Automatic Rail Weight Identification System (ARWIS),
determination of rail weight through computer software to
produce accurate rail wear information for rail asset
management.

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ABSTRACT

Historically, the maintenance of accurate rail weights by location has been an issue due to mergers, acquisitions and reporting change accurately. Cost effective rail management requires accurate and timely rail wear information to obtain maximum life of the rail asset and prevent service interruption for rail failure due to excessive wear. Accurate rail wear calculation requires the correct rail weight, however if rail information is inaccurate or unavailable, then automated methods may be used to determine the rail weight. Normal rail wear and instrumentation accuracy complicate automated rail identification due to similar rail dimensions (Example: 132RE, 136RE, 141RE) where small differences in measurement make difference rail weights look the same.

The Automatic Rail Weight Identification Systems (ARWIS) application overcomes the similar rail weight issue by combining several methods to attain an accuracy rate of 97% in real-time operation. Methods of measuring rail features, rules determined by replacement practices, limiting number of rail weight and pattern matching combine to provide accurate consistent rail identification that in turn provides accurate rail wear without prior knowledge of rail weight.

This paper describes the application methods, accuracy validation and use of the ARWIS software within BNSF Railway electronic track health monitoring systems. ARWIS software improves rail replacement capital planning and provides immediate feedback to field operations concerning the state of rail assets.
INTRODUCTION

The BNSF Railway maintains over 32,000 miles of track covering 28 states and 2 Canadian provinces. One of the primary components of the track structure is rail. General rail replacement philosophy is wear replacement in curves and rail fatigue in tangent segments. BNSF plans invest over 120 million in curve rail replacement in 2007. Average cost of relaying a mile of rail in 2006 was $40 a linear foot but this depends on several factors; like rail material, fasteners, location. Goal of BNSF capital maintenance plan is the replacement of rail at Engineering wear thresholds to maximize the life of the asset.

Basis for planning rail replacement is knowing the amount rail has worn off the top (Vertical Head Loss) of either rail or the wear of gage face of the high rail (Gage Face Loss). Different methods for determining rail wear is by hand with a template device or automated instrumentation that can capture a rail profile image for wear measurement. Either method requires knowledge of the Rail Weight to determine an accurate rail wear measurement. Rail can wear from less than 1/32” to high of 3/8” in one year depending on tonnage, curvature, grade and revenue traffic. Errors due to incorrect Rail Weight can cause rail to be changed several years early or kept in service beyond life, increasing risk of failure. Simple example, 136 pound rail has 3/16” more vertical head height than 132 pound rail, in track with average wear of 1/16” per year could cause replacement three years too early or three years beyond the rail life.

GOAL

The purpose of ARWIS application is to determine Rail Weight and compute accurate Rail Geometry, Vertical Head Loss, Gage Face Loss, Rail Cant in real-time without knowledge of existing rail weight. Rail Wear information is checked against Engineering limits during the active testing for possible rail section exceeding replacement criteria. Secondly, the wear information will flow directly into Track Predictive Indices (TPI) application for delivery to Managers Roadway Planning (MRP) in less than 14 days for yearly capital rail replacement planning. ARWIS
eliminates a Manual Rail Weight process that required additional effort that delays results delivery to MRP another 30 to 60 days.

**THE “CHALLENGE”**

Rail profile image systems have been in use by geometry measurement vehicles for over 20 years. Principles are simple, illuminate a narrow band of the rail with a laser then take an image of both sides of the rail with a CCD camera equipped with a special filter to highlight the laser band. The rail images are converted to a series of X/Y coordinates for computing an array of track geometry parameters and rail geometry; rail weight, rail head loss, rail cant, etc. Sounds easy so what is the problem? Rail Image systems are installed on a moving rail car that is traveling up to 70 mph. Rail is constantly changing position in the cameras field of view due to vehicle suspension. Track geometry affects the rotation of the rail in the picture. Fluctuation in lighting conditions (cloudy versus sunny, rain, dust) affects brightness of the rail profile picture which affects generation of the X/Y measurement coordinates. Material collection on the rail (lubrication, dirt, high ballast condition) distorts the accuracy of the rail image. Lens distortion and dirt on the lens also adds to the overall distortion of the rail image. These factors plus normal rail wear alter the rail profile image from the original rolled section dimensions. The reason image distortion plays a big role in rail recognition is rail weights sections are very similar in physical dimensions. BNSF uses Imagemap equipment with camera using 768 by 494 pixel array set-up to take Rail Profile images at 15’ intervals.

