THE CHALLENGES OF INTEGRATING NOVEL WAYSIDE ROLLING STOCK MONITORING TECHNOLOGIES, A CASE STUDY

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SUMMARY
Wayside condition monitoring of rolling stock is being adopted by many railroads around the world, particularly by freight and heavy haul. These technologies have progressed significantly over the last decade, enabling railroads to better target their maintenance resources at the worst performing vehicles with a goal to improve the long term efficiency and safety of their operations.

For railroads seeking to implement new wayside monitoring technology, acquisition of the technology is often the simplest part. Subsequent integration of the information provided by new technology into the well-established maintenance practices of railroads can, however, be a significant challenge.

Even with a strong business case supporting the repair or replacement of components that negatively impact the performance of a vehicle, the maintenance practices in place for decades at Class I railroads in North America may not yet be able to cater to the performance metrics provided by newer technologies.

This paper will examine how two North American Class I railroads and a private heavy haul railroad have integrated the same novel wayside monitoring technology, in this case bogie geometry - tracking behaviour, into their maintenance practices. This paper examines by how much this integration has been achieved to date, the inherent challenges experienced by these three quite different railroad environments in doing so, and an analysis of the outcomes that have been realized through these initiatives.

The paper concludes the analysis with recommendations for how the integration of this information may be furthered, with consideration of the discussed challenges that face each of the different railroad environments.

1. INTRODUCTION
The wheel-rail interface is the critical system for the functionality of a railway [1]. In the attempt to optimize and maintain this interface, wayside detection systems have been in use in North America railways for decades. From simple wheel sensors in the 1970’s, to the modern-day implementations of complex sites with multiple instruments. The initiative to gain more information regarding the health-state of the wheel-rail interface has been driven by the industry’s desire to increase safety by minimizing derailments, as well as minimizing the total cost of maintenance [2]. Averaging Federal Railroad Administration (FRA) reported statistics for the years 2000-2010, train accidents have cost the US federal rail industry just under USD$300 million per annum in equipment and track damage alone, even as derailments have lowered year-over-year under increased volume [3]. A Swedish study in 2004 demonstrated that wheel/rail interface-related maintenance costs for a railway could account for up to 50% of total maintenance, and sometimes more [2].

The first challenge railways face when implementing condition monitoring is to find the right measurement technologies, as valid and repeatable measurements are necessary for an
The diversity of these railways allows for a comparison based on standards published by the Association of American Railroads (AAR) and FRA, while private non-interchange railroads typically have greater autonomy.

The second challenge railways face is to acquire and install measurement technologies. The third challenge for railways is to decide on the maintenance thresholds, as well as the alarm thresholds used to flag condemnable/derailment risk issues. For North American Class I railways, the most severe thresholds are typically decided based on standards published by the Association of American Railroads (AAR) and FRA, while private non-interchange railroads typically have greater autonomy.

The fourth task is to integrate the data into the railway's operations. Each measurement must be transformed into relevant information, and made available to the relevant personnel. The business case must be made before implementing these systems. This paper argues that the third and fourth challenges are typically the greatest to overcome, and discusses how two North American Class I railroads, CSX and BNSF, and a private heavy haul railroad, ArcelorMittal Infrastructure Canada (ArcelorMittal), have overcome them in different ways, using a system in common as the case study: the detection of bogie geometry and tracking behaviour using the TBOGI system. This paper will discuss the outcomes that have been realized to date through these initiatives, and conclude with recommendations for how the integration of this information may be furthered, with consideration of the challenges that affect each of the different railroad environments.

2. PARTICIPANT RAILROADS

BNSF and CSX are two North American Class I railroads. ArcelorMittal is a private heavy haul railroad in North America. BNSF and CSX haul many different commodities as well as intermodal freight. BNSF operates approximately 51,500 km of track, and CSX operates approximately 33,500 km of track. ArcelorMittal hauls iron ore, and operates approximately 420 km of track. The diversity of these railways allows for a comparison of the different challenges experienced by each.

ArcelorMittal has rail operations in Quebec, Canada. CSX operates a rail network primarily throughout the East Coast of the United States, as well as Quebec and Ontario in Canada. BNSF operates a rail network primarily throughout the western and central United States, as well as operating a small amount of track in Canada.

