# ADVANCED TECHNOLOGIES IN AVALANCHE PROGRAMS

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Abstract

Abstract: Between 1985 and 2000, the Alaska Railroad operated a conventional avalanche risk mitigation program which relied heavily on artillery based risk mitigation and observer-based forecasting. In spite of these methods, occasional close calls continued that spoke of the need to augment the existing system with more advanced technologies. The winter of 2000 brought unusually large storm events, during which unforeseen events occurred with catastrophic results. This proved to be the impetus for the investment of almost $3,000,000 in more advanced systems for avalanche risk mitigation. New systems for gathering and dissemination of weather parameters, deployment of explosives, management of data, and avalanche detection were deployed in the field.

This paper describes the underlying problems with avalanche risk mitigation in the railroad corridor, and discusses the rationale behind introducing different kinds of technologies to solve issues. Also discussed are the pros and cons of different technologies and the lessons learned from applying advanced technologies to an existing program. Budgetary considerations are also provided.

KEYWORDS: avalanche, avalanche guard, detection, risk, mitigation, data management

## 1. INTRODUCTION

The Alaska Railroad (ARR) runs for 160 km. through the Chugach Range south and east of Anchorage, Alaska in an avalanche prone corridor. Along this route, a total of 40 avalanche paths impact the railroad in varying frequencies. All are large avalanche paths. Earlier work has identified the frequency and magnitude relationship of natural avalanches occurring on this corridor (Hamre, McCarty 1996).

Following the implementation of explosives based avalanche mitigation in 1986, avalanche risk was reduced substantially along the corridor. However, occasional close calls continued to occur during the following years. This ratio of close calls resulted in a proposed program to invest in more advanced technology in order to generate more risk reduction and reduce the incident rate. This program was in its infancy when a large storm cycle intervened in February of 2000. The resulting impacts, including the loss of a worker in a post-control release incident, accelerated the time table for project implementation.

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The following pages document the changes that have occurred in the avalanche program, along with lessons learned from this process.

## 2. PROGRAM STRATEGIES

### *2.1. Goals and Objectives*

The intent of program upgrades was to reduce risk by the application of technology without adding more avalanche personnel. This was to be done by making improvements in numerous work categories including forecasting, explosives application, detection, modification of equipment, and training. It was felt that, on a combined basis, these efforts would yield substantial positive results.

### *2.2 Improved Forecasting and Data Management*

Prior to 2000, the majority of weather information was gathered through manual observations. This required participation from observers, which proved difficult to accomplish on a consistent basis. Additionally, information from other agencies such as Alyeska Resort (ALY) and Alaska Department of Transportation (ADOT) was gathered, but disseminated only through phone calls.

Improved tracking of weather variables in such a large program area would likely lead to better focus for explosives based mitigation efforts. For that reason an expanded and improved network of weather stations would assist the avalanche forecasters. Additionally, there was a need to gather and store automated weather data in a format that was accessible to other agencies. The project settled on installing or upgrading a total of 10 weather stations. These were to be linked to a server that would poll the stations and provide the software base for observations. Most of these weather stations were installed and operated using commercial systems widely used by the avalanche field. The unique aspects involved the installation of an avalanche server with avalanche specific software, and an experimental weather station designed to counteract riming conditions in a remote location.

*2.3. Improved explosives delivery*

For 40km.of the program area the ARR and Seward Highway run parallel to each other and are affected by common avalanche paths. Their respective corridors diverge for the remainder, with each corridor being affected by a significant number of large avalanche paths. Both transportation systems require the ability to move up and down the corridor in order to provide effective explosives mitigation efforts. This ability to move is increasingly compromised in large storms as avalanche events begin to affect the corridor and cleanup efforts delay moving to the next firing position. As a result, it is difficult to make progress down the corridor quickly and to keep avalanche sizes small enough that they don't affect the transportation systems.

