on location(s) of the avalanche starting zones and the velocity of the avalanche at a specified point in the avalanche track. The mass centered velocity (Voellmy, 1955) of the Cow of the Woods avalanche is estimated at 45.0 $\frac{m}{s}$. With the avalanche detection systems located at 300 meters above Highway 189, this allows a ~10 second warning prior to an arrival of an avalanche at the highway.

The avalanche detection system is similar to the system located on SH 21 in Idaho. A datalogger/controller continuously monitor four sensors located in the avalanche track. When the datalogger/controller recognizes an avalanche, the datalogger/controller turns on a radio. The radio transmits a modulated tone to initiate the flashers at the road signs that advise motorists and to the alarm boxes located in maintenance vehicles. At the signs and audio alarms a tone decoder circuit deciphers the tone and turns on power to the sign lights, warning travelers of an avalanche, and sets off a 97 dB siren in WyDOT maintenance vehicles that may be working under the Cow of the Woods avalanche path.

Maintenance vehicles at risk include, primarily, rotary snowplows and front-end loaders being used to clean-up avalanche debris. When the siren sounds maintenance workers have ~10 seconds to move 30 meters (100 ft.) laterally along the roadway and out of the direct path of the on-coming avalanche. The maintenance vehicle alarm boxes are sufficiently portable that they can be easily moved from vehicle to vehicle. The motorist notification signs are located 400 meters (1300 ft.), in both directions, from the affected portion of roadway.

Geophones

Coupled with the sensors at the Cow of the Woods is the preliminary testing of geophones for their potential to serve as avalanche detection sensors. Geophones have the advantage of being non-invasive sensors. It is not necessary for them to be in the flow of an avalanche. In addition, they may be deployed at sites where the avalanche is not highly channelized. Past testing of geophones to detect avalanches is abundant (Saint Lawrence and

Williams, 1976 and Leprettre and others, 1996), yet it has been difficult to reliably determine the signal source, i.e. seismic activity, avalanche, etc., of a signal on a real time basis.

At Cow of the Woods on US 189 two geophones are placed 30 and 60 meters below the existing sensors. The geophones installed in Wyoming are event triggered. Event triggering eliminates the ambiguity between avalanche and non-avalanche events during this experimental phase. The application of two geophones installed parallel to the avalanche track allow for a time lag between the arrival of the avalanche waveform at geophone 1 and then at geophone 2 further downhill. The time lag in the waveform provides information on the velocity of the avalanche and as well as providing distinguishing characteristics between avalanches and a non-avalanche events.

Once the sensors that are in the avalanche flow are activated, the datalogger simultaneously samples the geophones at 20 Hz for 300 scans per geophone.

RESULTS

Corridor Avalanche Management SH 21-Canyon Creek (1997/98)

The first season of operation of the Corridor Avalanche Management System occurred during the winter of 1997/98. Data was recorded at avalanche path 96.92. In March 1998 the data was manually downloaded and analyzed for completeness and accuracy. Figure 5 represents the results from sensor 1 for the winter of 1997/98. The results from sensors 2 and 3 are identical to sensor 1. When the signal in Figure 5 reaches 0 volts the circuit is closed by the sensor reaching an angle of 90 degrees by an avalanche impacting the sensor. Since the sensor never reached 0 volts, no avalanches were recorded. These results correspond to observations made at slide path 96.92, along the Canyon Creek corridor, by ITD maintenance personnel. The winter season of 1997/98 was mild with a Snow Water Equivalent (SWE) measuring 85% of average. However, numerous avalanches from other none sensored avalanche paths effected the highway.

Corridor Avalanche Management SH 21-Canyon Creek (1998/99)

Two sites were monitored for avalanche activity during the second season of operation along the SH 21 corridor. Avalanche paths 96.92 and 100 were operational by November 1998. Data for the 1998/99 season was downloaded manually via a site visit.

1998/99-winter season recorded a SWE of 120% of average at Banner Summit. Numerous avalanches were reported at paths 96.92 and 100. These avalanches occurred during periods when SH 21 was already closed by ITD personnel.

In March the data was manually downloaded from avalanche path 100. The data was analyzed for completeness and accuracy. Figure 6 represent graphical a typical data set for the 1998/99-winter season at avalanche path 100. A spike of 2.0 to 2.5 volts in Figure 6 represents the sensor reaching an angle of 90 degrees from plum, thereby indicating the possibility of an avalanche. The sensors at slide path 100 were redesigned to eliminate the noise associated with the data sets as represented in Figure 5 at avalanche 96.92.

