1. Abstract

The BNSF Railway Co. has installed an OptaSense® distributed acoustic sensing (DAS) system in the Wind River Canyon on its Casper Subdivision to sense rock falls which could impact train operations. The OptaSense DAS uses laser pulses which are scattered back by natural imperfections in the cable. If the cable is disturbed by vibrations received through the ground, the back-scattered signal is changed and can be used to construct an acoustic image of the disturbance. A single OptaSense Interrogator Unit can “listen” to 40 km (24 miles) of standard telecoms fiber optic cable near the track with a resolution of 10m (32.8 feet), creating 4,000 virtual microphones which can sense and locate rocks falling on or near the track. BNSF installed 21.6 miles of fiber in the canyon at a distance of seven to ten feet from track centerline. The BNSF-OptaSense team conducted a test program of rock drops and rolls down the steep slopes of the canyon, allowing the system to achieve greater than 95% accuracy detecting target rocks while reducing nuisance alarm rates to an acceptable level for the dispatchers, maintenance forces, and train crews to address. The initial goal was no more than five nuisance alarms per day. The team achieved this by developing filters to exclude unwanted events such as non-threat rocks, animals, and thermal track movement. The OptaSense system was put into operation in November 2012 and is connected to a radio system for automatically communicating alerts to crews. OptaSense and BNSF continue to analyze the data to develop methods to further reduce the nuisance alarm rate.

2. The Problem

The Wind River Canyon runs roughly north to south on BNSF’s Casper Subdivision in the middle of Wyoming. A view looking south in the canyon is shown in Figure 1. This line is single-tracked dark territory and carries five to nine trains per day. There are several areas in the canyon where rocks can fall onto the tracks, potentially impeding train operations. Until the recent OptaSense installation, there was no rock-fall detection device in the canyon. In May 2010, a train struck a 30-ton rock that had fallen on the track, causing the lead locomotive to derail. The trailing locomotive and three cars also derailed. Fortunately the crew was able to exit the cab and was not seriously hurt. Due to this incident, the railroad considered installing a rock-fall detection system.

3. Potential Solutions

BNSF sought to evaluate available solutions for detecting, classifying and alarming on rock falls, and then select the one that seemed most cost-effective, yet provide high levels of detection. BNSF considered the following potential solutions:

3.1. Slide Fences

Slide fences have been the most commonly used system for detecting snow, rocks, mud and snow slides and even fallen trees. These fences consist of parallel wires that form circuits connected to the signal systems. When the fence
is hit, a circuit is opened, de-energizing an input to the signal system and setting the signals governing that section of track to STOP or RESTRICTING. The design of the fence varies, depending on the geography of the area around the track that needs protection. In areas where the slope is steep but not high, the fence may be only three feet high, but if the slope rises well above the track, the fence could be 6 to 12 feet high. In cut areas, or areas where rocks can drop directly onto the track, the fences may be in the form of an umbrella or a canopy over the track. Slide fences have two major disadvantages: (1) they must be repaired after being activated impacting traffic until this can be done; and (2) repairing the fences is often time consuming and difficult for maintenance personnel, particularly in the case of canopy-type fences where the workers are replacing broken wires high in the air over the track.

3.2. Distributed Acoustic Sensing (DAS)

During the summer of 2010, representatives of OptaSense, Inc. met with members of BNSF’s signaling and telecoms staff on three occasions to assess how the system might be applied to the railroad as a potentially better technology than slide fences for detecting, classifying and alarming on rock falls.

3.2.1. OptaSense Technology

OptaSense is a distributed acoustic sensing system that interrogates existing standard fiber optic communications cable by transmitting a conditioned pulse of light into the fiber to create an array of virtual microphones. The OptaSense Interrogator Unit is shown in Figure 2.

The virtual microphones are capable of sensing many types of defects in track and rolling stock, as well as rock falls and other ground hazards. By varying the size of the pulse, the virtual microphones can be spaced between 5 and 10 meters (16.4 and 32.8 feet) along the length of the fiber.

