THE SAFETY IMPACT OF WAGON HEALTH MONITORING IN NORTH AMERICA

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ABSTRACT
North American railroads and car owners are using a new process of condition-based freight car maintenance strategies designed to ensure that adverse vehicle conditions are identified and rectified. Current wayside detector systems implemented by North American railroads include wheel impact load detectors (WILD), hunting detectors, truck performance detectors (TPD), hot and cold wheel detectors, acoustic bearing detector systems (ABD), wheel profile measurement systems, brake condition monitoring systems, and cracked wheel detection systems. The Association of American Railroads (AAR) Advanced Technology Safety Initiative (ATSI) is an effort to make the overall freight interchange system safer and more efficient by taking advantage of new technologies that facilitate more sophisticated assessment of the condition of in-service equipment. This approach can both enhance the performance of rail equipment and prolong the life of railroad infrastructure.

AAR and Transportation Technology Center, Inc. (TTCI) have estimated the effect of ATSI on broken wheel and broken rail accidents, and on bearing-related accidents for Class I railroads on mainline track. The Federal Railroad Administration's (FRA) safety database was analyzed for these cause codes both before and after implementation of ATSI in October 2004. The results of the statistical analysis indicate that there are substantial safety benefits associated with wayside detector implementation, with the primary benefit being improved safety. Since the beginning of the ATSI program in 2004, the North American railway industry has realized reductions in broken rail and broken wheel derailments, and bearing-caused and car-hunting-related derailments.

This paper describes the current wagon health monitoring technologies, the current implementation of a new process of conditioned-based freight car maintenance strategies designed to ensure that adverse vehicle conditions are identified and rectified. It additionally presents results from a post audit conducted by an outside consulting firm to quantify the economic benefits of various wayside detectors deployed by the North American railways. The post audit conducted by the independent consultant showed that the net benefit of wayside detectors is estimated to be $226.7 million through 2008. Research costs from 1990 to 2008 are approximately 4.782 million, representing a return on investment of 47 times its total cost.

INTRODUCTION
As many railways around the globe migrate from government-run institutions to private concessions, there may be some lessons that can be learned from North American experiences. With increasing axle loads and annual tonnage on mainline tracks, there is a continuing need to implement technology to control the stress-state at the wheel/rail interface. The historic trend in the North American railroad industry has been to meet the demands of heavier axle loads by increasing the strength of the track structure. This method requires extensive capital expenditures and does not always produce the desired results.

With recent privatizations in Canada and Mexico, the railroads of North America now operate almost exclusively on privately maintained rights-of-way. Unlike other competing transportation modes, they are fully responsible for right-of-way maintenance and restoration. They operate on about 230,000 kilometers of route and own 786,000 freight cars and more than 24,000 locomotives.

In addition to the freight cars North American railroads own, they haul about 819,000 additional cars owned by private car companies, lessors, and shippers or consignees. In the United States alone, privately owned cars actually outnumber railroad owned cars by 776,000 to 617,000. Despite ownership, most railcars move seamlessly from one railroad to another toward their destination. (A few special cars move by agreement between the car owner and operating railroads, but these are the exception.) One of the primary functions of the AAR is to provide an industry-wide means of satisfying mechanical requirements for efficient interchange of freight cars.
Some of the maintenance strategy changes described in this paper will most likely rely on car owners taking proactive steps to correct problems before they reach levels where they adversely affect the stress state of the railroad and the rail vehicle as well. This effort is led by the ATSI Task Force appointed by the AAR’s Safety and Operations Committee. The latter committee is made up of the chief operating officers of North America’s largest railroads. Much of what is described here is a “work in process” and changes are incorporated as the newly revised processes evolve.

**TRACKSIDE WAGON HEALTH MONITORING SYSTEMS**

As new technologies come on line, the number and types of detectors with Internet data access capability have grown rapidly in North America. At last count, the North American railroads have 136 WILDs, 25 TPDs, 7 wheel profile measurement systems (WPM), and 13 ABDs. More of each type of detector system is on order or in capital plans. Machine vision and other available or emerging technologies are being actively developed by TTCI, USA, in partnership with suppliers worldwide and are expected to be on line within the next few years.