The Corridor Avalanche Management System in Idaho is operational for the winter 1999/2000. However, no data sets are available at the time of writing. *This data will be added prior to the May meeting in Austria.*

Time of Descent Avalanche Management (1998/1999)

The sensors and maintenance in-vehicle audio alarm boxes for Cow of the Woods avalanche were operational by December 1998. The motorist flasher warning lights along Highway 189 were operational by February 1999.

During the 1998/99-winter season WyDOT personnel observed avalanches between January, February, and April. These avalanches were naturally and artificially initiated. Figures 7 graphical represent a data set recorded by the datalogger from February–April 1999. A spike of 2.0 to 2.5 volts represents events. The event recorded by sensor 2 in Figure 7 on April 7, 1999 was initiated by manual excitation of the sensors by W/AEL personnel. The event of April 18, 1999 was an avalanche artificially released by WyDOT avalanche crews using artillery.

Geophones

The pair of phase lagged geophones recorded one event during the 1998/1999-winter season. This was the avalanche in Cow of the Woods of April 18, 1999. Figure 8 represents the geophone data set recorded by the datalogger with evidence of a time lag between the two waveforms in Figure 8. This geophone data gathering was triggered by the other avalanche detection sensors and hence corresponds with the exact time and date of the avalanche recorded by the datalogger and WyDOT maintenance personnel performing avalanche control work on April 18, 1999. Geophones 1 and 2 are located 30 and 60 meters, respectively, below the line of avalanche detection sensors.

Time of Descent Avalanche Management (1999/2000)

The system was operational by December 1999. The sensors at the Cow of the Woods avalanche path recorded three events during a January 2000 storm cycle. These three events are recorded in Table 2 and represented graphical in Figure 9. The first event was a natural avalanche that hit the road. The lights were activated at the roadway. WyDOT maintenance crews were notified and road clearance operations were initiated. The second and third event on January 11 and 12, 2000 was a false negative (an avalanche that reached the roadway without triggering flasher lighted road signs and/or in vehicle audio alarm boxes) and a false positive (an event, other than an avalanche, that triggered flasher lighted road signs and/or in vehicle audio alarm boxes). *Additional 1999/00 data will be added prior to the May meeting in Austria.*

DISCUSSION

Corridor Avalanche Management SH 21-Canyon Creek (1997/98)

The results from avalanche path 96.92 indicate the sensors and the datalogger/controller were operational, except during a four-week period in November/December. The sensor values in Figure 5 range between 0.5 and 2.5 volts (The drift in the signal is associated with the position of the mercury switch in the galvanized steel pipe. This problem is corrected by repositioning the mercury switch to read 2.0 to 2.5 volts for an event. These corrections were made to the sensors at avalanche path 100 on SH 21 and Cow of the Woods in Wyoming. Neither configuration is fail safe, but data interpretation becomes less confusing when identifying events.). Therefore, no avalanche or false alarms were recorded at the remote site. When the sensors record a reading of 0.0 an event has occurred. This is indicative of the sensor reaching an angle of 90 degrees and a completed circuit in the sensor. These findings collaborate with ITD observations of avalanche path 96.92 during the winter of 1997/98.

Corridor Avalanche Management SH 21-Canyon Creek (1998/99)

The Corridor Avalanche Management System at avalanche path 100 was operational and the data set is accurate and complete. Nine events were recorded during the 1998/99 season (See Table 1). These nine events, also, correspond graphical to the spikes in Figure 6. The events at avalanche path 100 along the SH 21 corridor occurred between January and March 1999. Since the SH 21 was closed between January 14, 1999 and February 26, 1999 no direct observations by ITD maintenance personnel of avalanches were confirmed. ITD maintenance personnel estimate that four avalanches reached the highway. This estimate is based on an examination of the various layering of avalanche debris during snow removal operations in March.

Upon examination of weather data obtained from ITD personnel and Snotel (a remote measuring device used by the Natural Resource and Conservation Service (NRCS) to measure snow water equivalent of snow, for forecasting river runoff.) data from Banner Summit along the Canyon Creek corridor, weather and avalanches can be correlated. ITD personnel made snow observations at mile marker 95.50 (elevation 1670 meters) and Snotel data was obtained from the NRCS-Idaho for Banner Summit (elevation 2100 meters).

