Development and Implementation of Automated Switch Inspection Vehicle

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ABSTRACT

This paper presents the development, field testing, validation and implementation of a new generation Automated Switch Inspection Vehicle (ASIV) for automated inspection of the rail portions of turnouts to include switch point, frog, stock rail and closure rails on both the open and closed sides of the switch. The inspection vehicle uses a new generation high speed rail profile measurement system to measure the switch and frog profiles and then analyzes these profiles using newly developed state of the art switch analysis software (SwitchWear). The software analyzes all of the key measurement areas of the switch and frog to include such key safety parameters as the gap width between switch point and stock rail, vertical and side wear on the stock rail, relative height of the switch point and stock rail, gage face angle and corner radius of the switch point, relative height and angle of the frog nose and wing rails, etc.

The full development cycle of both the vehicle and the analysis software to include preliminary concept testing, detailed proof-of-concept testing, and full scale field testing on two railways in the United States are presented. This represents testing of approximately 150 turnouts including high speed mainline switches as well as yard and siding turnouts. The testing and analysis included multiple run repeatability assessment, wear and safety analysis of switch, stock rail, and frog profiles, and matching the measured rail profiles with field observations and measurements.

In addition to the direct measurements of the switch and stock rails, the safety condition of the switch points, stock rails and frogs were checked against railroad and FRA standards to see if the conditions violated railway safety standards. These standards included checks to ensure there was no switch point damage, excessive wear or wear angle on the switch point or
stock rail, unacceptable contact between wheel flange and the switch rail, sharp gauge corner profiles, etc.

The results of the analyses and the follow up field inspections are presented to include switches where safety (“red”) or maintenance (“yellow”) conditions were identified and located. These include cases of measured large gaps between switch point and stock rail, conditions of gage face wear, sharp switch rail angle, improper wheel/rail contact, etc. The overall results of the field testing showed that the automated switch inspection vehicle has the ability to measure the rail portions of turnouts to include key switch point and stock rail wear and geometry parameters, as well as identify potential problems in the rail portion of the turnout to include potential derailment sites, damage, and wide gaps on closed switches. The system also provides accurate data on switch and stock rail condition which allows for the monitoring of degradation over time.
AUTOMATION OF TURNOUT INSPECTION

In modern railroad track, the turnout stands out as a complex component of the track structure that generates high levels of vertical and lateral dynamic forces when railway vehicles traverse the turnout. This in turn results in high rates of track degradation and associated high levels of maintenance [1]. Thus the turnout represents one of the major areas of track-caused derailments as well as a major cost area, estimated to be of the order of 10 times that of conventional track. As such it requires a high level of inspection, once a month for most switches and track crossings [2]. Currently, this monthly inspection is performed visually, by an inspector on foot. Recently, attempts have been made to provide hand held computer (PDA) systems to the inspector to provide for a more comprehensive inspection with a more accurate quantification of the various turnout component conditions [3, 4]. This has met with limited success, but still focuses on an inspector on the ground performing a manual inspection. Thus, while technologies have been introduced for all other major track components to allow for automated inspection via a higher speed inspections vehicle, the inspection of turnouts has remained a manual process with limited collection of reliable and accurate data on the turnout condition.

This paper presents the development, field testing, validation and implementation of a new generation Automated Switch Inspection Vehicle (ASIV) for automated inspection of the rail portions of turnouts to include switch point, frog, stock rail and closure rails on both the open and closed sides of the switch. The inspection vehicle uses a new generation high speed rail profile measurement system to measure the switch and frog profiles and then analyzes these profiles using newly developed state of the art switch analysis software (SwitchWear). The software analyzes all of the key measurement areas of the switch and frog to include such key safety parameters as the gap width between switch point and stock rail, vertical and side wear on
the stock rail, relative height of the switch point and stock rail, gage face angle and corner radius of the switch point, relative height and angle of the frog nose and wing rails, etc., as summarized in Table 1.

This includes all of the rail portions of all of the major component areas of the turnout:

- Switch Point
- Stock Rail (Straight and Curved)
- Closure Rail (Straight and Curved)
- Frog