Traditionally, detectors systems are set to alarm when preset criteria are exceeded. Most systems control signal aspects or are “talkers,” which communicate with the train crew by radio using a synthesized voice noting any exception detected and the axle count from the lead locomotive axle to the indicated defect.

Most wayside detectors are in an advanced stage of implementation throughout North America. The following is a description of the function and the use of some of the existing detectors in N. America.

Wheel impact load detectors, shown in Figure 1, measure vertical wheel loads as the car passes across the site. Their primary function is to measure vertical impact loads to identify out-of-round wheels for removal beyond a specific level. Many have subsequently been adapted to function as overload and imbalanced load detectors (OILD), as well as truck (bogie) hunting detectors (THD) The function of OILDs is self explanatory. THD utilize an algorithm based on the yawing motion of the wheels of the bogie relative to the track to identify poorly performing bogies and, in particular, 3-piece bogies with poor truck warp (lozenge) stiffness and/or low bogie rotational resistance to the body.

Truck performance detectors (TPD) have been deployed to monitor the tracking performance of vehicles, particularly on curved track. These detectors use either strain gages to measure vertical and lateral forces or laser position sensors to measure the lateral and yaw attitude of the wheelset (Figure 1). These detectors identify:

- Radially misaligned wheels occurring on 3-piece North American bogies when two side frames in the same truck have mismatched wheelbases
- Low bogie warp (shear) restraint from missing main or wedge springs, worn wedges, loose or worn column wear liners
- Mismatched wheel diameters on the same axle, either as a result of poor machining or as a result of eccentric profile wear between wheels on the same axle

Wheel temperature measuring devices (WTMD) use similar technology to hot box detectors (HBD) to identify unbraked wheels when they should be braking and unreleased brakes when the wheels should be running freely. Algorithms are developed to cater for a specific wheel’s temperature in relation to all wheels in the train. Unreleased handbrakes, inoperative or malfunctioning valves, and binding brake rigging are identified.

Wheel profile measurement systems measure the complete profile, identify traditional metrics (e.g., flange thickness, height, and rim thickness) and introduce new and additional useful metrics associated with the asymmetry of the wear on the wheel.

The Acoustic Bearing Detectors (ABD) are state-of-the-art in bearing defect detection systems (Figure 2). For many years railroads have relied on either HBDs or scheduled maintenance to prevent overheated bearings. The acoustic bearing detector allows railroad operators to detect defects long before they cause overheating and plan bearing maintenance based on performance. The ABD allows railroad operators to detect defects long before they cause overheating and to plan...
bearing maintenance based on performance. The minimization of service disruption is a major economic driver of an ABD as well as the prevention of catastrophic failures that can occur despite a network of HBDs. Due to the early warning capability of an ABD, a large number is not required provided that individual bearings are monitored over a reasonable time or mileage interval.

![Instrumented Track Section](image1)

**Figure 1.** The North American railway industry's existing array of wheel impact load and truck performance detectors provided the opportunity for rapid implementation of new rules for identification and removal of high-impact wheels and poorly performing trucks.

![TADS®](image2)

**Figure 2.** (l) TADS® installed on Union Pacific Railroad and (r) a photo of a defective bearing found by the system.

Recently TTCI partnered with DAPCO, a Connecticut-based ultrasonic inspection company, to develop a detection system capable of inspecting internal wheel defects such as shattered rims and wheel tread defects. The prototype system, which was subsequently installed at TTC, is capable of inspecting one side of a railcar at speeds up to 8 kph (5 mph). The design included servo-driven, tandem inspection heads guided by a rack-and-pinion system capable of tracking car wheels at speeds of 2.4 meters per second (8 feet per second). The inspection system is comprised of four stations, each with the probes and tracking systems to measure all four wheels of one side of a freight car. Figure 3 shows a production system installed at Union Pacific railroad at their Bailey yard in Nebraska. The system has been used to inspect thousand of trains and has prevented many derailments.
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Figure 3. The North American railway industry recently implemented an automated cracked wheel detector system that has prevented a number of broken wheel derailments.

Machine vision systems are the latest automated wagon inspection systems under development in the USA. Three machine vision based systems are currently being developed under the AAR's Strategic Research Initiatives Program. As shown in Figure 4 (left), the Automated Safety Appliance Inspection System (ASAIS) assesses the condition of a railcar’s safety appliances (e.g., ladders, handholds, and sill steps) and the Automated Inspection of Structural Components (AISC) system evaluates the condition of the railcar’s underframe and related structural members. The third system, referred to as the Fully Automated Train Scanning System (FATSS), is currently under development to create a complete image of the top, sides, and undercarriage of each car in a train, Figure 4 (right).