ArcelorMittal owns and operates all rolling stock on its track, which is a captive fleet of 26 locomotives and approximately 1,700 wagons. CSX owns over 4,000 locomotives and 62,000 rolling stock, and allows foreign owned wagons access to its track network. BNSF operates over 6,500 locomotives and 250,000 rolling stock, and also allows foreign owned wagons access to its track network.

The acquisition and integration of wayside monitoring technologies is driven by organisational objectives. For all three railways, the core objectives align. These three goals are: derailment prevention, service interruption prevention, and enabling predictive condition-based maintenance.

BNSF has set its vision for wayside monitoring technology to improve the safety, availability, reliability, and velocity of rolling stock by minimising derailments and service interruptions. Their plan includes augmenting manual inspections with data identifying defects in the dynamic state while en route. Inspections are conducted after unloading whenever possible, reducing train delays, and proactively identifying bad actors.

3. ACQUIRING AND INTEGRATING WAYSIDE MONITORING SYSTEMS

Wayside monitoring technology is defined as equipment that is installed at a fixed location, adjacent to the rails or within the rails. The goal is to monitor or measure some aspect without altering train operations. These systems typically involve sensor equipment, such as lasers, accelerometers, video imaging, strain gauges, load cells, fibre optics, infrared, temperature sensors, acoustic arrays, or induction coils. These systems often have ancillary equipment involved in installations, such as wheel sensors, trackside computer equipment, communication gear, and tag readers. If used, this ancillary equipment is sometimes shared across multiple monitoring systems, or is sometimes unique to each system.

Sites with multiple wayside detectors are often termed "supersites".

3.1 Acquisition

BNSF, CSX, and ArcelorMittal performed temporary wayside monitoring surveys in the 1990s.

BNSF first began acquiring permanent wayside monitoring technology in 2000, CSX in 2002, and ArcelorMittal in the 1990s.

BNSF began by installing hot bearing detectors (HBD), which were relatively simple devices and communicated directly to the train driver if a simple threshold was exceeded in a single pass. Then in 2001-2002, wheel impact load detectors (WILD) and acoustic bearing detectors (ABD) were installed. In 2002, BNSF began to accept alerts from these individual systems, however no centralised data storage was in place. TBOGI (otherwise known as optical geometry) systems were introduced in 2006, and since then eight TBOGI sites (3 of which are double track) have been installed.
CSX began implementing their wayside detector strategy within two major areas. Existing stand-alone hot bearing detectors were networked to provide centralized data. In parallel, CSX made construction plans for a limited number of supersites. The organisation used an optimisation algorithm to consider traffic patterns and finalize eight supersite locations. In 2007, CSX began deploying systems to these locations. The most common systems at these supersites were TBOGI, WILD, and ABD. Since then, CSX has installed eight TBOGI systems (2 are double track) and are now expanding the range of detectors at each site. ArcelorMittal implemented a TBOGI system, as well as a strain gauge (TPD) system, a WILD, and a HBD network.

3.2 Integration

Prior to acquiring wayside monitoring technology, bogie maintenance was performed on a time-based schedule and routine yard inspections. Wayside monitoring systems then began to provide data that could augment normal train yard inspections. These new data streams were interesting but had to be better understood and then incorporated into the organisation's business processes. Wayside measurements that were not integrated (with wagon initial, number for example) were not useful. Multiple initiatives were therefore undertaken:

- BNSF and CSX invested in developing databases that could house the data from all the wayside systems. Their ultimate goal was to provide a unified view of the rolling stock health and trigger maintenance actions. All three railways also used many of the specialised vendor-supplied databases for their analytical tools.
- ArcelorMittal invested in developing an internal database termed SPECTRE that could trend the data from the WILD and HBD detectors, and provide a combined view of the data from these systems. TBOGI data trending was already performed by the vendor-supplied database.
- The AAR began developing standards for rules based on data from wayside monitoring technology.
- BNSF, CSX, and ArcelorMittal invested in understanding the data to be able to develop and implement internal rulesets. These rulesets allowed maintenance interventions to be undertaken in response to data from wayside monitoring systems.
- Railways invested in building internal knowledge of the wayside systems and data, and developing the procedures and training necessary to facilitate a culture shift from reactive to proactive maintenance regimes.
- Development efforts to integrate Automatic Equipment Identification (AEI) with the wayside data.

4. CHALLENGES

This section will discuss the challenges faced by the railways when undertaking the activities needed to fully integrate wayside detector streams into normal operations.