An attendant issue is that any natural avalanches reaching the corridor are considered a close call or incident that represents risk and should be avoided. The ability to keep avalanche sizes small accomplishes this goal. In order to accomplish this, investments were needed in systems that would speed up the process of explosives delivery. Installation of several new mobile firing platforms as well as two new fixed platforms with howitzers was chosen as the most favorable option for accomplishing this goal. Additionally, an Avalanche Guard system was installed on an extremely remote, high frequency avalanche path.

*2.4. Detection systems*

Fully loaded freight trains running at high speeds have stopping distances of up to 2km. As a result, a significant risk is presented by a train traveling at full speed running into avalanche debris from a previous avalanche. Several accidents have occurred prior to 1980 on the ARR from encounters with avalanche debris. For that reason, many railroads have detection systems for rockfall and avalanches that consists of trip wires strung across the runout zone and connected to standard train signals. The ARR has no train signals so this type of system would be quite expensive to install. Additionally, there is avalanche risk to personnel in maintaining these types of systems since the wires must be re-set every time avalanches occur.

The potential risk identified above is thought to be significantly higher than the potential for a train to get hit by a moving avalanche. Accordingly, the ARR has a system where each avalanche path has a "slide zone" designation that is turned on or off depending on avalanche risk. When there is a possibility of an avalanche on a given path, the slide zone designation is put into effect. Under operating rules, trains must slow down to 7 m./s. while traveling through these zones until the way is seen to be clear. While this substantially reduces the risk of running into an avalanche that has already occurred, it increases the probability that a train will be hit by a moving avalanche. The ability to detect avalanches in an alternative way was needed in order to resolve this risk conflict.

To satisfy this need, an avalanche detection system was installed. This system has been discussed in previous literature (Gubler, 2000) and used in Europe extensively. The ARR installation was the first in North America and presented unique operating challenges with it's proximity to an arctic coastline and frequent earthquakes.

*2.5. Equipment modification*

A considerable portion of avalanche risk on the ARR is presented by the necessity of cleaning up high volume deposits of avalanche debris from the tracks and adjacent highway. While conventional safeguards have

been in place since the programs inception, they were not adequate to prevent an accident during the high speed post-control release incident of 2000. Among other commitments to providing improved safety margins, a commitment was made to design a protective cab for cleanup equipment that would yield much higher impact resistance. This project resulted in a fleet of four D-6 and D-7 bulldozers with strengthened cab parts.

*2.6. Training*

Conducting avalanche operations in a seniority based, union manpower environment has a number of challenges. With a bid and bump system it is difficult to keep personnel in a given location all winter. Given a large and mobile workforce, there is difficulty ensuring that everyone is appropriately trained. There is also the need to ensure sufficiently trained gun crews and observers to ensure that avalanche operations go smoothly. A need to stabilize and train manpower resources was thus identified.

## 3. IMPLEMENTATION AND RESULTS

*3.1. Forecasting and Data Management*

In Europe there are a number of different systems in use with the capability of managing complex avalanche data. Unfortunately, none of these are written in English. In North America, similar initiatives are not as complete. One of the more promising English language software packages available is STROV (Howlett, Trover 1998), with its roots in Little Cottonwood Canyon, Utah. While this software has been under development for a long period of time, it had always been used as a single client program. Program funds were used to develop this software into a multi-agency data base where ARR, ALY, and ADOT all had interfaces. Additionally, server software was developed to supplement the original client based software in order to have the capability of storing data on a more robust platform, and to achieve the required elements of data exchange.

As with any developmental program, the evolvement of STROV has been challenging. The current program allows the described data exchanges as well as providing the format for explosives tracking and inventory, weapons usage tracking, weapons personnel tracking, and documentation of firing missions. It automatically publishes all the incoming weather data to the external web on an hourly basis. Figure 1, following page, shows the entry screen interface.