**TABLE 1 Summary of Potential Measurements in the Switch Area**

<table>
<thead>
<tr>
<th>Rail Type</th>
<th>Measurement</th>
</tr>
</thead>
</table>
| Stock rail opposite a switch rail | Vertical wear  
                                  | Gage side wear  
                                  | Gage face angle  
                                  | Gage corner radius |
| Switch rail                | Gage face angle  
                                  | Breaking or chipping  
                                  | Gage corner radius |
| Stock + switch rails       | Vertical height difference  
                                  | Lateral gap width  
                                  | Wheel contact point through switch point |
| Closure rails              | Vertical wear  
                                  | Gage side wear  
                                  | Gage face angle |
| Guard rail                 | Guard flangeway gap width  
                                  | Relative height of guard rail |
| Frog nose and wing rail    | Relative height of nose and wing rail  
                                  | Wear/Batter on Wing Rail  
                                  | Batter/damage to frog  
                                  | Flangeway depth  
                                  | Flangeway width  
                                  | Surface damage: Batter, chipping  
                                  | Wheel contact through frog  
                                  | Wing rail profile (within field of view) |

The initial concept development and field validation of the turnout inspection concept was performed on Network Rail in the UK [5]. Using a modified Network Rail rail profile
measurement system\textsuperscript{1}, a series of 15 turnouts were tested in March 2009 in the vicinity of the Derby Midland Station with twenty repeat runs (10 in each direction). Accuracy and repeatability measurements were excellent. Accuracy comparisons were made against the industry standard MiniProf with the profiles measured from each system being virtually identical. In fact, for acute angles, because of the inability of the MiniProf rolling wheel to fit into corners, the non-contact automated system was superior in accurately measuring the rail profile, which is demonstrated clearly in the profiles of Figure 1. Because of the nature of switch rails it is likely that there will be acute angles in the rail profile or narrow gaps between the switch and stock rails which are more accurately measured by the automated system.

FIGURE 1: Accuracy Comparison of Profile Measurements versus MiniProf (Non-contact full profile shown as yellow; MiniProf contact system railhead shown as red)

In addition to measurements of the switch point and frog parameters presented in Table 1, the \textit{SwitchWear} software allowed for the determination of the safety condition of the switch and frog to see if it violates railway or government safety standards. Initial development focused on Network Rail (UK) Standard NR/L2/TRK/0053, “Inspection and Repair to Reduce the Risk of

\textsuperscript{1} KLD ORIAN Rail profile measurement system
Derailment at Switches,” which includes specific safety conditions that can be automatically checked at the switch point or frog that could potentially cause a train derailment [5]. Subsequent upgrades to the software extended to FRA Track Safety Standards [2].

This includes examination of wheel/rail contact to ensure there is no improper contact made between the bottom of the wheel flange and the switch point (switch rail), such that the flange could climb the switch rail onto the stock rail, causing a derailment. An example of this condition is shown in Figure 2.

**FIGURE 2: Contact Below the 60° Line (Improper Contact per Network Rail standards)**

![Contact Below the 60° Line](image)

A second such safety check, which is also part of the FRA track safety standards, is identification of a condition of an unsafe damaged switch point (switch rail) as shown in Figure 3.

**FIGURE 3: Switch Point Damage Example**

![Switch Point Damage Example](image)
AUTOMATED SWITCH INSPECTION VEHICLE (ASIV)

In order to introduce this concept into the US, ZETA-TECH designed and built the Automated Switch Inspection Vehicle (ASIV) as a state-of-the-art hy-rail vehicle for the inspection of turnouts and special trackwork (see Figure 4). This new generation vehicle is designed to test turnouts with a high degree of measurement accuracy and frequency and to generate a sufficient level of turnout rail condition data to allow for both safety and maintenance management of the turnout.

FIGURE 4: Automated Switch Inspection Vehicle (ASIV)

The ASIV is designed to inspect the rail portion of turnouts, to include the switch point, stock rail, frog, and closure rail, as defined in Table 1 and to:

- Measure switch point, frog and stock rail profiles, wear and key geometry parameters
- Identify potential problems with switch points, stock rails and frogs
  - Derailment hazards
  - Damage
  - Wide gaps on closed switches
- Provide viewable proof of rail condition
- Monitor degradation over time
• Identify Safety Hazards and Conditions to include FRA safety and railroad maintenance conditions

The ASIV vehicle uses a new generation high-sampling-rate profile acquisition system which acquires images at one inch (25 mm) intervals at a speed of 8 mph [or 3” (75 mm) intervals at a speed of 25 mph] on each rail. Thus for example, in the inspection of a Number 20 turnout, which is approximately 170 feet in length, the ASIV unit will acquire more than 8000 rail profiles (including the straight and diverging legs of the turnout). Furthermore, the entire turnout can be measured in less than 5 minutes.

The ASIV rail profile data is then used to develop 3-D composite images of the turnout and its key components. This is illustrated in Figure 5, which shows a SwitchWear generated 3-D image of the entire turnout and in Figures 6 and 7 which show the corresponding 3-D image of the (closed) switch point and frog.