4.1 Data

In the mid-2000s, both CSX and BNSF invested in centralized databases to store the incoming data from the variety of systems. These databases have also become tools for setting thresholds and rules to generate alerts and alarms based on the data.

The database developed by CSX, in conjunction with partner railways, is termed JWDS – Joint Wayside Diagnostic System. Initially, bearing temperature data was centrally collected and trended, and then the other systems were integrated gradually. Now wayside data and alarms can be queried via a single web interface. All employees across the corporation now have access to the data.

Similarly, BNSF personnel in the field are able to query data themselves via the InterISS database or the AAR’s Railinc database.

Several challenges have been experienced by BNSF and CSX in the development of these databases:

- **Database Development and Maintenance Costs.** The costs have been incurred over a number of years as requirements have progressed. CSX also partnered with other railways for development and cost sharing.
- **Structured Data.** Wayside systems often produce different measurement units, file formats, and relate to different aspects of the rolling stock. This challenge has been largely overcome by focusing on the structure of the back-end of the databases first, such as table structures, and header and file formats, and both railways are continuing to refine how data is handled.
- **Data Validation with Railroad Systems.** To ensure accurate data is acted upon, BNSF and CSX validate wayside systems against industry databases. The AAR’s UMLER database is used to verify characteristics such as axle counts, wagon stencilling, wagon type, and wheel size.
- **Alarm Integration to Railroad Systems.** As alarms are created from wayside systems, notifications must be pushed out to multiple internal railroad operating systems. For example, extreme alarms may warrant the
train to be stopped for immediate inspection. In this case, the alarm data stream must notify dispatching operations, wagon repair facilities and customers. Waybill systems are also referenced to provide load/empty status and commodity.

- **Volume of Data.** Only recently, purge-criteria have begun to be implemented to prevent the databases from becoming unwieldy.

CSX and BNSF have developed these centralised databases due to the number and variety of systems, and the number of sites. ArcelorMittal has fewer systems and sites so uses the vendor-supplied standalone databases, as well as the internal SPECTRE database which it developed in 2004 for HBD and WILD systems.

### 4.2 Standards and Rules

Three tiers of rules can be considered when implementing wayside detector technologies: 1. Internal rules set by each railway for its own rolling stock; 2. Interchange rules set by the AAR; 3. Rules set by the FRA.

#### 4.2.1 First Tier

For the first tier, BNSF, CSX, and ArcelorMittal have all been confronting the challenge of developing rulesets that are beneficial for each of their operations. The challenge of creating internal rulesets has been an ongoing project for all three railways. However, the following characteristics have made the specific challenges different for the different types of railway:

- BNSF and CSX have a much higher number of wagons and bogies to manage across their fleets; rolling stock equipment can be in-service for up to 65 years, leading to many revisions of wagon components and designs.

- BNSF and CSX must consider their internal maintenance capacity for both their own rolling stock, and foreign-owned wagons on their network. Fluidity within the yards and wagon repair shops is essential.

- ArcelorMittal has a relatively small fleet of wagons compared to a Class I railroad. In order to meet their iron ore delivery targets, high availability of rolling stock is needed, thus ArcelorMittal is required to be very selective about which wagons to pull for maintenance.

- ArcelorMittal has a higher concentration of curves and grades in their network.

To formulate internal rulesets, the Mechanical Department of CSX began by examining the data from each wayside system individually. For TBOGI data, this meant a concentrated study in 2008-2009 reviewing TBOGI data and inspecting wagons. After the distribution of the data was examined to determine “normal”, the team began teardowns of bogies that displayed extreme outlier performance. The goal was to fine tune the alerts from the data, and recommend specific, actionable repairs for the maintenance of the associated bogies.

Initial data was presented in bogie-based metrics, but after a year, the focus turned to include wheelset-based metrics. The wheelset-based measurements from TBOGI were successful to identify bogie geometry issues that are affecting a single axle, and were built into the rulesets to make them more complete. CSX has since implemented a rule addressing repeated occurrences of extreme lateral movement of individual wheelsets.

To formulate internal rulesets, BNSF began in 2003 by examining derailment histories to determine the physical limits of rolling stock. By examining the events prior to derailment, characteristics that could be measured with wayside monitoring technology were identified that may have indicated the imminent derailment. This work quickly required the consideration of multiple detectors, such as bogie geometry, brake shoes, and bearing temperature. Thereby composite rules began to be developed, and this work is ongoing.