The authors verified the event on March 20, 1999 as an avalanche. On March 24, during a site visit, sensor 1 was observed in the toe of the avalanche debris. The March 20 event did not reach SH 21. A wet avalanche occurred between 1300 and 1400 hours during a warming trend with the temperature reaching 19.2^{o} C at Banner Summit. This temperature on March 20 and the warm temperatures preceding this date are indicative of conditions leading to wet avalanche activity at this site. Also, to test the system, the authors triggered sensor 1 manually on March 24, 1999. The remaining events are speculative, but they correlate well with weather events that are likely precursors to avalanches.

Currently, ITD personnel use this data and information from the two sensored avalanche paths to judge their timing on road closures with the onset of avalanches at slide paths 96.92 and 100.

Time of Descent Avalanche Management (1998/1999)

The results from Hoback Canyon indicate that the system was operational during the 1998/99-winter season. Based on observations by WyDOT personnel, the system performed as expected. Since motorist flasher lights on the sign and/or vehicle audio alarm boxes were triggered, the sensors were operable.

During the 1998/99 season, the WyDOT personnel recorded four events. Of the four events, there were two successful avalanche detection events, one false alarm, and 1 unsuccessful avalanche detection event. The unsuccessful avalanche detection was a result of the avalanche starting below the sensor line. These events are recorded in Table 2.

Geophones

The geophone data in Figure 8 was analyzed using the following cross–correlation routine:

$$R_{xy} = x(t) \otimes y(t) = \int_{-\infty}^{\infty} x(t)\, y(t + t)\, dt \qquad (2)$$

where:

t=time.

τ=time delay between geophones.

This analysis technique finds the average time delay between two signals/waveforms (Geophone 1 and 2) in Figure 8. The cross correlation technique yielded an average velocity of the avalanche on April 18, 1999 of 19 $\frac{m}{s}$.

The significance of capturing an avalanche event on multi geophones parallel to the avalanche track is the potential to replace the existing avalanche detection infrastructure with a non-invasive sensors that does not need to be impacted by the avalanche flow. By continually sampling geophone data via an on-site CPU, threshold and cross correlation routines can monitor waveforms, in real time, for single or multiple avalanche path(s) and distinguish an avalanche from other natural or manmade energy sources. Also, velocities, via cross correlation, can be used to determine whether or not the avalanche will reach the roadway based on characteristics of the avalanche path.

Continued collection of geophone events is essential to further analysis of threshold and velocity values for event triggering. This one event is just a sample for the potential of such an analysis and future detection system.

Time of Descent Avalanche Management (1999/2000)

The early season results at the Cow of the Woods avalanche path indicate the system was operational and was functioning adequately. The first event on January 11, 2000 captured the avalanche event and via road signs warned on-coming traffic of roadway avalanche debris. Since WyDOT maintenance crews were not present in Hoback Canyon the in vehicle alarm boxes were not tested. The second event captured by the detection system was a false negative. The avalanche reached the roadway, depositing 0.15 meters of debris on the highway. WyDOT maintenance crews were unable to identify whether the avalanche initiated above or below the sensors due to poor visibility. Also, the possibility exists that the avalanche traveled underneath the sensors, due to the wet nature and volume of the debris on the road. The third triggered event was a false positive. Again, due to poor visibility, WyDOT maintenance crews suspect high winds triggered this event. Wind speeds at the time of the false positive were recorded at ~ 27 $\frac{m}{s}$.

SUMMARY

There are two distinct modes in which automation of avalanche hazard management may be implemented. If an entire transportation corridor is at risk from avalanches, then knowledge of the onset of avalanching can be used to close the hazardous corridor in a timely fashion and assess the need (or lack of) to initiate rescue. Conversely, if the time of descent of avalanches is long, then the relatively short section of roadway that may be effected is closed with motorist warning signs or other traffic control facilities such as automated closure gates.

The results of this investigation indicate that knowledge based avalanche hazard reduction and management systems have the potential to improve safety for highway maintenance personnel and motorists in rural, often low volume, winter/alpine transportation corridors. These improvements may be realized if highway maintainers and emergency response personnel can make timely responses to avalanches hazard or the onset of avalanching as a consequence of having deployed knowledge based avalanche detection and alarm systems.