FIGURE 5: SwitchWear Generated 3-D Image of the Turnout

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As noted previously, these three dimensional images are in fact composite images made up of 1” slices of the switch and frog sections, which are available for analysis individually and in an aggregated format. Thus, each of the key maintenance and safety parameters, such as summarized in Table 1, can be evaluated and compared to a defined standard. These standards can be either FRA Track Safety Standards or the railroad’s own maintenance standards. Corresponding deviations from these standards are labeled as Red defects when they exceed the safety standards and Yellow defects when they exceed the maintenance standards but no the safety standards. Figures 8 through 12 illustrate several of these defects as found by the ASIV vehicle during track inspections.
FIGURE 8: Switch Point Fit: The stock and switch rails should have a tight fit within at least the first 50% of the length of the planing (Maintenance)

FIGURE 9: Switch Point Gap: The gap between the switch and stock rails within the first 6” of the switch rail may not be more than 1/8” (Safety)
FIGURE 10: Switch Point Condition: The switch point should not have excessive wear, lip, chipping or other surface damage (Safety/Maintenance)

FIGURE 11 Frog Nose/Wing Rail Condition: The frog nose or wing rail should not have excessive wear, lip, chipping or other surface damage (Safety/Maintenance)
FIGURE 12: Frog Flangeway Depth: The flangeway depth within the frog must be at least 1 3/8” deep (class 1) or 1 ½” (class 2+).

Using the specific red and yellow defect data measured on each turnout, a Turnout Maintenance Priority Index can be calculated for each turnout to determine its overall condition and priority for maintenance or replacement. This index allows for the identification of high priority (very poor condition) turnouts for both main line and yard locations as illustrated in Table 2. It should be noted that approximately 1% of the turnouts inspected had a Turnout Index greater than 50 and 3% greater than 40.

TABLE 2: Sample of 10 High Priority Index Turnouts

<table>
<thead>
<tr>
<th>Track</th>
<th>Track Class</th>
<th>Switch Name</th>
<th>Low MP</th>
<th>High MP</th>
<th>Switch Dr</th>
<th># Straight</th>
<th># Diverge</th>
<th>FRA Maint</th>
<th>TO Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>3</td>
<td>SMETRC</td>
<td>366+3661.44</td>
<td>366+3782.56</td>
<td>RH</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>SMetra</td>
<td>376+2307.35</td>
<td>376+2417.32</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>SWME</td>
<td>366+2307.43</td>
<td>366+2417.32</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>NWME</td>
<td>366+3493.42</td>
<td>366+3683.74</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>North Yd</td>
<td>1</td>
<td>North Yd</td>
<td>936+6+2490.28</td>
<td>936+2608.07</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>North Yd</td>
<td>1</td>
<td>North Yd</td>
<td>937+6+2155.58</td>
<td>937+2241.61</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>Lambert</td>
<td>369+752.2</td>
<td>369+813.7</td>
<td>RH</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>NMETRC</td>
<td>368+2293.69</td>
<td>368+2416.53</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Main</td>
<td>3</td>
<td>SValleyY</td>
<td>369+4040.02</td>
<td>369+4165.86</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>North Yd</td>
<td>1</td>
<td>North Yd</td>
<td>9421S+9+2168.91</td>
<td>9+2247.83</td>
<td>LH</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

In addition by monitoring and analyzing the interaction between the turnout surfaces and a defined wheel profile, wheel rail interaction can be examined as part of a derailment risk
analysis. Thus, ASIV provides detailed information for derailment risk mitigation by identification of defects that can lead to component failure and derailment, and identification of rail profile and surface conditions that can lead to improper wheel rail interaction. The ASIV SwitchWear software has the ability to analyze multiple wheel profiles running through the actual turnout surface geometry as illustrated in Figure 13. This includes the ability to analyze new and worn wheel profiles for cars and locomotives. As noted in Figure 2, this allows for the identification of improper wheel/rail contact that can lead to wheel climb or other derailment modes and specifically to the identification of contact parameter thresholds for risk identification, such as Network Rail’s 60 degree contact point illustrated in Figure 2A.

In addition, a Turnout Derailment Risk Index can be developed that addresses potential risk of derailment, such as the wheel climb derailments that are associated with poor switch point condition (which is separate and distinct from the Maintenance Priority Index).