All avalanche related programs are now stored on the avalanche server. This system has dual processors and mirrored hard drives in order to reduce the possibility of system failures. It simultaneously runs the STROV program and the avalanche detection program, both of which utilize a common Loggernet interface with communications systems. With a combination of fiber, hard wire, and Free-wave radios, all the remote facilities are routed to report into the avalanche server. Users with client software are connected to the avalanche server with virtual private network (VPN) software which allows access to the data base. Both software developers have higher level VPN access which allows them to control the server from their remote locations in order to modify software, troubleshoot, or provide training without the expense of traveling to the site.

Efforts have also been made to perfect the old data base in the system. Names and locations can change over time. Each of the three agencies reviewed and perfected their old data bases, with an eye to making the data compatible with future GIS efforts. This will allow for easy implementation of GIS based forecasting schemes in the future.

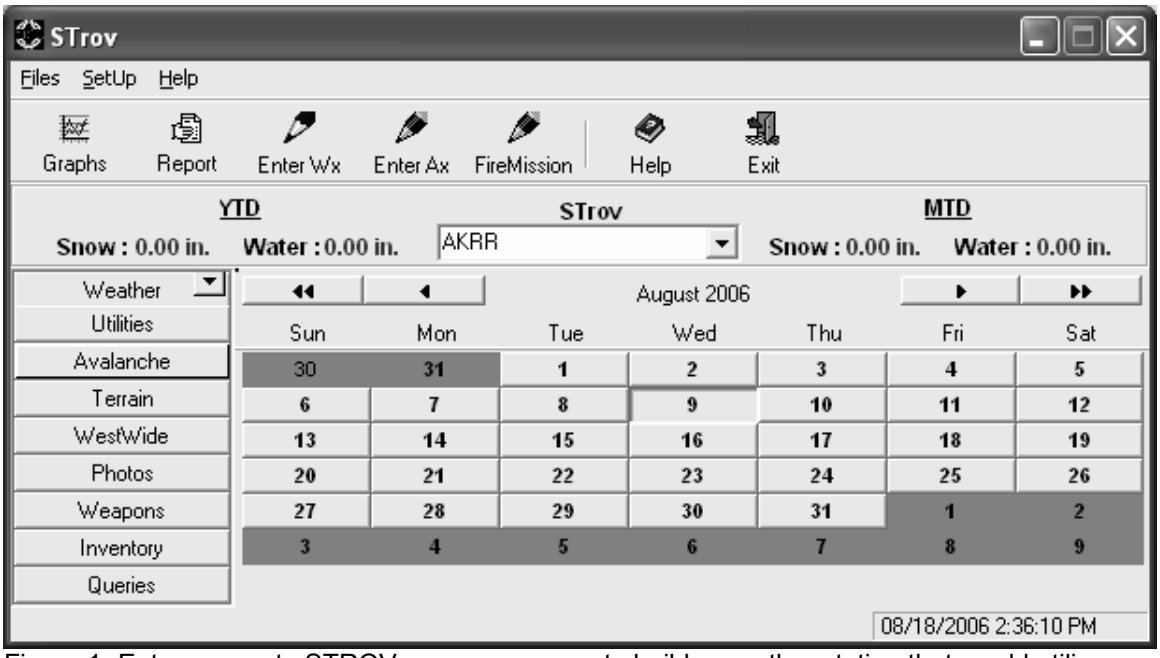


Figure 1- Entry screen to STROV program

Implementation of the STROV program in daily procedures has taken some time to accomplish. Initial programming glitches needed to be worked on. There is resistance to change in old-line forecasters. Through cooperative efforts, the software has come much closer to being bug free and the three users continue to rely more heavily on the STROV software as the base for their data management needs.

One other element of forecasting was the need to analyze free wind direction. As with any coastal mountain range, the Chugach Range has significant orographic effects. Wind direction is critical to the resulting pattern of precipitation deposits. Given it's proximity to the coast, the range suffers from heavy riming on virtually every storm.