Figure 4. Trackside Machine Vision Systems: (l) ASAIS installed at Union Pacific Railroad, USA (r) FATSS, a prototype, installed at the Transportation Technology Center, Pueblo, CO, USA

Wayside Detector Databases
Data collected from the detectors is stored in the InteRRIS® database, TTCI's Integrated Railway Remote Information Service. This database provides users with the capability to make predictive, condition-based maintenance decisions without having to rely solely on visual inspection. It also makes data available to a wider range of stakeholders than possible before. This means that car owners that did not previously have access to inspection data can (given railroad permission and a password to access the data) manage their assets remotely.

InteRRIS® gathers detector data over the Internet and feeds actionable readings to Railinc's Equipment Health Management System (EHMS) for dissemination to railroads and other car owners. The EHMS uses the AEI data acquired from detector sites to determine vehicle location, direction of operation, and load condition. This information can be utilized to determine optimal maintenance locations. The Car Repair Billing database currently reports repairs made on offline cars operating in interchange. Future plans call for expanding this system to include online cars so that a car maintenance database can be developed and maintained. Further plans call for bar-coding inventory
so that a car component inventory can be maintained. Figure 5 shows a map of the United States with various detector system already installed on railroads.

![Map of the United States with various detector system installed on railroads.](image)

**Figure 5. Map of the Freight Wagon Health Monitoring Installation in North America**

**IMPLEMENTATION**

The implementation of wayside detection in North America is managed by the ATSI committee, formed of representatives from all participating railways in North America. A consequence of the interchange system in North America is that there should be common agreement on all maintenance interventions initiated by participating railroads. Consequently, performance limits must be standardized in addition to a means for reporting, correcting, and charging for vehicles and components exceeding these standards. ATSI manages the implementation process by identifying candidate detectors having sufficiently advanced, accurate, and reliable monitoring processes; it ensures that algorithms are suitable and thoroughly tested and manages the publication of rules and negotiated disputes over specific implementation issues (general disputes being dealt with through traditional processes).

Under the ATSI approach, railroads and other car owners are encouraged to more efficiently manage their freight car fleets by performing proactive predictive maintenance within a finite “window of opportunity” based upon sound scientific and engineering assessments. The ATSI safety program is a predictive and proactive maintenance system that uses the best available technology to detect and report potential safety problems and poorly performing equipment before they result in accidents or undue rail damage.

The current approach to run repairs calls for a component to have exceeded a condemning limit as set by the appropriate AAR committee. A more efficient approach, in most cases, would be to affect

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repairs proactively as a condition worsens and when the vehicle is empty and at a suitable repair point. A database monitoring component condition makes just such a window of opportunity available. The “AAR actionable defect level” is set with a suitable remaining life to failure in order to provide adequate inspection opportunity before catastrophic failure. Using a proactive/predictive maintenance approach, the car owner is provided access to detector data in the Car Performance Database. This allows the car owner to set an opening for a window of opportunity during which time the handling railroad would expect the car owner to affect needed repairs. If the car owner fails to make the needed repairs during the window of opportunity, the railroad then would make the repairs at a bilaterally negotiated price.

ESTIMATED SAFETY BENEFITS OF WAYSIDE WAGON CONDITION MONITORING SYSTEMS

Estimated Safety Benefits of ATSI
AAR and TTCI have estimated the effect of the ATSI program on train accident rates in four cause categories: broken rails, broken wheels, bearing failures, and truck hunting. (A fifth category, brake failures, did not show statistically significant results.) The FRA’s train accident database was analyzed for the relevant cause codes for the six years before and the six years after initial implementation of ATSI in October 2004. The results of this analysis are described in the following sections.

Broken Rail and Broken Wheel Train Accident Rates
The metric of interest throughout this analysis is the FRA-reportable train accident rate per million freight train miles on mainline track on U.S. Class I freight railroads. For broken rail and broken wheels taken together, this metric over the six years after implementation of ATSI (post-ATSI rate) was 0.190, 20 percent lower than the pre-ATSI accident rate of 0.238 for the six years prior implementation (October 1998–September 30, 2004). The post-ATSI accident rate for broken rail alone was 0.146, 23 percent lower, and the post-ATSI accident rate for broken wheels was 0.044, or 11 percent lower. See Figure 6.