Finally, the turnout rail profiles can also be used for management of a rail grinding program through the turnout using specialized Switch and Crossing Rail Grinders [6].
FIGURE 13: Wheel/Rail Contact Analysis through the Switch Point

Wheel Profile Analysis

At switch point

6” past switch point

12” past switch point

39” past switch point – no contact with stock rail – note this profile was measured in unloaded state

Wheel profile is Network Rail (UK) P8, but any wheel profile can be superimposed

Testing and Validation
The ASIV vehicle underwent complete shakedown and validation testing on Conrail in the Southern New Jersey area during the fourth quarter of 2010. The validation portion of this activity included testing of dozens of switches in the Mt. Holly, Camden and Hammonton lines of Conrail to include repeatability testing, at a range of speeds between 4 and 10 mph, testing in forward and reverse direction and with the vehicle oriented so that both facing and trailing inspection moves were made with the vehicle in the forward and reverse directions. Evaluation of the inspected profiles was performed with the SwitchWear software and presented to the Conrail engineering team for review discussion, and guidance on how to optimize the analysis process and best make use of the analysis data for practical maintenance applications.
Subsequent to the shakedown activities, testing was performed on two major US Class 1 railroads. Testing included over 125 turnouts in four yards and approximately 20 turnouts on mainline. In all cases, productivity was excellent with the ability to test both the straight and diverging legs within a few minutes (if both were available). Based on a testing speed of 8 mph through the turnout, a complete turnout inspection (both legs) was performed in less than five minutes, to include large number 20 turnouts. Productivity rates in yards allowed for testing of 30 to 40 turnouts in 1 to 3 hours depending on track time and access. For main line track, 20 turnouts per shift was obtained, but as expected track time and access to both sides of the switch determined the actual productivity rates.

On the ground verification was performed for the key switch inspections. Figures 14A and 14B show 3-D and real views of a broken switch point with profiles before and after the break point (14B). Likewise, Figures 15A and 15B show 3-D and real views of a battered and worn frog nose and wing rail with the associated profiles showing batter and wear on the nose and wing rail (15B). Figure 16 also shows a damaged wing rail with 3-D and profile views and well as an actual view (photo). The resolution of the 3-D images was excellent with the ability to identify, locate, and measure small chipping of the points, wear of the wing rail, as well as all of the key measurements noted previously in Table 1.

**FIGURE 14A: Chipped/Broken Switch Point with Real and 3-D Views**
FIGURE 14B: Key Profiles Before and After Break

FIGURE 15A: Battered Frog Nose and Wing Rail with Real and 3-D Views

FIGURE 15B: Battered Frog Nose and Wing Rail with Key Profiles
FIGURE 16: Damaged Wing Rail; 3-D, Profile and Real Views
CONCLUSIONS

A new generation Automated Switch Inspection Vehicle (ASIV) has been developed and introduced for the automated inspection of the rail portions of turnouts to include switch point, frog, stock rail and closure rails on both the open and closed sides of the switch. The inspection vehicle uses a new generation high speed rail profile measurement system to measure the switch and frog profiles and then analyzes these profiles using newly developed state of the art switch analysis software (SwitchWear). The software analyzes all of the key measurement areas of the switch and frog to include key safety and maintenance parameters.

By capturing images at very short intervals, of the order of 1 inch (25 mm), the high accuracy systems allows for the building up of a three dimensional (3-D) picture of the turnout and its key components to include the switch point and stock rail, frog and associated wing rails, and the intermediate closure rails. By acquiring up to 8000 images per turnout a high level of accuracy can be obtained for identification and measurement of defects and unsafe conditions. These components are analyzed by the SwitchWear software looking at a comprehensive set of safety and maintenance parameters which is measured against defined railway and government standards. Red (safety) and yellow (maintenance) exceptions are detected and reported.

Validation testing on three railways in the United States as well as in the UK shows the system to be accurate, repeatable, and capable of identifying safety and maintenance conditions under a wide range of different railway conditions. This includes the ability to identify FRA and railroad defects as well as high derailment risk conditions, together with accurate measurement of the profiles and rail geometry of the turnout components. In addition a Maintenance Priority
Index can be calculated for each turnout to help railroads plan and schedule their maintenance activities with limited maintenance resources.

As a result, the ASIV technology has been shown to be an effective way to evaluate the condition of turnouts as well as to project the rate of degradation forward to manage and schedule maintenance of the turnout. This includes management of component repair (grinding, welding, etc.) or replacement in order to optimize the service life of the turnout and minimize turnout maintenance costs. Given the very expensive nature of turnout maintenance, this has the potential for significant extension of turnout asset life and associated maintenance cost savings.