There will be a continuing need to improve the robustness and reliability of the field deployment hardware and communication interfaces of these systems. In addition, successful avalanche hazard reduction, using knowledge based systems, will also require that local highway maintenance personnel and emergency response agencies plan for, coordinate, and de-brief their experiences with this technology. These latter efforts will assure that there is a basis for training and optimizing, with respect to highway and emergency management agency, response to avalanche detection and alarms from knowledge based avalanche hazard reduction and management systems.

Corridor and Time of Descent Avalanche Management Systems couple with and compliment the present method of avalanche hazard reduction as practiced in North America; avalanche forecasting and active control with explosives. With further research and modifications, these new, innovative, and cost effective systems will improve the winter travelling safety of rural highway corridors.

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Tables and Figures

Tables

Date	Time	Sensor #1	Sensor #2	Sensor #3	Sensor #4	Sensor #5
1/23/99	0200	X				
2/7/99	1200	X	X	X		
2/17/99	0500		X	X		
2/17/99	0800	X		X		
2/19/99	0600		X			
2/24/99	1400		X			
3/12/99	1100			X		X
3/20/99	1400	X				
3/25/99	1300	X				

Table 1 Sensor events at avalanche path 100 SH 21, Idaho (1998/99).

Tables and Figures (continued)

Date	Sensor Triggered	Avalanche	Artificial or Natural Release	Weather
January 15, 1999	X	-	-	Windy
January 20, 1999	-	X	N	Snow
January 21, 1999	X	X	A	-
February 2, 1999	X	X	N	Snow
April 18, 1999	X	X	A	Clear
January 11, 2000	X	X	N	Snow
January 11, 2000	-	X	N	Snow
January 12, 2000	X	-	-	Snow/Windy

Table 2 Sensor events observed by WyDOT personnel in Hoback Canyon, Wyoming, US Highway 189, 1999/2000.

<u>Figures</u>

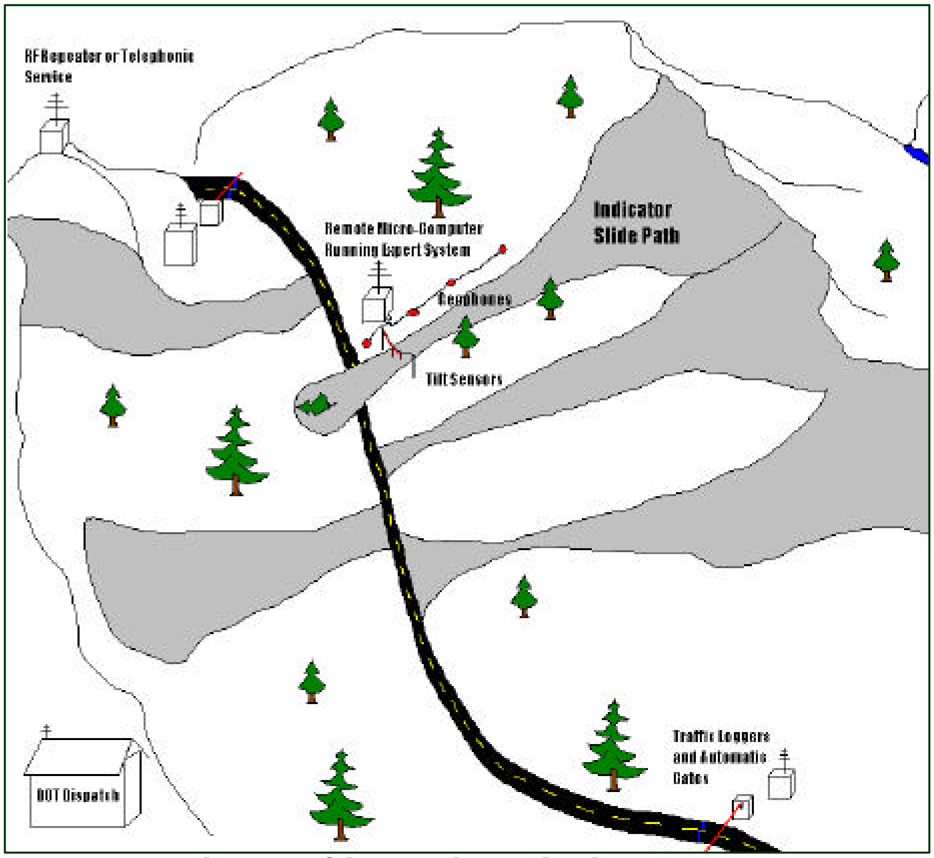

Figure 1 Schematic of the Corridor Avalanche Management System.