OptaSense operates on the principle of Rayleigh backscatter. All fiber optic cable has small manufacturing imperfections, unwanted attenuation for telecom but important for OptaSense, which depends on backscattered light from them. When vibration traveling through the ground disturbs the fiber, the relative position of the imperfections is changed and the result is a signal proportional to the disturbance. A typical rock fall signal is displayed on the screen by the control unit as shown in Figure 3.
Figure 3 – A waterfall image of a fall. This rock rolled for a short distance then landed on the track.

Figure 4 – The rock corresponding to the waterfall image in Figure 3.
This “waterfall” image is similar to the displays developed by sonar engineers. In Figure 3, current time is at the top of vertical axis while earlier time is nearer the bottom. The horizontal axis gives the channel number, which is directly related to distance along the fiber. In Figure 3, the first event -- the rock hitting the ground near the track – is shown as the larger mark, while the three succeeding signatures show the rock rolling across the track. Figure 4 shows the actual path of the rock as it rolled across the track.

The OptaSense technology also has two advantages over conventional slide fences: (1) it does not have to be repaired after an event, and (2) because it doesn’t have to be repaired, it does not subject maintenance personnel to trackside exposure while being repaired. Both BNSF and OptaSense believed that DAS technology would be well adapted to rock-fall detection, The system is sensitive and OptaSense was quite certain that the probability of detection would be above 95% and that with carefully planned test programs, the nuisance alarm rate could be reduced to fewer than five per day, which BNSF felt was an acceptable level for this site.

Finally, BNSF performed a cost study on all options for rock-fall detection and determined that OptaSense was cost-competitive with all other detection techniques.

4. Installation Details

4.1. Fiber Optic Cable

The Wind River Canyon is dark territory and had no communications fiber; only standard radios were being used and these were not effective throughout the entire canyon. It was decided to use a rail plow to install 21.6 miles of cable to be used both for the railroad’s radio communications in the canyon as well as for the OptaSense system. (See Figure 5.) From MP 338 to MP 336, the fiber is 96 strands and buried in 2 ½ inch conduit at a depth between 18 and 48 inches. From MP 336 to MP 331, the fiber is 48 strands and buried in 2 ½ inch conduit at a depth of 48 inches. The final cable run is from MP 331 to MP 317.8; the fiber is 48 strands and is buried 18 to 48 inches deep. There are three tunnels in the canyon and the cable is in four-inch steel pipe in each one. OptaSense performs best when located as close as possible to the track centerline without fouling the ballast. Because of the site geology, it was often impossible to maintain close distances, but in this case the installers were able to keep the fiber distance from the track centerline between 8 and 10 ft. in the areas where there is potential for rock falls.
Figure 5 – A rail plow was used in to install almost 22 miles of fiber to improve radio communications in the Wind River Canyon and to serve as a sensor for the OptaSense system.

4.2. OptaSense Installation
An 8x8 bungalow was installed at MP 338.17 to house the complete OptaSense system and Electrologixs unit. This building is shown in Figure 6. Figure 7 depicts the bungalow’s interior with the OptaSense Interrogator Unit (IU) in place.

Figure 6 – Bungalow in which OptaSense is installed.

Figure 7 – The OptaSense Interrogator Unit installed in the bungalow.
Figure 8 shows the OptaSense display screens. The ElectroLogIXS is used to send the alarms to Fort Worth using ATCS Protocol. The bungalow is climate-controlled so that the system operating temperature range is maintained. Power in the amount of 220 volts is brought into the building. BNSF installed an AC/DC converter and batteries to run the system for 72 hours on battery backup if commercial power is lost.