Thus, the ASIV vehicle and the associated SwitchWear analysis software has been shown to be a viable system for identifying key classes of turnout safety conditions, which can lead to derailments, and enhancing the current switch inspection approach used by railway maintenance of way departments. The introduction of the ASIV technology as an integrated part of the rail profile monitoring program will reduce reliance on field measurements and also allow more frequent, comprehensive, and convenient analysis of turnout condition. This in turn will allow for the more effective management of turnout maintenance and minimization of turnout maintenance and replacement costs while maintaining a safe operating environment.
REFERENCES


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TABLES

TABLE 1  Summary of Potential Measurements in the Switch Area
TABLE 2  Sample of 10 High Priority Index Turnouts

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FIGURE 3  Switch Point Damage Example
FIGURE 4  Automated Switch Inspection Vehicle (ASIV)
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FIGURE 8  Switch Point Fit: The stock and switch rails should have a tight fit within at least the first 50% of the length of the planing (Maintenance)
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FIGURE 10  Switch Point Condition: The switch point should not have excessive wear, lip, chipping or other surface damage (Safety/Maintenance)
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FIGURE 12  Frog Flangeway Depth: The flangeway depth within the frog must be at least 1 3/8” deep (class 1) or 1 1/2” (class 2+).
FIGURE 13    Wheel/Rail Contact Analysis through the Switch Point

FIGURE 14A   Chipped/Broken Switch Point with Real and 3-D Views

FIGURE 14B   Key Profiles Before and After Break

FIGURE 15A   Battered Frog Nose and Wing Rail with Real and 3-D Views

FIGURE 15B   Battered Frog Nose and Wing Rail with Key Profiles

FIGURE 16    Damaged Wing Rail; 3-D, Profile and Real Views

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Development and Implementation of an Automated Switch Inspection Vehicle

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Introduction to Turnout Inspection

• Turnout critical and complex component of track structure
  – Major cost area
    • Estimated at 10 times conventional track
    – Major category of track caused derailments
• Currently relies on manual inspection for maintenance and safety management
• Improved management of turnout condition and maintenance desired by track maintenance departments
  – More accurate information needed on turnout condition
• New improved inspection techniques needed
  – To provide more detailed information about key portions of turnout
Automated Switch Inspection

• Paper presents initial development and implementation of new generation turnout inspection technology for automated inspection of rail portions of turnouts
  – To include switch points, stock rails, closure rails, and frogs
• Technology includes specially designed high-image-acquisition-rate laser rail profile measuring systems
• New generation turnout rail inspection system mounted on hy-rail inspection vehicle
  – Automated Switch Inspection Vehicle (ASIV)
• New generation analysis software for key turnout information
  – SwitchWear
Potential Inspection Areas in a Typical Turnout

The above diagram shows a typical turnout, with the preferred names.
**Key Potential Measurements**

<table>
<thead>
<tr>
<th>Rail Type</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock rail opposite a switch rail</td>
<td>Vertical wear&lt;br&gt;Gauge side wear&lt;br&gt;Field side wear&lt;br&gt;Gauge face angle&lt;br&gt;Gauge corner radius</td>
</tr>
<tr>
<td>Switch rail</td>
<td>Gauge face angle&lt;br&gt;Breaking or chipping&lt;br&gt;Gauge corner radius</td>
</tr>
<tr>
<td>Stock + switch rails</td>
<td>Vertical height difference&lt;br&gt;Lateral gap width&lt;br&gt;Wheel contact point through switch point</td>
</tr>
<tr>
<td>Closure rails</td>
<td>Vertical wear&lt;br&gt;Side wear, side angle</td>
</tr>
<tr>
<td>Frog</td>
<td>Frog flangeway gap width and depth</td>
</tr>
<tr>
<td>Frog nose and wing rail</td>
<td>Relative height of nose and wing rail&lt;br&gt;Wear/Batter on Wing Rail&lt;br&gt;Batter/damage to frog&lt;br&gt;Surface damage: Batter, chipping&lt;br&gt;Wheel contact through frog&lt;br&gt;Wing rail profile, wear, batter, chipping</td>
</tr>
</tbody>
</table>
Lateral Gap Between Stock and Closed Switch Rail

Gap width = 2.79 mm
Switch Point Damage
Relative Height of Stock and Switch Rails

Switch blade above stock rail

Switch blade below stock rail
Relative Height of Frog Nose and Wing Rail
Wheel/Rail Contact

Through Switch, Closure and Frog
Initial Concept Validation and Testing

- Initial concept development and field validation on Network Rail in UK
- Initial concept development in 2008
- Validation of Concept and field tests March 2009
  - Network Rail in vicinity of Derby, Midlands, UK
  - Used a modified Network Rail rail profile measurement system
  - Series of 15 turnouts over 20 complete runs
Map of Switch Trial Runs of 9 March 2009
Sampling Rate, Repeatability and Accuracy