**BASIC RAIL RECOGNITION**

A step in rail weight recognition is to position the rail image so comparisons can be made with a rail profile template. The process of shifting/rotating the rail image establishes a reference coordinate to compare rail features. It is easier to shift/rotate one image than the many rail profile templates to match high number of possibilities of a rail in a digital frame of 768 by 494. Step one is to shift alone the X-axis and rotate until center of web is 90% to base (Figure 2A). This sets up
for step two, shift the image along the Y-axis position by location of the best fillet match (Figure 2B).

**ARWIS APPROACH**

ARWIS identification accuracy was establish at 97% which was determined from the ARWIS version accuracy level of 94% plus what additional percentage could be attained with in a 3 month work effort. Basically split the difference between initial 94% and 100% to equal 97.5%.

The application uses a systematic approach of various methods to deal with challenges of Rail Profile imaging system.

**Methods**

- Be realistic, a philosophy
- Reduce the Number of Rail Weights to Consider
- Rail Feature Recognition
- Rules for Tie Breakers

**Be Realistic, A Philosophy**

Rail recognition with a image that is distorted because of several factors can not realistically attain 100% accuracy rate! Consider the fact of only a small percentage of rail (BNSF has over 70,000 linear miles of rail records) is changed every year and rail has a life of 2 years in very high tonnage to 20 years plus in moderate to low tonnage. Second, consider the frequency of rail geometry testing (2 to 6) and amount of rail wear per year (average 1/16” to highs of 3/8”) missing information from a single test will not seriously compromise rail wear information. Finally, all capital rail projects are field inspected prior to final approve.

**Reduce the Number Rail Weight in Consideration**

Railway companies with a 150 year history have a high number of rail weights due to changing axle loads and consolidation of railroads. BNSF standard plans for rail sections list 91 rail sections from 136 to 80 pound rail. The number decreases when considering only rail weights most common in today’s track structure, 34 rail sections for 136 to 115 pound rail. Finally reduced the number of rail weight to 16 through evaluation of BNSF rail information and selecting weights
with a certain percentages of mainline. The set of rail weights ARWIS considers in rail identification are:

80, 85, 90, 100, 110, 112TR, 112RE, 115, 119, 129TR, 131, 133, 132, 136, 141, 155

Rail Features

ARWIS calculates a set of rail features over a process of comparing a new rail profile template against the adjusted rail image. Rail image contains several hundred to thousand X-Y pairs that are not always in the same position from image to image. Rail image is not complete due to overhead position of laser illuminating rail and camera taking the image (Figure 3).

Once the rail image is in the template position, template variance is calculated from all 16 rail weights then a Chi Square Confidence Test is done to select the rail weight with a 95% or better level of confidence. Values in Chi-Square Confidence Table were formed from the rail image variances that produced correct Rail Weight Identification. Chi Square Confidence Test works great when all Rail Features calculate properly but due to challenges with the rail profile image systems, features maybe distorted and not available. To compensate a penalty system is incorporated for rail features assessment, penalty values are determined by set of thresholds for each feature. Simple example is Vertical Height exceeds Template Rail Height hence would yield a negative vertical head loss (rail grows). Fillet radius has to be with a pre-set radius range determined by several million images where rail recognition was successful. A second important function of penalty system is determine the validity (good/bad) of rail features. Primary features or too many bad rail features will mark the entire rail profile image bad for no further processing. ARWIS requires one fillet radius, one web radius, height, head width, web width and flange angle to perform final rail recognition on a rail image. **Uncataloged Rail Weight**