AAR ran a linear regression on the highly seasonal broken rail and broken wheel accident count for the 14-year period of January 1997–September 2010, as a function of season (month), train-miles, and presence or absence of ATSI. The ATSI variable has the correct sign; i.e., it reduces the mainline accident count by an average of about 2.3 per month, and it is statistically significant at the p<0.0001 level. Accident costs avoided, just for reported damage to railroad track and equipment, exceed $1 million per month.

Figure 6. Impact of Wayside Detection Technology on Safety and Derailments
**Roller Bearing Failure Train Accident Rates**

On January 1, 2007, ATSI launched an effort to identify and repair cars with defective journal bearings using information from TADS®. On that date, the AAR Acoustic Bearing Detector rule went into effect. AAR compared derailments caused by burned-off journals for the 45 months either side of January 1, 2007 (the pre-ATSI period of January 2003–December 2006, excluding October–December 2003, versus the post-ATSI period of January 2007–September 2010). The analysis included FRA cause codes E53C (journal bearing, roller bearing, and overheating failure) and E55C (journal fracture, cold break, and previously overheated). As Figure 6 shows, accident rates for burned-off journals declined from 0.060 to 0.038 (37%) from the pre-ATSI to the post-ATSI period. The ATSI variable indicates a reduction in the accident count of about 1.7 per month and is statistically significant at the p<0.0001 level. Track and equipment damage costs avoided are estimated at $200,000 to $400,000 per month.

**Truck Hunting Train Accident Rates**

In July 2006, ATSI launched an effort to identify and repair freight cars prone to truck hunting. In the four years just prior to this ATSI initiative, there were about four main track truck hunting accidents per year on Class I freight railroads. In the four years since (October 2006–September 2010, the latest month that we have data), there have been a total of five train accidents attributed to truck hunting on main track in the U.S., or 1.25 per year. The accident rate has fallen by two-thirds and the accident count is down by three to four per year. Despite the low numbers, this reduction is statistically significant at the p=.001 level. Track and equipment damage costs avoided are about $100,000 per month.

As Figure 6 shows, ATSI has reduced main track accident rates from broken rail and wheels by 20 percent, from bearing defects by 37 percent, and from truck hunting by 66 percent.

**ECONOMIC BENEFITS OF DETECTOR TECHNOLOGY**

A post audit of the AAR's wayside detector research was commissioned to estimate the costs and benefits of wayside detection research for U.S. Class I railroads realized through 2008 (see Table 1 and Figure 7). The post audit considered safety benefits, research costs, and costs from increased wheel replacements. The post audit was performed by Cambridge Systematics of Boston, USA, under TTCI direction. Data from the FRA, described previously, was used for the post-audit. However, the analysis for the post audit was based on calculation of observed accident costs rather than accident rates. The following approach was used in analyzing the data:

- Categories of derailments defined for analysis included broken wheel/broken rail, overload/imbalanced load, bearings, brake related, and truck related. The cause codes previously identified by AAR as associated with each type were used for the analysis. Analysis periods for each type were established based on railroad industry interviews concerning when various types of wayside detectors were implemented.
- Queries were performed to determine the number of derailments and corresponding costs for each Class I railroad, as well as the train miles and freight train miles for each Class I railroad during the analysis period.
- The accident costs were adjusted to account for inflation using the Railroad Cost Recovery Index and multiplied by a factor of 1.65 to account for other loss and damage, wreck clearing, and unreported property damage costs, not included in the FRA-reported costs.
- The adjusted accident costs were supplemented with an estimate of the delay cost using estimated hours of train delay calculated as a function of million gross ton level calculated for previous TTCI economic analyses.
- The estimated difference in the accident cost per freight train mile was calculated before and after application of wayside detection. This unit cost was multiplied by actual freight train miles to determine estimate accident costs reductions from the time wayside detectors were implemented through 2008.