Numerous schemes have been devised over time in order to defeat rime on anemometers. The only truly successful system known to the author is the heated Taylor anemometer. This system requires a constant power source of approximately 2,000 watts. An alternative is needed that has relatively low fuel usage, and low maintenance costs. Generators required for the Taylor system require periodic and expensive maintenance.

As an attempt to solve this problem in a different way, the program manager decided to build a weather station that would utilize a different heat source. Powering remote weather stations in Alaska is very difficult in the heart of the winter due to short daylight hours and lack of sunshine for solar systems. Typical installations require careful calculations of energy balance, large panels, and even larger battery banks to supply just a data logger and radio. Any additional heat was unlikely through solar sources. On another project in Alaska, Thermal Electric Generators (TEG) (Figure 2) have been used successfully.

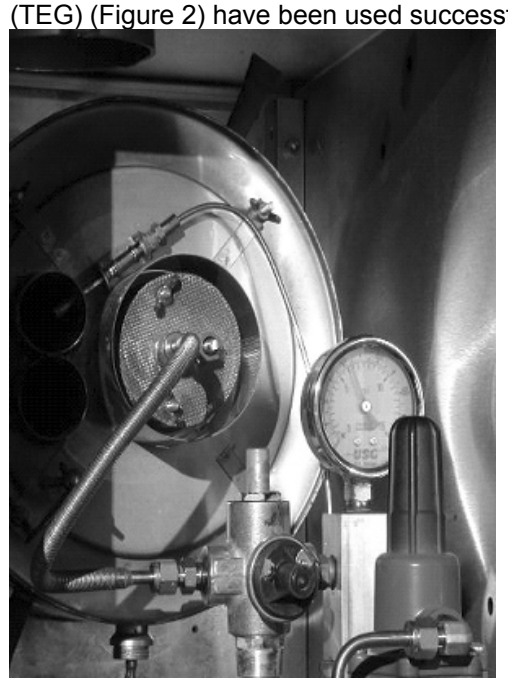


Figure 2- Thermal Electric Generator

TEG's use a bi-metallic structure heated by a propane flame to generate electricity. There are no moving parts, so maintenance requirements are very low. An additional benefit is that a TEG producing 100 Watts at 12 v. also produces 6,000 BTU of waste heat that can be captured through a device called a Power Environmental Module (PEM). This waste heat is then used to heat the inside of a small shelter and subsequently pumped by fan up the middle of an insulated 45 Cm diameter tower, exiting through two Taylor Anemometer heads (Figure 3) The entire system was designed to run on 2,000 liters of propane fuel unattended for 7 months.

Figure 3-Shelter and Tower

Results of this project have proven the feasibility in concept. In practice, TEG's are very difficult to operate and maintain in a windy, mountainous environment. After four years of efforts, the station is being removed to a lower, more accessible location so that technical problems can be identified more readily. Several times the TEG was operating when there was a riming event that shut down a non-heated control anemometer. The TEG heated Taylor heads rimed up considerably slower. Following each storm event the heating system would then gradually clear accumulated rime. There was not sufficient heat generated to ensure the anemometers didn't rime at all, so the effectiveness of this system is in doubt. Consideration is being given at the current time to incorporating a different type of generator/heater system called Whispergen (www.whispergen.com) into the system. Alternatively, programming could be developed into the Campbell dataloggers which would identify riming conditions and turn a conventional generator on and off to counteract riming events.

*3.2. Explosives Delivery*

Locating two fixed howitzer positions with on-site explosive storage, and adding new platforms for road-based gun systems has reduced the time necessary to conduct a full round of explosives work from 2 days with 2 crews, to one long day with a single crew. There is very little logistics involved in moving firing systems. Additional benefit is gained because equipment failures rarely compromise mitigation capability. By having the ability to use explosives every day, it is rare that more than .5 meters of snowfall occurs without having an explosive charge delivered to key starting zones.

New in the program is the Avalanche Guard (Figure 4) installation of four boxes on 2 masts.