Important feature of ARWIS is “Uncataloged” Rail Weight, when a image Chi Squared Confidence Test fails to find a confidence level of 95% or better the rail image is mark as “Uncataloged”, if there is no confidence in the selection ARWIS will not apply a best guess. This feature plays two important functions;
1) Monitor the quality of measurement instrumentation in real-time, high number of “Uncataloged” would indicate hardware or calibration problem because images not matching known Rail Weight

2) Mark Rail Profile images so they can be located easily for investigation of possible rail weight outside recognition set or problem building with a specific vehicle instrumentation if percentage rising.

**Business Rules**

After the math is done there are cases where the Rail Weight selection is not clear, for these cases a set of additional business rules are employed to come to a decision.

*A. Gage Face Angle Check*

Cases that involve a decision with 141 pound rail the 5 degree Gage Face Angle is brought in to increase confidence of the Rail Weight choice.

*B. Rail Replacement Practices*

Rail Weights with very small differences in rail features that highlight when worn (Example 132/136) had a tendency to flip from one Rail Weight to another in a single track section. To minimize the indiscriminate Rail Weight change when confidence level is not significantly different as set of business rules based on how BNSF replaces rail is employed to decide and maintain a constraint Rail Weight through like track types (Curve & Tangent).

1. Tangent Track BOTH Rails same Weight, any change must happen on BOTH rail to change the establish Rail Weight

2. Curve Track SAME Rail Weight though out the Curve but different Rail Weights is allowed on High and Low Rail.

3. Track Features allow the Tangent and Curve Rules to be broken.
VALIDATION PROCESS

ARWIS application went through an extensive validation process prior to production implementation; Rail Weight identification and Rail Wear parameter accuracy were measured and adjusted. Prior to ARWIS, BNSF Railway employed a method of manual review/correction of Rail Weight selections for Rail Profile image data. A tedious and time consuming process that limited the amount of Rail Wear data that could be delivered to the Roadmasters and Managers Roadway Planning (MRP) in a timely manner for yearly capital rail replacement planning. The Manual Rail Profile results were perfect for comparing ARWIS Rail Weight selections and Rail Wear calculations. No field verification was done.

Validation data set contained system-wide results collected over 4 years (2002 to 2005) from BNSF railbound vehicles Car 80 and 85. One design aspect of ARWIS is the duplication of file formats used in Manual Rail Profile process, hence the effort of performing comparison, gathering differential metric for large data set was far more efficient and productive than the manual view of individual Rail Profiles. Set of automated comparison utilities were created with a process of manual reviewing 25% of Rail Profiles with differences between ARWIS and Manual Rail Weight. Manual review of Rail Weight differences was used to identify the issue for incorrect identification and make adjustments to ARWIS if the frequency was high. Process also captures the inaccuracies of Manual Rail Profile process.

Beta version of ARWIS used 55 million Rail Profiles (15’ intervals) to compile an accuracy rate of 94% correct Rail Weight selection of usable Rail Profile images. Image rejection rate was 5.5% with “Uncataloged” rate of 1%. ARWIS-II amassed an accuracy rate of 96% with 62 million Rail Profiles images with a drop of image reject rate to 4.5% and “Uncataloged” rate to less than 0.1%. Final production release of ARWIS used a new benchmark data set from 2006 due to some enhancements made to Rail Profile image equipment with final resulting accuracy rate of 97.7% Rail Weight identification with increased reject rate of 5.8% and “Uncataloged” rate of 0.27%. Rejection rate increase was due to some hardware upgrade issues that have been resolved to bring down the rejection rate to 3.8% in 2007.
Second part of the validation process was to ensure Rail Wear parameters results did not change with ARWIS. Matching the file formats allowed review of sample by sample differences for Gage Face loss, Vertical Head loss and Rail Cant. Large differences were identified quickly for investigation and software adjustment. ARWIS did change method used for Gage Face Loss in heavy lip situations (signature was zero to negative Gage Face Loss saw tooth signal), new method automatically looks for the normal Gage Face to produce a realistic measure.