Tables and Figures (continued)

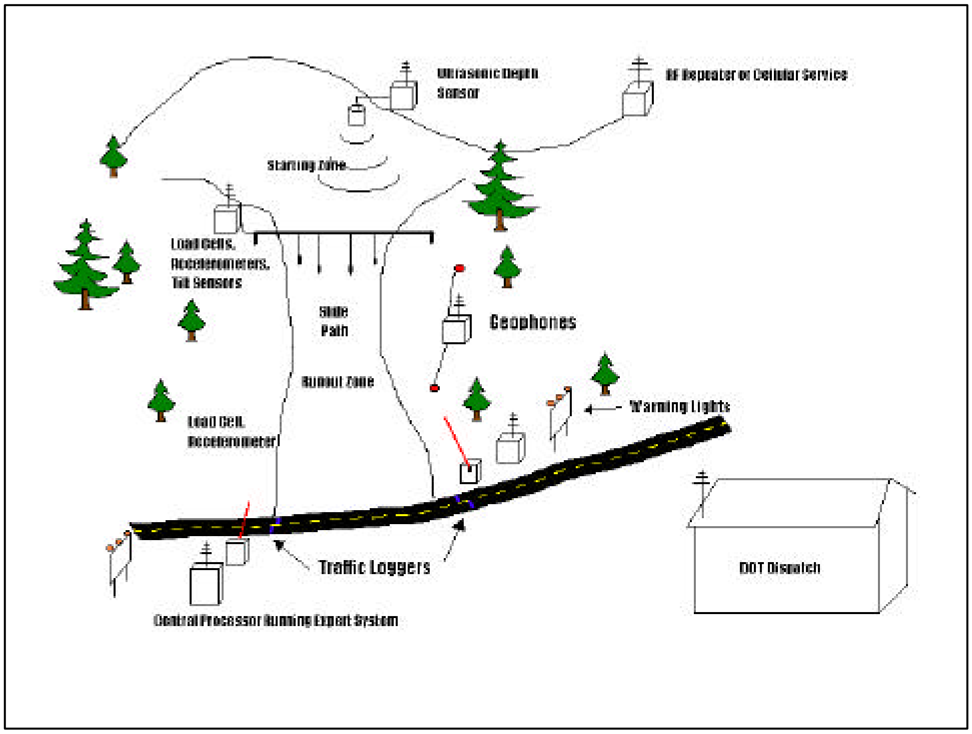

Figure 2 Schematic of the Time of Descent Avalanche Management System.

Figure 3 Aerial view of Canyon Creek section of SH 21, Idaho.

Tables and Figures (continued)

Figure 4 Vehicle travelling underneath Cow of the Woods, US Highway 189, Wyoming.

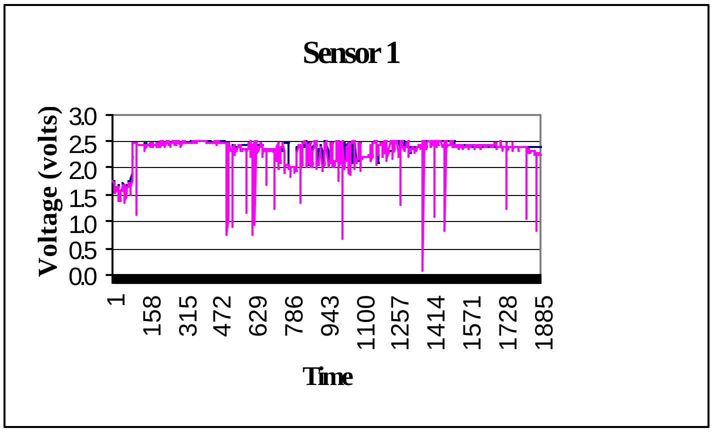

Figure 5 Voltage-Time History from 1997/98 SH 21, Idaho-avalanche path 96.92 sensor 1.