- Initial validation testing measured switch profiles every 2.2 inches (56 mm)
  - Subsequently reduced to every 1 inch in later generation systems (ASIV)
- Evaluations of system repeatability performed with 20 repeat runs over all 15 turnouts
  - 10 runs in each direction
- Profile quality for these runs was good
- Repeatability was very accurate
  - Included measured profiles in same and opposite directions
- MiniProf used for accuracy comparison to the profile system
  - Profiles measured from each system were virtually identical
  - Non-contact automated system superior in accurately measuring narrow gaps between switch point and stock rails
Accuracy Comparison of Profile Measurements vs. MiniProf
Development of Automated Switch Inspection Vehicle

• After successful testing in UK, ZETA-TECH designed and built Automated Switch Inspection Vehicle (ASIV)
  – State-of-the-art hy-rail vehicle for the inspection of turnouts
• ASIV inspection vehicle is designed to inspect rail portion of turnouts, to include the switch point, stock rail, frog, and closure rail
• Uses a new generation high-sampling-rate profile acquisition system
  – Acquires images at one inch (25 mm) intervals at speed of 8 mph
    • 3” (75 mm) intervals at a speed of 25 mph
  – Acquires over 8000 images in inspection of a Number 20 turnout
    • including straight and diverging legs of turnout
    • measurements take less than 5 minutes
• Profile data used to develop 3-D composite images of turnout and key components
• SwitchWear software used to analyze key parameters and generate Red and Yellow exceptions
Automated Switch Inspection Vehicle (ASIV)
ASIV Measurement and Test Capabilities

- Measure switch point, frog and stock rail profiles, wear and key geometry parameters
  - 3-D composite images
- Identify potential problems with switch points, stock rails and frogs
  - Derailment conditions/hazards
  - Damage/wear
  - Wide gaps on closed switches/Improper flangeways
  - Improper wheel/rail contact
- Monitor degradation over time
- Identify Safety Hazards and Conditions
  - FRA safety and railroad maintenance conditions
ASIV Analysis Capabilities

• *SwitchWear* software analysis
  – Highly automated analysis program
  – Develop 3-D profiles

• Determine safety and maintenance conditions

• Compares against thresholds to determine exceptions
  – Determine if switch exceeds safety standards (red)
  – Determine if approaches or exceeds maintenance limits (yellow)
  – Additional comparisons available for wheel/rail contact, derailment hazards, etc

• Calculates a maintenance priority index

• Generate detailed turnout report
Series of Samples (1 of 30)
Series of Samples (2 of 30)
Series of Samples (3 of 30)
Series of Samples (4 of 30)
Series of Samples (6 of 30)
Series of Samples (7 of 30)
Series of Samples (8 of 30)
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Series of Samples (22 of 30)
Series of Samples (24 of 30)
Series of Samples (25 of 30)
Series of Samples (27 of 30)
Series of Samples (28 of 30)
Series of Samples (29 of 30)
Three dimensional Image of Switch Point and Stock Rail (Closed side)
3-D Composite View of Frog and Wing Rail

Straight Leg

Diverging Leg
## Conditions and Thresholds

Red indicates FRA exception  
Yellow indicates maintenance exception

<table>
<thead>
<tr>
<th>Condition</th>
<th>Defect Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch Point</td>
<td>Excessively worn, chipped, or damaged</td>
</tr>
<tr>
<td>Frog Point</td>
<td>Excessively worn, chipped, or damaged</td>
</tr>
<tr>
<td>Wing Rail</td>
<td>Excessively worn, chipped, or damaged</td>
</tr>
<tr>
<td>Switch/Stock Rail Fit</td>
<td>Does not fit tightly for at least the first 50% of the planing</td>
</tr>
<tr>
<td>Obstruction</td>
<td>Obstruction to the operation of the switch or the clear passage or a train through a turnout</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Defect Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch/Stock Rail Gap at Point</td>
<td>Cannot exceed 1/8&quot;</td>
</tr>
<tr>
<td>Open Switch Rail Flangeway Clearance</td>
<td>Nothing within 2 1/2&quot; from gage face of stock rail</td>
</tr>
<tr>
<td>Relative Height of Switch and Stock Rails</td>
<td>Top of switch rail should be between 11/16&quot; and 1&quot; below the top of stock rail at the point</td>
</tr>
<tr>
<td>Relative Height of Switch and Stock Rails</td>
<td>Top of switch rail should be at least 3/16&quot; above the stock rail where the gage-to-gage distance of the switch and stock rails is 4 1/2&quot;</td>
</tr>
<tr>
<td>Relative Height of Wing Rail to Frog Nose</td>
<td>(Approximates batter) Should not exceed +/- 1/4&quot; at the frog point</td>
</tr>
<tr>
<td>Frog Flangeway Depth</td>
<td>Should be at least 1 3/8&quot; (class 1) or 1 1/2&quot; (class 2+)</td>
</tr>
<tr>
<td>Frog Flangeway Width</td>
<td>Should be at least 1 1/2&quot;</td>
</tr>
<tr>
<td>Guard Flangeway Width</td>
<td>Should be between 1 1/2&quot; and 2 1/2&quot;</td>
</tr>
<tr>
<td>Gage Side Wear</td>
<td>Limited based on rail section (generally 3/16&quot; to 11/16&quot; limit)</td>
</tr>
<tr>
<td>Vertical Wear</td>
<td>Limit generally 1/2&quot; from the original rail section</td>
</tr>
<tr>
<td>Rail Lip on Gage Corner</td>
<td>Cannot exceed 1/8&quot;</td>
</tr>
</tbody>
</table>
Switch Point Gap: The gap between the switch and stock rails within the first 6” of the switch rail may not be more than 1/8”
Maint