5. Test Programs

After installation of the OptaSense system, several Receiver Operating Characteristic (ROC) test programs were conducted in the canyon to tune the trade-off between probability of detection (P(d)) and nuisance alarm rate (NAR), with the goal of attaining the highest probability of detection while limiting the NAR to less than five per day. Table 1 lists the test activities that BNSF and OptaSense jointly performed to tune the OptaSense system for higher P(d) and lower NAR, and describes the test programs conducted between March and August 2012 as well as the program conducted in January 2013.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011:</td>
<td>Dec 15 Equipment shipped to site</td>
</tr>
<tr>
<td>2012:</td>
<td>January 3 – January 6 Initial installation of OptaSense in Thermopolis, WY, and field investigation</td>
</tr>
<tr>
<td>March 19 – March 23 Initial rock-fall tests (used for tuning algorithms)</td>
<td></td>
</tr>
<tr>
<td>May 7 – May 11 Updated OptaSense software, integration with ElectrologIXS system, further rock-fall tests</td>
<td></td>
</tr>
<tr>
<td>June 25 – June 29 Field assessment of nuisance alarms through ground-truth documentation, additional rock-fall and roll activities</td>
<td></td>
</tr>
<tr>
<td>August 20 – August 24 Late summer ROC trial to reassess the probability of detection with new lower nuisance alarm rate. 97% detection rate, 3 NAs /day</td>
<td></td>
</tr>
<tr>
<td>2013:</td>
<td>January 7 – January 11 Winter ROC trial to reassess the probability of detection during winter weather</td>
</tr>
</tbody>
</table>

Table 1 – A brief outline of project activities
5.1. Test Programs and Analysis – March through May 2012
BNSF and OptaSense performed the first set of ROC tests in March 2012, using a grapple truck to drop 500-lb. steel weights to simulate rock falls. The tests were performed at several threat locations throughout the canyon to document the sensitivity of the system to rock falls, establish the baseline probability of detection (P(d)), and later, during the analysis, to understand the NAR and begin to develop techniques to reduce it. Figure 9 shows the grapple truck and Figure 10 illustrates the method of dropping weights in order to record OptaSense’s ability to detect rocks of different weights. During these tests, we also used the truck to roll actual rocks down slopes as well as drop them on or near the track (Figure 11). Using actual rocks found in the canyon was a better simulation of actual conditions; therefore, all subsequent test programs used this technique to establish the P(d). The March 2012 test program showed that the P(d) was better than 95%.

Figure 9 – Grapple truck used for dropping weights and rocks
Figure 10 – Grapple truck dropping a single 500 lb. weight on track protected by ties.

Figure 11 – Grapple truck preparing to roll a rock down the hillside
In May 2012, an OptaSense team re-visited the BNSF site to install software tuning updates based on the work with the staged rock-fall data collected in March, and on the initial analysis of the nuisance alarm rates during April operations. OptaSense personnel also integrated the system with the BNSF ElectrologicIXS system to allow alerts to be relayed to remote dispatchers. The system was still aggressively tuned to ensure that all rock falls that could be of concern would be detected; it was now ready for the first real test to ensure that any significant rock falls were detected and classified, and to determine the effective nuisance alarm rate (NAR) for these tunings.

The 751 rock fall “activity” alerts during this period included a significant rock fall that was successfully detected by the system. The rest were nuisance alerts occurring at a rate of approximately 20-25 per day. Inspection of the data allowed a diagnosis of the high nuisance-alarm rates:

- The spatial distribution of alerts was broad and random. There was no single area which had an excessive number of alerts, indicating that a local noise source (e.g. a lube oil pumping station) was not the cause.
- Alerts were equally likely on any given day. There was no clear link to “one-off events”, or weekly or monthly periodicities.
- Alerts tended to increase during the day, with the minimum occurring at 4 AM. The level increased throughout the day until 10 PM. We believe that one significant cause of these alerts is “rail pops” due to thermal expansion and contraction. It has also been noted that the wind can often increase throughout the day.
- Several areas were investigated to determine whether the “zoning” of the OptaSense System could be improved. As a result, areas in the canyon identified as having no risk of rock-falls were zoned out.