Figure 4- Avalanche Guard Installation

This system provides explosive charges to a ridgeline approximately 1 km wide with multiple release zones. It is very remote and difficult to access, which has made it expensive to operate. For the first three years of operations, considerable control problems with dropped communications links were encountered. Because of intersecting technologies (software, hardware, radio, telephone, fiber, computer), determining the exact location of the difficulties proved to be very difficult. In the summer of 2005 a concerted effort identified the problem as poor radio connections. A re-worked radio system for 2006 has been robust and solved the technical issues.

This tool has proven to be important for protection on the 43 Mile slide path. Its remote location demanded a large crew and considerable resources for a weapons based approach, even if the weapons were left on site. With the Avalanche Guard system, a heavy equipment operator and avalanche technician can accomplish the job in ¼ the time. This helps ensure that all the critical paths receive an explosives treatment on each day of a large storm cycle, thereby reducing risk.

*3.3. Avalanche Detection*

After review of available options, the Alpug system was chosen. This system uses doppler radar and geophones as detectors, monitored by Campbell data loggers, with a radio interface from each of the three stations to a communication hub at Portage, Alaska. (Figure 5)

Figure 5- Avalanche Detector

The original installation used dial up strings to communicate with the avalanche server. This was later modified to use high speed fiber connections. Alarms are generated on-site by the detectors with a call back system. Simultaneous to the call back to the avalanche server, a talk radio alarm is broadcast on the local radio channel for train operations. Once the alarm reaches the avalanche server, a batch file is generated and sent to train system dispatchers, who receive this notification on their control screens. The talk radio alarm is running within approximately 10 seconds of avalanche release, and the dispatcher alarm is activated at approximately the same time as the avalanche is reaching the railroad tracks.

This system has proved to be robust and operates as it is designed to operate. Two significant issues have arisen from usage however.

The first is a high false alarm rate generated when freeze levels rise to the starting zone. High rates of rainfall, when combined with high wind levels, are detected by the doppler radar in the same manner that an avalanche dust cloud or flowing avalanche might be. For that reason the system sends an alarm signal as if it's seeing an avalanche. This problem is particularly prevalent at the central detector site, which is an unusually windy location. Fortunately this site is a secondary one for detection. When these conditions exist, the radar's at this site can be turned off and thus avoid false alarms.

The second issue is that Alaska has considerably more earthquakes than Europe where other installations are located. Even relatively small earthquakes generate an alarm via the geophones. Raising the alarm threshold would negate the effectiveness of the alarms. Following identification of this issue in the first year of operation, the system designer developed programming necessary for each station to check with an adjacent station when a geophone alarm is detected. Given the separation of stations, there is no chance that a single avalanche event would be detected by the geophone in two different stations. Therefore a geophone alarm at the same time at two stations must be an earthquake, and the revised programming cancels the alarm.

In four years of operation, except for annual maintenance checks, this system has worked faultlessly. More importantly, while there continues to be a few false alarms due to the conditions described, there has never been a failure to detect an avalanche event that reached the tracks. Last season confidence levels were sufficient enough to begin running trains through this slide zone without speed restrictions.

*3.4. Equipment modification*

Heavy equipment used to clean up avalanche debris on the ARR is limited to bulldozers due to track structure and access issues. Since dozers commonly have roll-over protection cages (ROPS), this became a starting point for systems analysis.

Engineering calculations were performed on existing ROPS designs to determine their ability to withstand lateral impact pressures. The systems that are used on the railroad's D-6 and D-7 dozers are capable of withstanding 150 kPa of lateral pressure. Ordinary glass used in these cages would fail at well under 25 kPa. Similar conditions are encountered in grain elevators, so CAT has designed a window system for the newer model D-7 cats that will withstand 138 kPa of impact pressure, or very close to the 150 kPa yield of the ROPS cage. This glass package was retrofit into existing cats and new dozers are ordered with it. Two older cats in the fleet underwent the same analysis and glass packages were designed to withstand similar pressures. In addition, heavy steel grates are installed on the exterior of the glass to resist impacts from heavier objects in the debris such as rocks or trees.