Table 1 details the estimated derailment benefits resulting from wayside detection by year and type. The net present value of the benefit from reduced derailments and other accidents attributable to wayside detection is estimated to be approximately $334.6 million through 2008.
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Table 1. Estimated Accident Benefits from Wayside Detection

<table>
<thead>
<tr>
<th>Year</th>
<th>Broken Wheel/Rail</th>
<th>Over/Imb. Load</th>
<th>Bearings/Brakes</th>
<th>Trucks</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0</td>
<td>2,601,508</td>
<td>0</td>
<td>7,083,381</td>
<td>9,684,889</td>
</tr>
<tr>
<td>2002</td>
<td>0</td>
<td>2,663,751</td>
<td>0</td>
<td>7,252,856</td>
<td>9,916,607</td>
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<tr>
<td>2003</td>
<td>0</td>
<td>2,832,734</td>
<td>0</td>
<td>7,712,963</td>
<td>10,545,697</td>
</tr>
<tr>
<td>2004</td>
<td>4,195,681</td>
<td>3,111,497</td>
<td>0</td>
<td>8,471,978</td>
<td>15,779,157</td>
</tr>
<tr>
<td>2005</td>
<td>19,384,372</td>
<td>3,593,839</td>
<td>0</td>
<td>9,785,299</td>
<td>32,763,510</td>
</tr>
<tr>
<td>2006</td>
<td>21,350,075</td>
<td>3,958,278</td>
<td>23,572,933</td>
<td>10,777,593</td>
<td>59,658,879</td>
</tr>
<tr>
<td>2007</td>
<td>21,128,527</td>
<td>3,917,203</td>
<td>23,328,318</td>
<td>10,665,754</td>
<td>59,039,803</td>
</tr>
<tr>
<td>2008</td>
<td>21,302,534</td>
<td>3,949,464</td>
<td>23,520,442</td>
<td>10,753,594</td>
<td>59,526,034</td>
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<tr>
<td>Total</td>
<td>87,361,189</td>
<td>26,628,274</td>
<td>70,421,693</td>
<td>72,503,418</td>
<td>256,914,576</td>
</tr>
</tbody>
</table>

The accident benefits resulting from wayside detection are partially offset by the costs of this technology, including costs related to installing and maintaining wayside detectors, and costs of increased wheel maintenance. Table 2 summarizes the net costs of wayside detection from 1994 to 2008 for U.S. Class I railroads. As indicated in the table, the net benefit of wayside detectors is estimated to be $226.7 million through 2008. AAR’s wayside detector research costs during this period totaled $22.6 million and are included in the $36.1 million shown in the table for equipment operation, maintenance, and research. The results show a benefit-cost ratio of over 3.0 from investments in wayside detection research and a substantial return on investment on the railroad industry’s wayside detection research investment (Figure 8).
Table 2. Estimated Net Benefit of Wayside Detection

<table>
<thead>
<tr>
<th>Description</th>
<th>NPV ($ 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment installation</td>
<td>84,953,517</td>
</tr>
<tr>
<td>Equipment operation, maintenance &amp; research</td>
<td>36,128,522</td>
</tr>
<tr>
<td>Equipment salvage value</td>
<td>-35,130,500</td>
</tr>
<tr>
<td>Increased wheel replacement</td>
<td>22,041,530</td>
</tr>
<tr>
<td>Accidents</td>
<td>-334,644,304</td>
</tr>
<tr>
<td>Total</td>
<td>-226,651,235</td>
</tr>
</tbody>
</table>

CONCLUSIONS
There are several different benefits associated with wayside detector implementation, with the primary benefit being improved safety. Since the beginning of the equipment health management program in the USA, the Class I freight railroads have realized the following safety benefits:

- The number of high impact wheels (wheels generating impacts greater than 623 kilonewtons (140,000 pounds) have been reduced by approximately 75 percent.
- Rates of accidents caused by broken rails and broken wheels have been reduced by 20 percent.
- Rates of accidents caused by roller bearing failures have been reduced by 37 percent.
- Rates of accidents caused by truck hunting (lateral car instability) have been reduced by 66 percent.

A post audit of the AAR's wayside detector research was commissioned to estimate the costs and benefits of wayside detection research for U.S. Class I railroads realized through 2008. The post audit considered safety benefits, research costs, and costs from increased wheel replacements. The post showed that the net benefit of a limited number of wayside detector implementation is estimated to be $227 million through 2008.
REFERENCES