Switch Point Fit: The stock and switch rails should have a tight fit within at least the first 50% of the length of the planing.

Switch/stock rails do not mate for most of the planing, straight switch rail.
Turnout Inspection Points

FRA Switch Point Condition: The switch point should not have excessive wear, lip, chipping or other surface damage

Chipped switch point, diverging switch rail
Turnout Inspection Points

Maint

Relative Height of Switch Rail to Stock Rail: The switch rail should be between 11/16” and 1” below the stock rail at the switch point.

Switch rail sitting high to stock rail, straight switch rail
Relative Height of Switch Rail to Stock Rail: At the point where the lateral distance between gage points of the switch and stock rails is 4 ½”, the switch rail should be at least 3/16” above the stock rail.

*Straight switch rail sitting too low to stock rail*

*Straight switch rail sitting too low to stock rail*
Frog Point Condition: The frog point should not have excessive wear, lip, chipping or other surface damage.

Chipped/damaged frog, damage on diverging side of frog.
FRA  Wing Rail Condition: The wing rail should not have excessive wear, lip, chipping or other surface damage

Worn wing rail, damage on diverging side of frog
Turnout Inspection Points

Maint Relative Height of Wing Rail to Frog Nose: As an approximation of frog batter, the relative height of the wing rail and frog nose should be no more than +/- 1/4”

Wing rail very high relative to frog nose, suggests frog rail batter
Frog Flangeway Depth: The flangeway depth within the frog must be at least 1 3/8” deep (class 1) or 1 ½” (class 2+)

Frog Flangeway Width must be at least 1 ½”
Turnout Inspection Points

**FRA** Obstruction: There should be no obstructions to the operation of the switch or the clear passage of a train through a turnout

*Obstruction on diverging leg*
**Turnout Inspection Points**

**Maint** Gage Side Wear: The wear on the gage side of the railhead at a depth of 5/8” below the top of rail is limited based on rail section (generally 3/16” to 11/16” limit)

**Maint** Vertical Wear: The limit on vertical wear is generally ½” from the original rail section

*Gage side wear on diverging leg*

*Excessive vertical wear on straight leg*
Turnout Inspection Point: Wheel/Rail Contact

- Evaluate wheel/rail contact
- Identify potential safety condition
  - UK standard: No wheel flange contact allowed on switch rail below 60° line
  - FRA standard: Wheel does not contact gage side of stock rail past switch rail planing
Derailment Risk Management and Wheel Rail Interaction

- Identification of rail profile and surface conditions that can lead to improper wheel rail interaction
  - Can analyze multiple wheel profiles running through the actual turnout surface geometry
    - To include new and worn wheel profiles
    - Identify improper wheel/rail contact that can lead to wheel climb or other derailment modes
  - Identify contact parameter thresholds for derailment risk identification
    - Such as Network Rail’s 60-degree contact point
Wheel Profile Analysis

At switch point

6” past switch point

12” past switch point

39” past switch point – no contact with stock rail – note this profile was measured in unloaded state

Wheel profile is Network Rail (UK) P8, but any wheel profile can be superimposed
ASIV Testing in US

- ASIV vehicle underwent complete shakedown and validation testing on Conrail in 2010
  - In Mt. Holly, Southern New Jersey area
  - Over 30 switches were tested with numerous repeatability runs
  - Speed range of 5 to 10 mph

- Testing on two major US Class 1 railroads
  - RR #1 November 2010 in South-Central US
    - Approximately 100 turnouts tested in both main line track and in yards
  - RR #2 January 2011 in South-Central US
    - Approximately 50 turnouts tested primarily in yards
Test Results