Impact pressure calculations were performed on the largest avalanche paths affecting the railroad. These calculations showed that in rare circumstances, loads could be as high as 3 times the design load of the ROPS cages. Unfortunately, there is no easy way to re-design the ROPS cages to withstand these higher pressures as they would have to start assuming spherical shapes and go through massive review processes. Calculations show that once impact pressure rise above 50 kPa, the entire machine would begin to move with the debris and thus start to reduce impact pressure.

*3.5. Training*

In order to accomplish these goals, negotiations with union representatives resulted in a system where an "avalanche territory" was created. Personnel wishing to bid or bump into this territory during the avalanche season are required to have attended a basic 8 hour avalanche course. Once they bid in, they couldn't leave and then come back for the rest of the winter. All personnel working in this territory receive an additional percentage pay for the training needed to operate in avalanche terrain. Additionally, several positions were created with premium pay rates that have required certificates such as a weapons loader or gunner. This is intended to keep the same personnel in the same job year after year, an important part of any avalanche program.

## 4. PROJECT ANALYSIS

*4.1. Developing performance metrics*

Little attention has been paid in avalanche research to developing objective performance metrics so comparisons of program effectiveness can be measured. Tools exist for the calculation of risk along highways by generating an Avalanche Hazard Index (Shaerer, 1989), with adaptations of this model completed for railroad situations (Hamre 1994, 2004). The AHI model depends heavily on avalanche frequency. Changes in density of traffic, size or avalanche frequency provide directly proportional changes to the resulting AHI. In order to simplify analysis of the described avalanche program, use of a frequency and/or size relationship was chosen as an appropriate indicator.

From 1946 until 1985, the ARR had no avalanche program. Avalanches reaching the tracks during this period were systematically logged, and were all naturally occurring avalanches. Since 1986 there has been an active explosives mitigation program so the majority of avalanches are artificially triggered. Natural avalanches reaching the tracks with no closure in place are the risk events that the avalanche program seeks to mitigate. For that reason, the focus for development of a performance metric was on natural avalanches reaching the tracks. This would allow for comparisons between 40 years of natural occurrences without a program, along with natural and artificially released avalanches in more modern times.

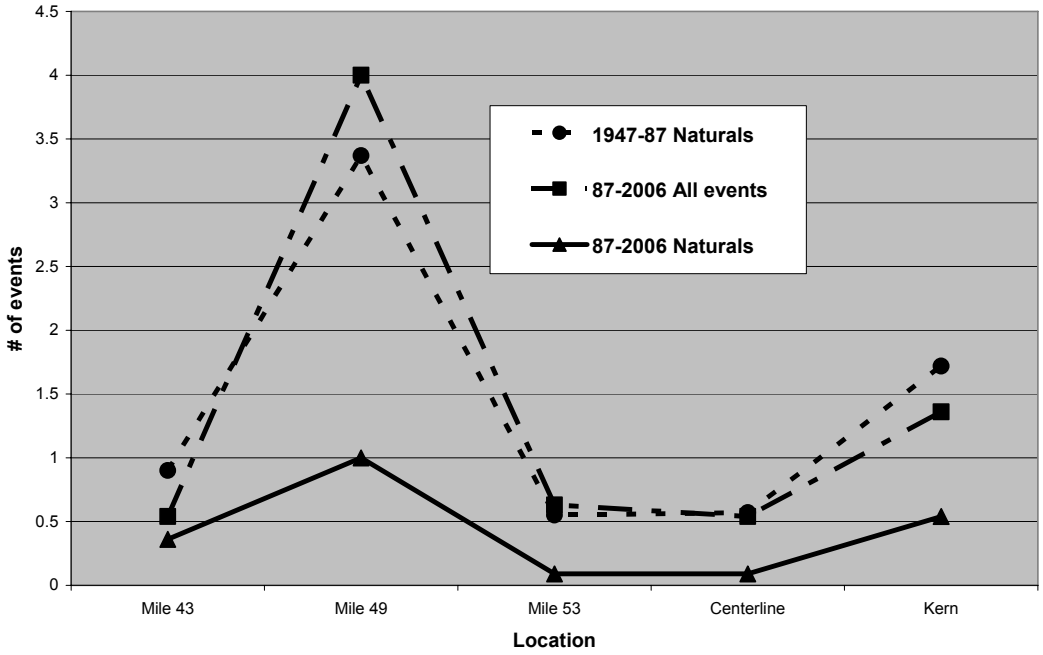
When making comparisons of this nature, the results must be viewed with a certain amount of skepticism. There is high variability of avalanche frequency in natural systems. If risk was added as a variable it would greatly complicate the comparison because closure periods would have to be considered. Focus here rests on identifying whether explosives based avalanche programs in general work, and whether the application of advanced technologies serves to reduce natural avalanche frequency and size to the railroad tracks.

