The Cascade Tunnel is the longest railroad tunnel in the United States and, at the time of its construction, it was the longest tunnel in North America. It is 7.8 miles long and was constructed between 1925 and 1929 near Stevens Pass in Washington on the Skykomish to Wenatchee route operated by BNSF Railway. When it opened, it reduced the route length by 8.7 miles and eliminated 21 miles of treacherous grades of two percent or steeper. The tunnel is at an elevation of 2,894 feet above sea level at the east portal and it has a grade of 1.57 percent rising from west to east. The tunnel is single track and its alignment is tangent along its entire length (more about this later). In 1993, the tunnel was listed as a US Engineering Landmark.

The Cascade Tunnel serves as a crucial route for BNSF in hauling varied cargo to and from the Port of Seattle. It is also used by Amtrak on its Empire Builder scenic route.

Though the tunnel has aged well as a consequence of its sound engineering design, the structure itself does require upkeep to combat environmental factors as well as changes in the rail industry. In 1956, a ventilation system was installed to allow diesel locomotives to pull straight through the tunnel, eliminating the need to couple and uncouple electric engines at each end. In 1984, a crown cutting project was completed to create notches in the crown of the tunnel to accommodate additional height requirements of double stack container cars.

This brings us to 2012 when BNSF began to assess the need for alignment and clearance envelope improvements in the tunnel. However, due to the corridor’s voluminous traffic, engineering and survey crews are limited to no more than one or two hour access windows at any
given time. With these access constraints it would take weeks just to survey the track using conventional survey methods, to say nothing of modeling the interior of the tunnel which was required to determine clearance optimization plans.

With this challenge at hand, BNSF contacted J.L. Patterson & Associates, Inc. (JLP) to think of innovative ways to model the tunnel. JLP partnered with our mapping subconsultant, SAM, Inc., to develop a survey program combining a control survey and a LiDAR survey to map the track and inside surface of the tunnel, in effect developing a 3D model of the 7.8-mile tunnel.

LiDAR is an acronym for light detection and ranging. It uses optical sensors to measure the distance to a target illuminated by pulses from a laser. The LiDAR equipment used at the Cascade Tunnel was configured on a high-rail vehicle capable of directly accessing the track. The system utilizes two 360-degree LiDAR sensors, two 5-MP roof mounted cameras, two GPS receivers, an Internal Measurement Unit (IMU) and a Distance Measuring Instrument (DMI) to provide data density of up to 150 points per square foot. This minimally invasive method of surveying can be operated day or night with efficient acquisition of millions of 3D design points per minute. The data collection was accomplished in one hour. That was the easy part!

Because of the length and depth of the tunnel, GPS reception was non-existent and therefore many of today’s modern survey tools would have been inoperative. The model of the tunnel needed to be one homogeneous representation of the entire tunnel rather than separate cross sections.

The survey effort provided two distinctly separate challenges: (1) determining the location of the trajectory of the LiDAR sensor; and (2) determining the relative location of discrete elements of the tunnel surface with respect to the LiDAR sensor. To address the first challenge, the JLP team established horizontal and vertical survey control. Pairs of control targets were placed at each portal and control targets were placed every 1,500 feet along the tunnel floor. The control targets were referenced to the North American Datum of 1983 and the North American vertical datum of 1988. The control points and inertial navigation data were used to determine the smoothed best estimate trajectory of the three dimensional route of the mobile mapping system. The second challenge was addressed with the point cloud from the LiDAR sensor as it traversed the tunnel on a specially equipped high rail vehicle.

With the point information, JLP developed the following workflow to analyze the tunnel’s existing condition:
JLP utilized Bentley Microstation V8i Select Series 3 to accomplish the engineering analysis. The specific software packages included: Bentley Rail Track Select Series 2, Tunnel plug-in tool, Roadway Modeler and supplemented with on-line Tutorials from Bentley’s Learn Server.

Utilizing these tools, the JLP team developed a digital 3D model of the tunnel’s interior surface and extracted a precise center line of the track alignment as well as the location of the existing notches within the tunnel. To our surprise, the allegedly tangent track alignment had shifted slightly over the years of service and maintenance. This shifting caused the track to become misaligned with the notches, causing unwanted and dangerous interaction between train/containers and the tunnel notch in this rather restricted space.

Armed with this powerful information, JLP then prepared proposed alignment modifications that would minimize clearance conflicts while maintaining the alignment within the tolerances for tangent track. To best serve our client, JLP proposed a track realignment consisting of 37 horizontal tangents through nearly 8 miles of tunnel. These segments consisted of minimum constructible lengths utilizing almost negligible bearing shifts and large radii to make any curves or angle points virtually undetectable.

A maximum angle break of 0° 1’ 23” was used to propose alignments that would follow the notch alignments to a reasonable and constructible degree while maintaining track alignment and speed standards for FRA Class 3 track. An added bonus to our analysis was the finding of a segment of track with up to three inches of cross level condition. The cross level condition is produced when one rail is higher than the other in a segment of track. This was causing rail cars to lean and create additional conflicts between them and the clearance notches of the tunnel. Therefore, our proposal also included a vertical alignment correction in this segment of the tunnel to eliminate those conflicts all while avoiding extensive re-notching of the tunnel.

In conclusion, JLP’s engineering solution to benefit BNSF included a recommendation for modifying the track alignment to fit the existing tunnel clearance notch. The track alignment modifications represent minimally invasive measures to address the misalignments in lieu of extensive removal of hundreds of cubic yards of material in this busy tunnel. JLP calculated that the removal of approximately 177 cubic yards of material and the impacts to operations were going to originally cost BNSF approximately $10 million. Instead, JLP ascertained that the new proposed notching of the tunnel would amount to only 8.3 cubic yards and the cost would be decreased to approximately $1 million, an unbelievable 90% reduction from the original estimate.

Through this study and the innovative use of technology, JLP realized a considerable savings in construction time and funding to bring the tunnel up to current clearance standards. In all, JLP analyzed several million data points amounting to more than 2 TB of point data and was able to model the tunnel without affecting BNSF operations in this busy corridor.

JLP and our partners, SAM, Inc. are proud to leverage technology to benefit our clients. We understand the railroads are investing significantly to improve their infrastructure and doing it largely within the rights of way that have been in place for over a hundred years. The rail industry is now seeing a substantial resurgence because rail is a safe, reliable, and cost effective transportation alternative that plays a vital role in our nation’s economy.