• ASIV was able to clearly identify full range of turnout rail conditions
  – Important to define standards for red and yellow exceptions
• Resolution of 3-D images was excellent
  – Ability to identify, locate, and measure even small chipping
  – Accurately measured key turnout measurements
• Productivity was excellent
  – Ability to test both straight and diverging leg within a few minutes
• ASIV achieved high productivity rates
  – Main line track: 20 turnouts per shift
  – Yards: 30 to 40 turnouts in 1 to 3 hours (depending on track time)
  – Track time and access determines actual productivity rates.
• On the ground verification performed
On the Ground Verification: Broken Switch Point
Field Verification of Conditions

Severely chipped switch rail, straight leg

Consecutive Profiles
Field Verification of Conditions

*Frog and wing rails in poor condition*
Field Verification of Conditions

Frog and wing rails in poor condition
Field Verification of Conditions

Cracked and broken out wing rail
Maintenance Priority Index

• Each exception category is given a weight
  – FRA exceptions are weighted x3
  – Maintenance exceptions are weighted x1
  – All exceptions are weighted by track class

• Example
  – FRA exception on class 3 track = 9 points
  – Maintenance exception on class 1 track = 1 point

• Priority Index is the sum of weighted exception count for both legs of the turnout
  – Higher Priority Index indicates more maintenance required
# Example of Maintenance Priority Indices

<table>
<thead>
<tr>
<th>Track</th>
<th>Track Class</th>
<th>Switch Name</th>
<th>Low MP</th>
<th>High MP</th>
<th>Switch Dir</th>
<th># Straight</th>
<th># Diverge</th>
<th>FRA</th>
<th>Maint</th>
<th>TO Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main 3</td>
<td>S METRO</td>
<td>386 + 3661.44</td>
<td>386 + 3782.56</td>
<td>RH</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>S Ponder</td>
<td>376 + 2302.35</td>
<td>376 + 2417.32</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>S WYE</td>
<td>385 + 2807.43</td>
<td>385 + 2926.14</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>N WYE</td>
<td>386 + 3493.42</td>
<td>386 + 3648.74</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>North Yd 1</td>
<td>9359</td>
<td>6 + 2490.28</td>
<td>6 + 2608.07</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>34</td>
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</tr>
<tr>
<td>North Yd 1</td>
<td>9375</td>
<td>6 + 2155.58</td>
<td>6 + 2241.61</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>Lambert</td>
<td>369 + 75.22</td>
<td>369 + 81.37</td>
<td>RH</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>N METRO</td>
<td>388 + 2295.69</td>
<td>388 + 2416.53</td>
<td>LH</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Main 3</td>
<td>S ValleyV</td>
<td>399 + 4040.2</td>
<td>399 + 4165.86</td>
<td>RH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>North Yd 1</td>
<td>9421S</td>
<td>9 + 2168.91</td>
<td>9 + 2247.83</td>
<td>LH</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>10</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>
Benefits of Automated Switch Inspection

- Accurately measure wear, defects, condition and geometry parameters
- Identify potential problems with switch rails
  - FRA safety violations
  - Railroad maintenance conditions
  - Derailment hazards
  - Damage
- Accurate supplement to visual track inspection
- More accurate determination of maintenance requirements
  - More effective scheduling of switch maintenance
- Monitor degradation over time
  - Effective maintenance planning
Conclusions

• New technology for inspection of the rail portion of turnouts was introduced
  – Switch points, stock rails, closure rails and frog portions of the turnout
• New state of the art hy-rail turnout inspection vehicle
  – Automated Switch Inspection Vehicle (ASIV)
  – New generation software analysis package (*SwitchWear*)
• Tested on railways in both US and UK
• Testing demonstrated that technology is repeatable and accurate
• Able to clearly identify full range of turnout rail conditions
  – Capable of defining red and yellow condition exceptions
• Resolution was excellent
  – Ability to identify, locate, and measure even small chipping
  – Accurately measured key turnout measurements
• High productivity allows for inspection and analysis of large number of turnouts
Conclusions (Cont)

- Technology shown to be effective way to evaluate condition of turnouts
  - Identify hazardous conditions that could cause derailment
    - Identify FRA safety violations
    - Accurately identify wear/degradation conditions
- Individual rail profiles evaluated for key safety and maintenance parameters
- 3-D (three dimensional) view of key switch components developed
  - To include switch point, frog, stock rail, closure rail
  - Provides comprehensive view of switch condition variation
- Ongoing measurement allows for monitoring of deterioration of switch
  - Proactive, rather than reactive, maintenance on the switch
- ASIV vehicle and SwitchWear analysis software allows for improvement of current switch inspection and maintenance
  - Enhance safety
  - Improve Maintenance
  - Extend Asset Life