*4.2. Performance calculations*

Several different comparisons were made to determine the extent of frequency and size variation. Almost 50% of the risk calculated through the AHI model is generated on five avalanche paths. These five are the focus of the majority of mitigation effort. Avalanche cycles that are big enough to generate large events from the remaining paths have generally forced closure of the railroad tracks through avalanche events in one of these five paths first, and thus the risk from the remaining paths is not as great.

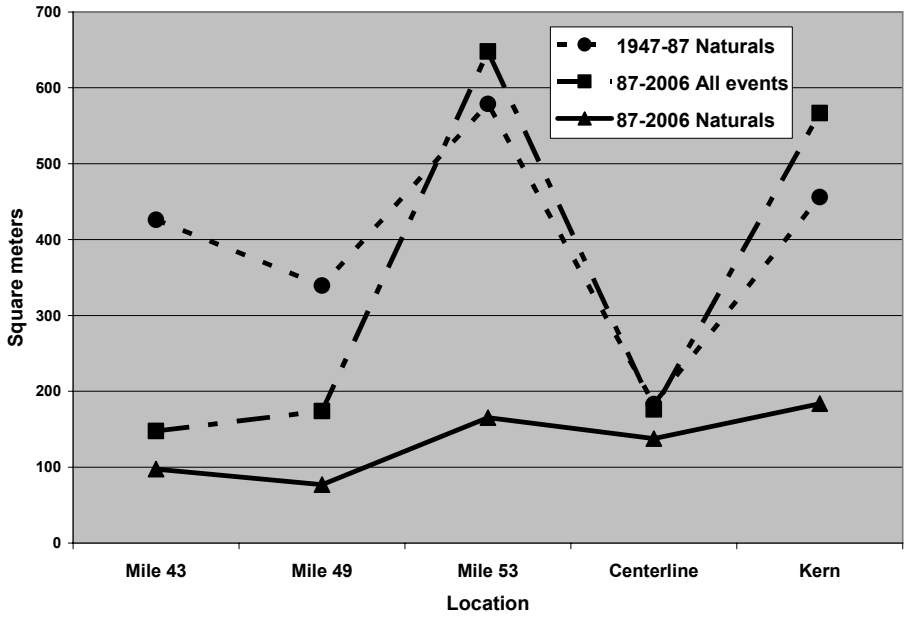
Records analysis shows that avalanche deposits on the tracks are only slightly less wide with avalanche mitigation in comparison to the period of natural avalanches. More dramatic results appear in analysis of frequency as identified in Figure 5. While the older record of natural avalanches and that of all recent events are similar, there has been a dramatic reduction of approximately 75% of natural avalanches reaching the track.