A field assessment of the NAR was performed in June 2012, after which an intensive analysis and tuning program was performed. This analysis resulted in development of several methods for classifying nuisance alarms. OptaSense developed an initial filter to remove pops due to thermal movement of the track, which was the largest source of nuisance alarms. Based on the analysis, tuning changes were designed to bring the NAR to less than five per day, the criterion established by the BNSF signal and operating personnel.

5.2. August 2012 Receiver Operating Characteristic (ROC) Test Program
During the August 2012 ROC test program, rocks were dropped on the tracks and rolled down the hillside onto the tracks while recording the OptaSense system response to each event. Figure 12 shows a rock being lifted in preparation for dropping near the track. Figure 13 shows several rocks that were rolled down a hillside to simulate a threat situation. This test program confirmed that the P(d) of threat rocks was still better than 95% while the NAR had been reduced to less than five per day. A total of 67 drops and 58 rolls, realistically simulating the characteristics of real events, were performed by a team of BNSF and OptaSense staff.
The results show that:

- Target-sized rocks (large enough to cause damage and in a position to be struck by a train) were detected 100% of the time (12 out of 12).
- Less than target-sized rocks (large enough to cause damage, and close enough to the track to be within the location margin of error) were detected 97% of the time.

The test showed that the system could provide the rock-fall security desired by BNSF at an operationally feasible NAR. The software tuning was not changed as a result of the August 2012 tests. Before these tests the Nuisance Alarm Rate averaged 3.1 per day. We expect this NAR to persist.

Table 2 and Figure 14 show that from March to August, the number of nuisance alarms per day was reduced from a high of 25 in March to just three. These results allowed BNSF and OptaSense to feel confident that the rock-fall detection system was ready to go “live,” sending alerts to the dispatchers over the BNSF ElectroLogIXS system.
Table 2 and Figure 14 – The results of OptaSense improvements made between March and August 2013. A dash means the value is undefined. The number of alerts per day was reduced from 25 in March to 3 in August while maintaining a very high probability of detection.

<table>
<thead>
<tr>
<th>Date (2012)</th>
<th>Nuisance alerts per day (NAR)</th>
<th>Probability of detection (Pd)</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>January-March</td>
<td>Installation only: system not configured</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May-June</td>
<td>25</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>3</td>
<td>94%</td>
<td>71-100%</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>97%</td>
<td>80-100%</td>
</tr>
</tbody>
</table>

5.3. January 2013 ROC Test Program

The objective of the January ROC test program was to establish whether OptaSense’s fundamental sensitivity had changed due to the change in environmental conditions from the August 2012 installation to the frozen soil conditions of January 2013. The team performed a total of 104 individual trials to realistically simulate real rock falls. Further testing included the addition of new sensitivity calibration techniques, improvements to the NAR by simulating thermal track movement, and further enhancements to the OptaSense setup which included refinements to the thermal filter. The track was heated with Firesnake\(^\text{®}\) and the noise due to thermally induced track movement was recorded by OptaSense for analysis and use in upgrading the thermal filter. Table 3 and Figure 8 show the history of the P(d) and NAR during the period between June 2012 and January 2103.

Table 3 and Figure 15 - Evolution of the NAR and probability of detection (P(d)) with confidence intervals (CI). \(^1\) Results carried over from previous trial. \(^2\) ROC test dates removed from NAR statistic due to high levels of track activity.

<table>
<thead>
<tr>
<th>Date (2012-13)</th>
<th>NAR</th>
<th>P(d)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>January-March</td>
<td>Installation only: system not configured</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May-June</td>
<td>25</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>3</td>
<td>94%</td>
<td>71-100%</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>97%</td>
<td>80-100%</td>
</tr>
<tr>
<td>September</td>
<td>3.4</td>
<td>97%(^1)</td>
<td>80-100%(^1)</td>
</tr>
<tr>
<td>October</td>
<td>5.4</td>
<td>97%(^1)</td>
<td>80-100%(^1)</td>
</tr>
<tr>
<td>November (Threshold update)</td>
<td>1.6</td>
<td>94%(^1)</td>
<td>80-100%(^1)</td>
</tr>
<tr>
<td>December</td>
<td>1.2</td>
<td>94%(^1)</td>
<td>80-100%(^1)</td>
</tr>
<tr>
<td>January(^2)</td>
<td>2.0</td>
<td>98%</td>
<td>56-100%</td>
</tr>
<tr>
<td>January 11-28 (after M/H update)</td>
<td>0.8</td>
<td>98%</td>
<td>56-100%</td>
</tr>
</tbody>
</table>