APPLICATION USE

ARWIS application was place in production in January 2007, primarily used on-board all BNSF rail bound vehicles (Car 80, 85, 87). Onboard or real-time ARWIS resides on a single rack mounted PC that is connected by Ethernet to BNSF Geometry Systems (GEOWIN). GEOWIN is a BNSF application that receives measurements, analyzes, reports and stores track measurement results. GEOWIN sends Rail Profile images and location data to ARWIS and ARWIS returns Rail Weight/Wear data for exception analysis by GEOWIN. ARWIS must recognize Rail Weight and compute Rail Geometry in less than 3 seconds to be analyzed with all other geometry parameter in GEOWIN application. GEOWIN uses the Gage Face Loss and Vertical Head Loss parameters to analyze for exceptions using replacement limits established by BNSF Engineering Instruction. Along with Rail Wear exceptions GEOWIN produces a Strip Chart (Figure 5B) detail report with all primary Rail Wear parameters; Vertical Head Loss, Gage Face Loss, Rail Cant, Gage and Curvature.

Once the test measurement results is transmitted to office facilities at the end of the week, all onboard reports are uploaded into Engineering Visualization Information Center (EVIC) web application for access by all Maintenance of Way (MOW) personnel. Detail Rail Wear information (15') is loaded into Track Predictive Indices (TPI) repository for Rail Wear Book production (Figure 5A) and produce predictive Rail Wear results. Rail Wear predictive results are available through BNSF Track Predictive Indices (TPI) desktop application for territory or individual track
segment information. ARWIS has an office version to reprocess Rail Profile information if problems occurred on the test vehicle or further improvements have been made to ARWIS rail recognition or rail wear results.

Resulting goal is making all track measurement information (high-level and detail) available to all MOW personnel within 10 to 14 days of test, BNSF Track Condition Information Systems.

**BENEFITS**

The primary benefit of ARWIS is to automate and improve a manual process to delivery more, improved results in a time frame that meets MOW needs for effective capital rail replacement activates. Second, a real-time Rail Wear exception system that identifies conditions that may present a high risk to train operations. Finally, an automated quality control system that provides real-time feedback on the quality of Rail Profile measurements.

**CONCLUSION**

ARWIS was a three year project where more than 50% of the effort went into validation and analysis of results to create an application with high level of confidence in results. The accuracy goals of the application and large amount information base required a continuous cycle of investigate, redesign/adjust and retest to meet goals. Once accuracy goals were attain in an office environment the ARWIS had to operate in production conditions for 6 months to further prove readiness.

Track measurement applications need to serve as a tool for MOW to improve their effectiveness if the application does not produce believable timely results that hits the target then the application is another piece of deadware consuming resources with negative value.
ACKNOWLEDGMENTS

Development of ARWIS was supported by contract firm Tata Consultancy Services Ltd. of India. Imagemap Corporation application were used in the validation and investigation phases of ARWIS application development.
FIGURES AND TABLES

Figure 1 Rail Profile Image System

Figure 2A X-Axis Shift & Rotate Image   Figure 2B Y-AXIS Shift.
**Fixed Features**

1. Height
2. Head Width
3. Web Width
4. Web Radius Left
5. Web Radius Right
6. Fillet Radius Left
7. Fillet Radius Right
8. Gage Face Angle Left
9. Gage Face Angle Right

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**Figure 3 Rail Feature utilized by ARWIS**

**Figure 4 ARWIS Integration into Track Condition Information Systems**
Figure 5A Rail Wear Plot

Figure 5B Rail Wear Strip Chart
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Table is a matrix of the Chi Squared Confidence Test where a value of 0 signifies exact match between Rail Weight Template and Rail Image. Bold and Underline values indicate possibilities where two Rail Weight match can occur. In cases of two possible Rail Weights additional Business Rule are executed to make the correct selection.