**Figure 5-Avalanches Reaching RR tracks in average frequency/yr.**



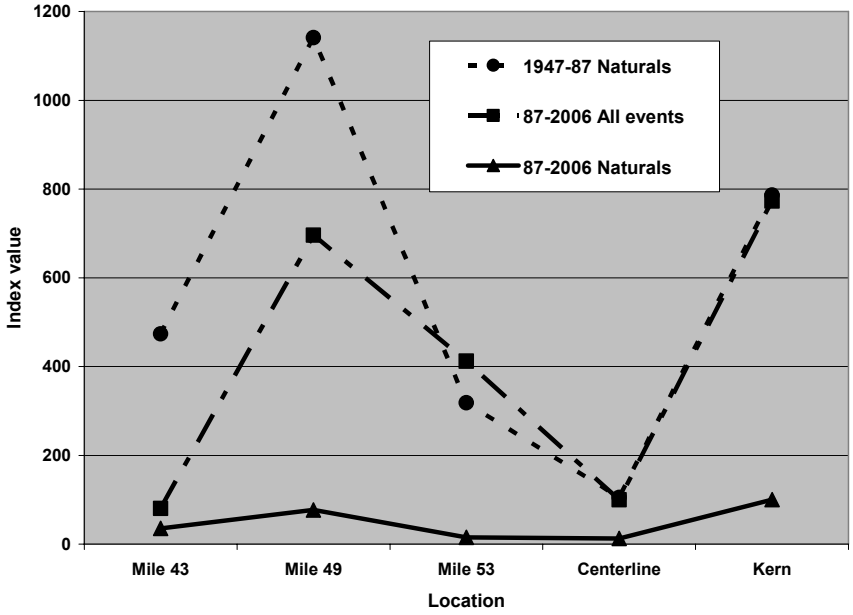

Also of importance is the magnitude or size of events reaching the tracks. Since objective records have been kept for the past 60 years on the length and depth of avalanche debris on the tracks, a simple multiplication of length and depth reveals, as shown in Figure 6, the volume of debris on the tracks. This calculation shows a similar pattern to that produced in Figure 5, with similar deposits from the old natural avalanche profile and the new data from largely artificially induced events. More recent natural events show a dramatic decrease in size.

**Figure 6- Debris on track-Length X Width in Meters**




From these results, a "Severity" index can be calculated by multiplying the frequency and volume figures. The results, shown in Figure 7, provide good evidence that the avalanche mitigation program significantly reduces the risk of natural avalanches to railroad interests.

**Figure 7- Severity Index-Debris on tracks X Frequency**



*4.3. Changes from Advanced technology*
Even more difficult to quantify is how the application of advanced technologies has changed the mitigation program. Statistically, there has been a drop in the average frequency of natural avalanches reaching the tracks from 2.4/yr. to 1.4/yr. This observation must be tempered by the relatively short observation period of 4 years. There has been no unusually large avalanche cycles since these systems were installed.

Perhaps more importantly, avalanche forecasters are more comfortable that they are acquiring useful data, and are able to implement protective measures in a more timely and informed manner. Inherently these factors will help reduce risk in the long term. Personnel operating on the track are better informed and feel more secure. Critical decisions are being made in a more conservative manner because of the wealth of information available. While the risk remains that an unforeseen event could occur, it is intuitively felt that this risk has been reduced.

Costs for managing the program have escalated substantially. While the program continues to operate with only one forecaster, that position is now year round due to maintenance and troubleshooting of complex systems. Helicopter costs have increased, as have costs for outsourcing technical talent. Overall, the program has seen an increased budget from approximately $100,000 US per yr. in 2000 to approximately $175,000 US per year currently. Amortization of capital costs would add significantly to this amount. The benefits from this increase, while difficult to quantify, are felt to be worth the expenditure in better safety margins.

## 5. CONCLUSIONS

Application of advanced technologies in avalanche mitigation programs can be effective from a risk reduction viewpoint, but increase costs substantially. Upgrades with advanced systems typically require a substantial learning curve and familiarization time to bring their full potential to fruition. Users should carefully consider applications on a case by case basis to solve unique problems.

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