Tables and Figures (continued)

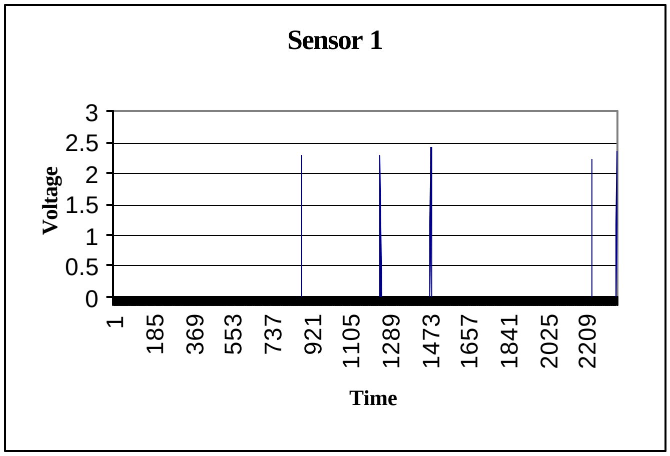

Figure 6 Voltage-Time History from 1998/99 SH 21, Idaho-avalanche path 100 sensor.

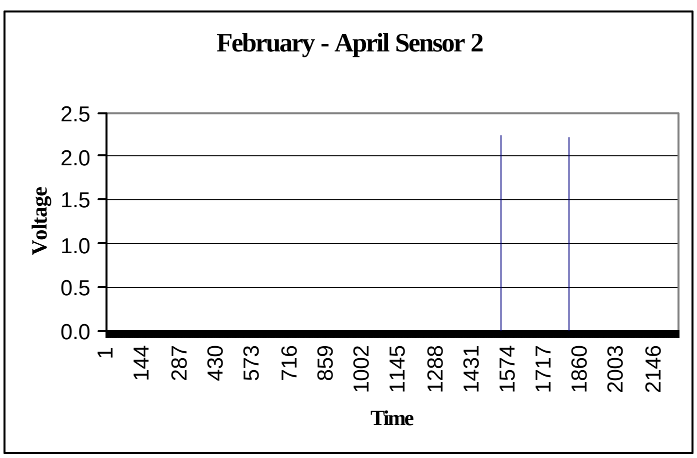

Figure 7 Voltage-Time History from 1999 US Highway 189, Wyoming sensor 2.

Tables and Figures (continued)

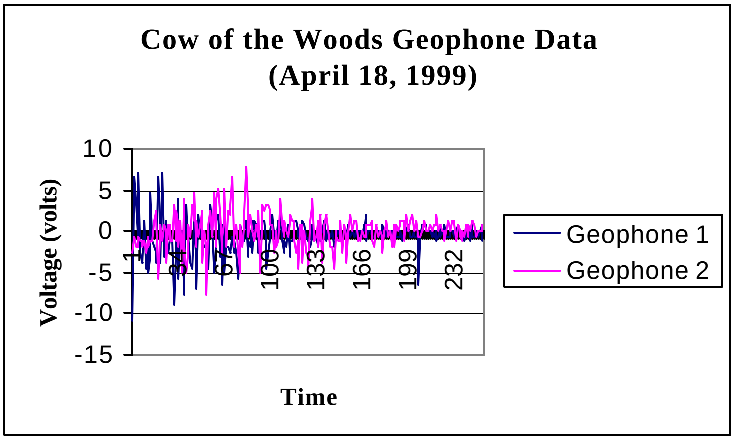

Figure 8 Geophone waveforms recorded April 18, 1999, US Highway 189, Wyoming.

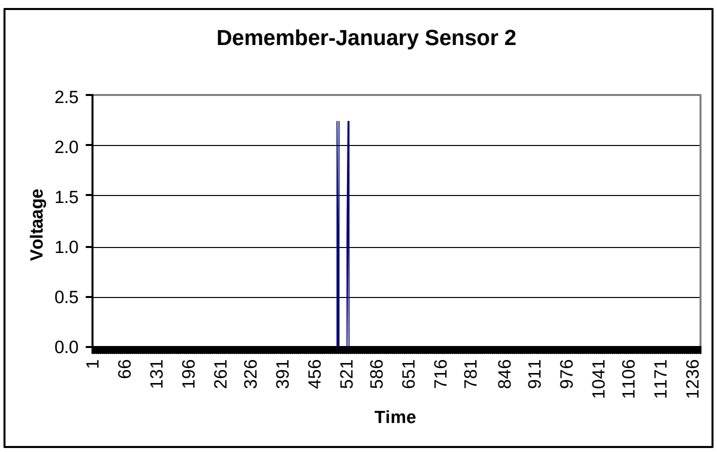

Figure 9 Voltage-Time History from 1999/2000 US Highway 189 Cow of the Woods, Wyoming sensor 2.