Detailed objectives are shown below:

- **Detection performance.** Performing further rock drop and roll trials helped OptaSense to continue the performance assessment of the system. There was some chance that the sensitivity of the system may have changed due to the extreme change in weather.
- **Develop new methods of calibration.** Quickly establishing the current sensitivity of OptaSense is important to ensure performance. Sources that are easy to acquire and simple to use will allow sensitivity tests to be performed at any time. There were two methods to test: a Hi-Rail vehicle and a Ramset nail gun.

- **Gather experimental data to aid in understanding nuisance alarms.** To continue reducing the NAR, experimental data is required for further development. Ground truth is essential for understanding nuisance alarm mechanisms. Further environmental information will help improve the setup of OptaSense.

- **Update system based on findings.** If the underlying sensitivity of the system has changed, OptaSense’s settings will need to be altered to compensate. Also, if architectural improvements can be made (e.g. zoning out all manholes and fibre service loops), these will be implemented.

The Winter ROC trial showed that the sensitivity of OptaSense did not change significantly from the late summer ROC trial. The probability of detection was approximately the same as measured in August. However, the confidence intervals of the probability of detection are large because fewer trials were conducted in January, due to the shorter trial period and use of a single crew.

The tests showed that the NAR continued to drop with each improvement to the OptaSense system, without affecting the probability of detection. In January 2013 it stood at approximately one nuisance alarm per day. It was also shown that rock drops of 500 lb. from 10 ft. were approximately equivalent to rolling rocks of the same weight that start from 50 ft. up the hill.

In addition to the P(d) measurements during frozen conditions, further experimental work was undertaken to understand the characteristics of thermal rail pop signatures and to identify a new way to periodically document and verify the sensitivity of the system. Tests with the Ramset nail gun clearly showed it did not have adequate energy for use as a calibration tool. Therefore the calibration method involved recording the signature of a moving Hi-Rail vehicle of consistent characteristics and looking for differences in the OptaSense response among these recordings.

### 5.4. Nuisance Alarm Analysis

In July and August 2012, OptaSense began a NAR reduction program using the data collected through June, with the aim of reducing the NAR to less than five per day. This program consisted of analyzing and classifying previous data, designing methods to mitigate nuisance alarms and a continuous monitoring of live data to ensure NAR performance.

Several different categories of Nuisance Alert were identified:

- Conduit expansion
- Rail pops due to temperature changes
- Animals
- Conduit resonance
- Possible small rock falls
- Hi-rail vehicles and other maintenance activities

The cumulative effects of these nuisance alarms resulted in a NAR of approximately 25 per day. A selection of alerts was classified according to the previous definitions. Based upon the data analysis above, OptaSense processing algorithms were adjusted to improve performance. This consisted of several small internal changes to implement the custom filters described in the July Support Report and a comprehensive re-tuning of the algorithms based on all past and new data. During these activities, detector and classifier improvements were always retested against past rock fall data to ensure continued high probability of detection of threat events.

A summary of changes is listed below:

- New customized filter that places nulls (complete removal) at specific track resonances.
- Detector setting modifications:
  - Rock fall detector (activity):
    - Thresholds based upon comprehensive review of past data.
    - Detects > 95% of all large rock falls (where large means approximately 500 lbs. or greater).
    - Improved suppression capability based upon realistic train lengths.
• Greater robustness due to new thresholding scheme.
  – Vehicle detector
    • Improved tracking capability by allowing vehicle detection along the entire fiber. Results in better suppression of train-originated nuisance alerts.
    • Adjusted settings and thresholds to better represent trains and Hi-Rails.
• System modifications
  – Moved the first acquisition point to beyond the initial fiber patch panel. Allows vehicle tracking from the beginning of the fiber.
  – Added new vehicle detector toward the end of the fiber due to variation in sensitivity.
• Manholes containing drums of spare fiber were zoned out as they are a source of pops. This had negligible effect on threat rock detection.