For BNSF, prior to 2003, all the alerts were handled manually. To integrate this more fluidly into the business, BNSF progressed to generating automatic alerts, with either automated or manual handling, depending on the severity level of the alert. This process has been integrated now into three formalised alert procedures:

- **Level 3 (least severe):** Automatically generated and automatic handling. Handled at destination or during empty cycle.

- **Level 2:** Automatically generated and manual handling. Due to the increased severity, manual handling is required to pick more specifically when and where it would be best to inspect.

- **Level 1 (most severe):** Automatically generated and manual handling. This alert level may mean the train needs to be stopped immediately.

In terms of rule-setting, CSX and BNSF now have capabilities advanced to the stage where the complexity of the wayside technology is almost irrelevant, and the complexity of the rules are also almost irrelevant. The rules engines can be coded to issue alerts based on a variety of characteristics.

Before 2006, ArcelorMittal was maintaining bogies on a manual basis with little integration of the data from the wayside systems. Beginning in 2006-2007, a concerted effort was made to integrate the data to help determine maintenance windows and augment maintenance procedures. For TBOGI data in particular, this work meant examining the
reconditioning procedures for bogies, and an intense campaign for addressing bogies with severe defects. The attention helped determine thresholds and maintenance procedures for their internal rulesets, such as optimising maintenance procedures for wheel hollowing, flange wear, wedges, bearing adaptors, side frame dimensions, and rotational resistance/interference.

By 2009, ArcelorMittal had achieved more formal processes for maintenance and repairs, incorporating rulesets for wayside data. Now, when a bogie has reached a particular lifespan in mileage, ArcelorMittal routinely checks the health-state of the bogie in the TBOGI data. If TBOGI thresholds are exceeded at this time then the bogie is inspected, and ArcelorMittal's maintenance recording system produces a step-by-step list to repair the bogie. Hollow wheel wear is also examined at this time, and re-profiled proactively.

### 4.2.2 Second Tier
AAR standards define the second tier of rules to consider, and AAR rules affect all interchange railways in North America. Rolling stock repairs on the North American interchange railroads are governed by the AAR's Field Manual. Foreign-owned wagons cannot be shopped unless specific “Cause for Attention” conditions are present in the inspection yard. The AAR standards also include certain thresholds from wayside monitoring data. The early AAR WILD rules were implemented in 2004.

For CSX and BNSF, this requirement meant that the rules or patterns needed to target wagons that met industry standard defects. Pattern development must now consider measured values vs. AAR condemnable limits. Both railroads attempt to avoid unplanned work events, so more complexity has been incorporated into the rulesets to increase the effectiveness of scheduled work events. Data and resulting alarms are also shared in a central system administered by the AAR to give all rolling stock owners access to wagon health/maintenance planning information.

### 4.2.3 Third Tier
The third tier of rules to consider are those set by FRA and Transport Canada standards. These are the most severe condemnable thresholds and require immediate attention.

### 4.3 Culture
Throughout the process of integrating wayside monitoring technologies, culture changes have been required to bridge the gap between making data available, and producing useable information. Achieving this goal is perhaps one of the greatest challenges to overcome.

Since the introduction of wayside systems, there has been a gradual shift from purely reactive maintenance towards introducing proactive elements.

Using wayside data, ArcelorMittal has been able to introduce proactive maintenance measures, such as:

- targeting bogies to inspect before components reach severe defect levels
- revised maintenance procedures to address defects during scheduled inspections, as well as the components causing the defects
- using the data to see if problems redevelop after an inspection/repair

Due to the greater size and complexity of their operations, BNSF and CSX have more stakeholders than ArcelorMittal. Cultural change therefore needs to be considered at a larger scale. At a basic level, BNSF and CSX need to answer the same fundamental questions: what should be repaired, when, and where. This decision needs to be optimised for train velocity, service interruption, repair cost, and getting maximum lifespan from the assets.

Even with a strong business case supporting repair or replacement intervention of a component that is negatively impacting the performance of a vehicle, AAR Interchange Rules need continued efforts to keep pace as well with the performance metrics provided by wayside technology.