Since the August 2012 ROC test program, the number of alerts has been closely monitored. The average number of daily alerts for each month and the number of nuisance alarms (i.e. not rock falls or maintenance activities) are shown below in Table 4. Thermally induced movement of the track causes the vast majority of current nuisance alarms (80%), with the remaining ones caused primarily by vehicles (usually hi-rails and stopping trains).

<table>
<thead>
<tr>
<th>Month</th>
<th>Average number of daily alerts</th>
<th>Average number of nuisance alarms</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>November (Threshold update)</td>
<td>3.2</td>
<td>1.6</td>
</tr>
<tr>
<td>December</td>
<td>2.2</td>
<td>1.2</td>
</tr>
<tr>
<td>January*</td>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td>January 11-28 (after manhole update)</td>
<td>0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* Alerts caused by extensive trackside activities during winter ROC trial were removed from the average. Data collected up to 28/01/13.

Table 4: NAR statistics since the first ROC trial. The NAR is reducing over time. Jumps in the NAR correspond to system improvements and updates.

6. Operation

The OptaSense unit sends alerts using two different methods: (1) Moxa boxes to the ElectroLogIXS unit to the dispatcher in Fort Worth; and (2) a single output using an IP address to a MOXA box in Fort Worth.

6.1 Dispatchers Operation

The OptaSense unit has approximately 3500 zones for the 20-mile segment to detect rock slides. Each milepost between 319 and 338 was tested and the zones were configured to match each of the mileposts, in order to reduce the number of outputs to the ElectroLogIXS and to the dispatcher. The dispatcher views the track segments in one-mile blocks; when an alert is sent to Fort Worth, the corresponding milepost segment turns red and flashes “slide” on the screen.

6.2 Radio Operation

The OptaSense unit uses a single output to send one alert from all 20 alerts through an IP address to provide an input to a Moxa Box in Fort Worth that is tied to three MicroTalkers. The MicroTalkers are programmed to provide a message to alert the train crews in the area across three base-station radios. The message covers the entire canyon from MP 319 to 338 in case the dispatcher is away from the desk or busy directing other train movements in the territory. The MicroTalkers also perform another function: they will initiate a 911 call to the dispatchers pod to turn on the beacon for this dispatcher. The beacon is there to alert anyone in the area that there is an emergency for this territory that needs attention, in case the dispatcher has stepped away from the desk.
6.3 ElectoLogIXS Operation

The OptaSense unit has four Moxa boxes, each of which has six outputs. Three boxes provide 18 alert signals for each of the mileposts, and one box sends two more signals for mileposts and one for an OptaSense system failure, one for ElectroLogIXS or communications error and one for Commercial Power Outage.

Figure 16 shows the layout of the BNSF/OptaSense System Layout.

7. Conclusion

OptaSense went live to the dispatchers on November 15, 2012. The system is performing very well, with a high P(d) and a NAR which is improving over time. The average NAR is now approximately one per day, except during change of seasons. At these times the NAR tends to spike for a few weeks as wide temperature swings cause increased thermal movement of the track. Because thermal issues cause 80% of the nuisance alarms, BNSF and OptaSense are moving ahead to develop a new thermal filter, which we expect will eliminate most of these alarms. A NAR of less than five per day—the original goal of the project—is feasible because the traffic in the Wind River Canyon is low (five to eight trains per day) and travels at relatively slow speed. The ultimate goal is to reduce the NAR to less than one per day. When this is accomplished, OptaSense might be deployed on lines with heavier traffic.
Fiber Optic Sensing for Detecting Rock Falls on Rail Rights of Way

Jeffrey Akkerman

Fred Prahl

October 1, 2013
The Problem - Rock Falls

- Wind River Canyon - Casper Sub Wyoming
- Single tracked dark territory with five to nine trains per day
- Several areas prone to rock falls
- Until recently no detection method for rock falls
- In 2010 a train hit a 30 ton rock resulting in a derailment

Potential Solutions - Slide Fences

- Slide fences are the traditional solution
- Slide fences have two disadvantages
  - They must be repaired after being activated, impacting traffic
  - Repairing the fences is time consuming and difficult for maintenance personnel
  - Canopy-type fences are especially difficult to repair

Potential Solutions - Distributed Acoustic Sensing

OptaSense, a QinetiQ Company

- Converts standard telecom fiber optic cable into an effective acoustic sensor over long distances
- Picks up sound via ground vibrations using:
  - Buried fiber
  - Interrogator unit
  - User display (map, charts, audio)
- Deployed on cables up to 50km long with a different listening 'channel' typically every 10m

Advantages of OptaSense

- The system doesn’t have to be reset after an event
- Therefore maintenance personnel are not subject to trackside exposure
- The probability of detection is >95%

Project Outline

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
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<td>Dec 15</td>
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<td>Updated OptaSense software, integration with ElectroLogIXS system, further rock-fall beds</td>
</tr>
<tr>
<td>May 11</td>
<td>Algorithm tuning activities carried out remotely at OptaSense facilities</td>
</tr>
<tr>
<td>June 25</td>
<td>Algorithm tuning activities carried out remotely at OptaSense facilities to achieve half of less than 5/day</td>
</tr>
<tr>
<td>June 29</td>
<td>Algorithm tuning activities carried out remotely at OptaSense facilities</td>
</tr>
<tr>
<td>August 20</td>
<td>Late summer ROC trial to reassess the probability of detection with new lower nuisance alarm rate. 97% detection rate, 3 hrs./day</td>
</tr>
<tr>
<td>August 24</td>
<td>On-going monitoring and classification of alerts. System went live on 11/15/12</td>
</tr>
<tr>
<td>2013:</td>
<td>Winter ROC trial to reassess the probability of detection during winter weather</td>
</tr>
</tbody>
</table>

Fiber Installation Details

- 21.6 miles of fiber optic cable were installed using a rail plow
- The purpose was to enhance radio communications as well as to provide a sensor for OptaSense
- From MP 338 to MP 336, the fiber is 96 strand; from MP 336 to 331, and from MP 331 to 317.8 the fiber is 48 strand
- The fiber is buried 18 to 48 inches deep.
- In potential rock fall areas, fiber distance to track center line is 8 to 10 ft.
**OptaSense Installation Details**

- In January 2012, the system was installed in a built-for-purpose bungalow.
- The bungalow also houses an ElectroLogixS system which sends alerts from OptaSense to the dispatchers in Fort Worth.
- 220 volt power is brought into the building
- BNSF installed an AC/DC converter and batteries to run the system for 72 hours in case commercial power is lost.

**Test Programs**

- Several Receiver Operating Characteristic (ROC) tests were conducted.
  - Purpose: attain the highest probability of detection
  - Limit the nuisance alarm rate (NAR) to less than five per day
- Tests conducted by dropping rocks on or near the track and also rolling rocks down hillsides onto the track.

**First ROC test Program - March 2012**

- Used grapple truck to drop 500 lb steel weights
  - Used to simulate rocks
  - Dropped singly and in a cluster of four (2000 lb)
- Also used truck to roll “rocks of opportunity” down the slopes
  - Better simulation of actual conditions
  - Subsequent tests used this technique to establish the P(d)

**First ROC Test Program - Results**

- 751 rock fall activities
  - Included a significant rock fall that was successfully detected
  - Probability of detection (P(d)) was better than 95%
  - Nuisance alarm rate too high (20 - 25 per day)
  - Spatial distribution of alerts was broad and random
  - Alerts equally likely on any given day
  - Alerts tended to increase during the day
  - Several areas of the canyon with no risk of rock falls were “zonéd out.”