Therefore, BNSF and CSX are undertaking the following initiatives to gradually overcome this challenge:

- Working on composite rules to better target suspect components, without exceeding repair shop capacities. The goal is to be able to target wagons suffering from a critical alignment of defects and thus pose the highest operational risk.
- Working on optimisation strategies for when and where to repair defective wagons, targeting for overall velocity, the number of service interruptions required, the repair cost, cost to the operation, and derailment risk.
- Examining ways to better standardise procedures and data management across many different wayside detectors.

The above initiatives, and the associated rules and standards are still in the early days of development. Various AAR committees are also considering wayside standards and rules.

### 4.4 Vehicle Identification
Vehicle identification has been a challenge since the introduction of wayside monitoring. Knowing what data element relates to what wagon component is critical. Both CSX and BNSF have
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installed and integrated AEI systems alongside of their major wayside installations. CSX has designed local area networks to provide the AEI data file to each detector within their supersites. All the wayside detectors, including the HBDs, at ArcelorMittal are equipped with AEI systems. Currently, each of the different detector manufacturers is responsible for merging the measurements with the AEI data. Some variation has been seen between manufacturers, mostly in error handling.

When co-located or integrated AEI systems are not available, both CSX and BNSF have applied “virtual AEI” processes to fill the gaps at the remaining sites. The virtual AEI process makes inquiries against nearby AEI systems, looking for consist data based on direction of travel, axle count and time of travel.

5. OUTCOMES TO-DATE

This section will discuss the outcomes realised to-date by each railway by overcoming the challenges discussed in the previous section, using the case study of the integration of geometry - tracking behaviour data into maintenance practices.

Outside of derailment prevention and service interruption prevention, the business benefits realised by improving bogie geometry - tracking behaviour are not discussed in-depth in this paper. However there are also important implications for rail life, wheel life, and rolling resistance [5-12].

5.1 Derailments

Derailment counts and statistics are publically available for CSX and BNSF via the FRA database [13]. Queries were run on this database to look at main line derailment counts per calendar year between 2009 and 2014. The primary cause category used was mechanical and electrical failures, and the resulting list of cause codes (see Appendix) was limited to include only cause codes that would manifest as detectable geometry - tracking behaviour defects. See Figure 1 and Figure 2 below.

The downward trends can be seen over time; however 2013 for CSX is an outlier.

In the spectrum of geometry - tracking behaviour, BNSF has also been integrating hunting data (bogie lateral instability) from TBOGI, with more detailed internal rulesets for the data developed in 2010-2011. Hunting derailments are excluded from Figures 1 and 2. Figure 3 below shows the derailment counts for BNSF for bogie hunting only (FRA derailment cause code E4TC).
The BNSF data in Figure 3 considers only derailments of wagon bogies; it does not include derailments caused by hunting locomotive bogies. The integration of locomotive bogie hunting is only recent. BNSF experienced a derailment in 2013 caused by a hunting locomotive bogie, and since then efforts have been made to integrate hunting data for locomotive bogies as well.

ArcelorMittal is able to maintain bogie defects below thresholds such that they have not experienced derailments related to bogie geometry or tracking defects since 2003.

5.2 Exposure to Risk

The integration of wayside data enables a railway to move towards predictive condition-based maintenance. Being able to target limited maintenance resources at bogies with the worst alignment of defects improves asset utilization. Other benefits include more effective initiatives for derailment prevention, and service interruption prevention, lowering a railway’s overall exposure to risk.

During routine inspections, a maintainer can see that a defect has not exceeded a threshold. But the maintainer cannot recognize abnormal trends or predict the timing of a future condemnable measurement. Moving to a predictive model limits the surprises that can arise from rolling stock.

Repairs can be planned to balance workshop loads, group like repairs together, and address wear before components become non-repairable, which reduces the likelihood of having to cut a bogie out of service at an inconvenient time and bear the associated risk and costs. The wayside data can also help maintainers address not only the defect, but also the components causing the defect.

5.2.1 Hunting

The effect of this integration of wayside data can be seen in a few ways, using the case study data. As discussed in the previous section, BNSF has been able to reduce its derailments due to geometry and tracking, as well as hunting derailments specifically. Figure 4 shows the downward trend of extreme hunting (>33 mm lateral peak-to-peak sinusoidal hunting motion of the bogie) as a percentage of total traffic. Some seasonality is evident in the prevalence of hunting, but the downward trend can be seen, and how the trend correlates with the downward trend seen in Figure 3. The trend line in Figure 4 shows an effective halving of BNSF’s exposure to risk from extreme hunting.