**Field Assessment - June 20**

- Field assessment resulted in intensive remote tuning from OptaSense offices
- Developed an initial filter remove thermally induced track noise
- Implemented tuning changes designed to bring NAR to less than five per day.
August 2012 ROC Test Program

- Test included both rocks dropped on the tracks and rolled down the hillside.
- The program confirmed that the P(d) was still better than 95% and the NAR had been reduced to less than five per day.

January 2013 ROC Test Program

- Objective: Determine if OptaSense’s fundamental sensitivity changed due to seasonal changes between September 2012 and January 2013.
  - Detection performance
  - Gather experimental data regarding NA
  - Update system based on findings
- Develop new methods of calibration that BNSF can use for each seasonal change.
  - Calibrated hi-rail vehicle - the best option
  - Ramset nail gun - not enough energy

January 2013 - Rock Drops

- Rolling and falling rocks
- 95% detection probability
- 1 nuisance alarm per day
- 2500 lb rock fall detected in tunnel during trial.

January 2013 - Rock Drops

- Location: Wyoming
- System: OptaSense DAS system
- Installation type: Rock fall detection
- Temperature: -20 → -5 °C
- Purpose:
  - Ensure detection performance
  - Develop new methods of calibration
  - Gather experimental data of nuisance alarms
January 2012 - Rock Rolls

- Rolls
- 100% Threat Detection

Results of January 2013 ROC Tests

Little change in OptaSense sensitivity from summer ROC trial
NAR continued to drop with each improvement
  - No change in P(d)
Further work to understand thermal rail pops.

Changes made to ameliorate NAR

- New customized filter that places nulls at specific track resonances
- Threshold changes based on comprehensive data review
- Improved vehicle detector
  - Improved tracking by allowing vehicle detection along entire fiber
  - Adjusted settings and thresholds to better represent trains and hi-rails
- Manholes containing drums of spare fiber zoned out - were a source of pops

<table>
<thead>
<tr>
<th>Month</th>
<th>Average number of daily alerts</th>
<th>Average number of nuisance alarms</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>October</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>November (threshold update)</td>
<td>0.2</td>
<td>0.6</td>
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<tr>
<td>December</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>January*</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>January 11-28 (after manhole update)</td>
<td>0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Live Operation

- OptaSense sends alerts by Moxa boxes to the ElectrologIXS then to the dispatcher in Ft. Worth
- Dispatcher Operation
  - 3,500 OptaSense zones configured to match each milepost to reduce the number of outputs to the ElectrologIXS system
  - When an alert is sent to Ft. Worth, the corresponding milepost turns red and flashes “slide” on the screen.
- OptaSense uses a single output to provide an input to a Moxa box in Ft. Worth tied to three MicroTalkers
  - MicroTalkers provide a message to the train crews in an area across three base stations.
  - MicroTalkers also initiate a 911 call to the dispatcher pod to turn on the beacon for this dispatcher.
- The OptaSense unit has four Moxa boxes each of which has six outputs
  - Three boxes provide 18 signals for each milepost; one box sends two more signals for mileposts, one for OptaSense failure, on ElectrologIXS error and one for commercial power outage.
Conclusion

- OptaSense went live to the dispatchers on November 15, 2012
- The system is performing well with a high P(d) and a NAR which is improving with time.
  - The average NAR is approximately one except during change of seasons when wide temperature swings cause increased thermal movement of the track.
- Because thermal issues cause 80% of the nuisance alarms, BNSF and OptaSense are developing a new thermal filter.
  - We expect the new filter will eliminate most of the alarms.
- The ultimate goal is to reduce the NAR to less than one per day.

Thank You!

Jeff Akkerman - Detector Engineer, BNSF Railway
Jeff.Akkerman@BNSF.com

Fred Prahl - Manager Advanced Projects, OptaSense, Inc.
frederick.prahl@optasense.com