5.2.2 Tracking Position

Another metric that has been increasingly integrated by all three railways - BNSF, CSX and ArcelorMittal - is the lateral tracking position (TP) of individual wheelsets. For example, a zero TP would be a wheelset that is tracking centred between the rails, and on tangent track this is ideal behaviour. A TP of 28 mm means a wheelset that is tracking laterally off-centre by 28 mm. This behaviour is considered independent of angle-of-attack (AoA). All three railways have developed internal rulesets for when to inspect a wheelset in response to extreme TP. Also, the AAR has completed a statistical analysis that a TP measurement of 24 mm or greater correlates with the AAR’s thin flange condemnable threshold.
Tracking position defects have a very close fit to a normal distribution. At a fleet level, as the mean value is zero (healthy), then the standard deviation ($\sigma$) of defects illustrates how dispersed the fleet is from a healthy state. Between 2009 and 2014, the standard deviation of tracking positions of each railway’s traffic has been monitored.

By integrating the wayside data and developing rulesets, over these six years all three railways have seen a steady decline in the standard deviation of tracking position defects (see Figure 5):

- **BNSF** has experienced an aggregate reduction of 4%
- **CSX** has experienced an aggregate reduction of 3%
- **ArcelorMittal** has experienced an aggregate reduction of 19%

These changes in standard deviation, although they appear slight, mean a large difference to the number of defects witnessed in the extreme tails of the distribution of defects. This tighter distribution is of great benefit to the railways, as the defects in the tails of the distribution are the extreme defects, which do the most severe damage to the track and bogie components. The significance of the difference is summarised in Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>TP Defect Count &gt;28 mm (5$\sigma$ in 2009)</th>
<th>TP Defect Count &gt;27 mm (5$\sigma$ in 2009)</th>
<th>TP Defect % of Traffic &gt; 28 mm (5$\sigma$ in 2009)</th>
<th>TP Defect % of Traffic &gt; 27 mm (5$\sigma$ in 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>21</td>
<td>26</td>
<td>0.0005160%</td>
<td>0.0006389%</td>
</tr>
<tr>
<td>2014</td>
<td>18</td>
<td>42</td>
<td>0.0000393%</td>
<td>0.0000916%</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>TP Defect Count &gt;29.5 mm (5$\sigma$ in 2009)</th>
<th>TP Defect Count &gt;28.5 mm (5$\sigma$ in 2014)</th>
<th>TP Defect % of Traffic &gt; 29.5 mm (5$\sigma$ in 2009)</th>
<th>TP Defect % of Traffic &gt; 28.5 mm (5$\sigma$ in 2014)</th>
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</thead>
<tbody>
<tr>
<td>2009</td>
<td>11</td>
<td>18</td>
<td>0.0000694%</td>
<td>0.0001135%</td>
</tr>
<tr>
<td>2014</td>
<td>2</td>
<td>18</td>
<td>0.0000084%</td>
<td>0.0000752%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>TP Defect Count &gt;18.6 mm (6$\sigma$ in 2009)</th>
<th>TP Defect Count &gt;15 mm (6$\sigma$ in 2014)</th>
<th>TP Defect % of Traffic &gt; 18.6 mm (6$\sigma$ in 2009)</th>
<th>TP Defect % of Traffic &gt; 15 mm (6$\sigma$ in 2014)</th>
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<tr>
<td>2009</td>
<td>15</td>
<td>92</td>
<td>0.0021312%</td>
<td>0.0130715%</td>
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<tr>
<td>2014</td>
<td>9</td>
<td>107</td>
<td>0.0004608%</td>
<td>0.0054782%</td>
</tr>
</tbody>
</table>

Table 1: Counts and percentages of tracking position (TP) defects for 2014 compared to 2009, based on thresholds chosen using standard deviations

In Table 1, the defect levels for each railway are compared between 2009 and 2014 for 5$\sigma$ for BNSF and CSX, and 6$\sigma$ for ArcelorMittal. The counts and percentages of the defects above those values are shown. The 6$\sigma$ values are used for ArcelorMittal due to their data being more condensed around the mean, so more standard deviations are required to reach the extremities. The standard deviation values specific for each railway demonstrate the performance improvement achieved within each railway, not between railways.
If the performance achieved in 2014 is applied to the traffic measured back in 2009, normalised to the 5σ and 6σ values of 2009, the following is found:

- BNSF 5σ level of 2009: instead of 21 defects >28mm, it would have been 2 defects
- CSX 5σ level of 2009: instead of 11 defects >29.5mm, it would have been 1 defect
- ArcelorMittal 6σ level of 2009: instead of 15 defects >18.6mm, it would have been 3 defects

The converse also applies: if the performance of 2009 had remained unchanged and still applied in 2014, normalised to the 5σ and 6σ values of 2014, the following could be expected:

- BNSF 5σ level of 2014: instead of 42 defects >27mm, it would have been 293 defects
- CSX 5σ level of 2014: instead of 18 defects >28.5mm, it would have been 27 defects
- ArcelorMittal 6σ level of 2014: instead of 107 defects >15mm, it would have been 255 defects

The case study extrapolations above illustrate some of the gains that have been achieved by the improvements that have been gradually realised between 2009 and 2014, and how a seemingly small gain in the distribution has a large effect on the number of extreme defects.

6. FUTURE INTEGRATION

Although great strides have been achieved in the integration of wayside data, it is still a "young" science in the railway industry. Looking forward, future challenges include:

- **More Data**: Even with the wayside systems employed to date, all three railways are collecting large amounts of data. Opportunities exist for additional wayside systems to examine additional dimensions in vehicle or component performance. However that will mean more data, and more complex rules.
- **More Data Types**: Future initiatives may include the integration of other data types with the wayside data. For instance, the integration of track data from on-board monitoring may be able to determine which combinations of rolling stock and track should be avoided. Also, there may be the option to augment AEI reliability by supplementing it with the railroad’s train dispatch system or within the locomotive’s operating system.
- **More Refined Rules**: More work is being done to refine the basic and composite rules in place for existing wayside systems. Also, the integration of further wayside systems will create additional data for these rules to accommodate, and the rules at all industry levels will need to keep pace with the performance metrics available. The business case in doing so for the above-rail and below-rail is becoming better understood, as are the potential safety benefits.
- **More Users**: In North America, rolling stock owners have access to much of the wayside data streams. The challenge will be for each of the companies to understand the significance of wayside measurements and integrate the information into their maintenance processes.

7. CONCLUSION

This paper has discussed the initiatives undertaken by BNSF, CSX, and ArcelorMittal to integrate wayside condition monitoring data, and the challenges that have been experienced in the process.

BNSF and CSX have experienced similar challenges, and both have made notable achievements in the progress towards integrated data and rules to increase the effectiveness of planned inspections and reduce unplanned work events. The ongoing development of more granular composite rules is aiming for fewer alarms but more targeted alarms.

Because of the captive nature of their trains, ArcelorMittal has been able to optimise maintenance procedures and repair causal components with better efficiency, and have realised great gains in their wheel and rail life.

All three railways began with manual data handling and manual alerts. All are now making marked progress towards automating the alerts and handling procedures where possible.

Ultimately, it may be achievable that when a train is in-bound to a station for inspection, it will be possible for the inspector to do a virtual roll-by of the train before it even arrives.

8. REFERENCES

ASME Rail Transport Division Fall Conference; 2009 October 20-21; Fort Worth, Texas; 2009. P. 1-6


9. APPENDIX

Derailment Cause Codes: The FRA derailment cause codes used for source data for both Figure 1 and Figure 2 are E23C, E24C, E25C, E26C, E40C, E41C, E43C, E44C, E45C, E46C, E47C, E48C, E4BC, E60C, E67C.

Definition of FRA: The Federal Railroad Administration (FRA) is an agency in the United States Department of Transportation. The agency was created by the Department of Transportation Act of 1966. One of the responsibilities of the FRA is to promulgate and enforce rail safety regulations. The wear limits specified by the FRA are legal limits.

Definition of AAR: The Association of American Railroads (AAR) is an industry trade group representing primarily the major freight railroads of North America. The AAR works to improve the efficiency, safety and service of the railroad industry. It is responsible for the industry's interchange rules and equipment specification standards. The wear limits specified by the AAR for interchange rules are in general less permissive than the FRA, but are not legally binding. For example, the AAR limit for thin flange is 15/16", the FRA limit is 7/8".