Managing wheel/rail performance on Amtrak's Northeast corridor

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Abstract

Amtrak's Northeast corridor (NEC), with 150 mph Acela passenger trains operating on tracks shared with much slower and heavier freight trains, places unique demands on the wheel/rail system. The traffic mix runs the gamut between slow moving heavy axle load trains operating at considerable under-balanced elevations and high speed trains running at up to 7 inches of cant deficiency over an alignment far more curved than any other high speed corridor around the world. This poses a particularly challenging maintenance environment in which to operate a high-speed service.

Among its many efforts to facilitate higher speeds and more efficient services on passenger lines, the Federal Railroad Administration (FRA) has initiated a landmark project to help Amtrak engineer the wheel/rail interaction on the NEC for improved safety, ride quality and lower maintenance costs.

This paper reports on the improved curved-rail profiles that have been designed to maximize the effectiveness of limited rail grinding resources during the 2002 grinding cycle. It reports on an alternate wheel profile that will soon be tested for its ability to reduce flange wear on the high-speed Acela vehicles and for its impact on stability, wheel climb, wear and contact fatigue.

Beyond the important safety implications of this program, Amtrak is working to apply the findings to improve system reliability and to maximize the cost effectiveness of wheel and rail maintenance. The paper discusses maintenance management in general and reports on a wheel/rail management system being developed jointly between Amtrak and the National Research Council of Canada. This system will perform an integrated engineering analysis of an increasing number of data streams (e.g. measured rail and wheel profiles, track alignment and geometry measurements, and vehicle performance data) to provide guidance on wheel and rail maintenance policies and practices.

1 Introduction

In June of 2000, Amtrak and the FRA Office of Research & Development began a joint program for improving their understanding of the overall wheel/rail interaction on the Northeast Corridor with the first goal of optimizing its wheel/rail performance. It was anticipated that the optimized performance would improve ride quality, reduce maintenance costs, and enhance safety through reduction in wheel and rail wear and the corresponding forces on track and vehicle components. This effort was also in part to assist both organizations in continually assessing the impact of introducing Acela high-speed rail service to the Northeast Corridor and to provide a greater understanding of the wheel/rail system requirements for safe operations of high-speed trains in a mixed traffic environment. At the time, the Acela high-speed trainsets were in their final stages of safety qualification testing and near their introduction into 150 mph revenue service between Washington and Boston.

To facilitate progress in this effort, Amtrak and FRA also recruited technical experts from the National Research Council of Canada (NRCC) and Ensco to assist in data gathering and analysis of wheel and rail conditions and to investigate the potential for improvement in their performance. Through the course of its activity, the joint technical team collected numerous wheel profile measurements at various stages of wear from a variety of passenger and freight equipment operating on the Northeast Corridor, utilized laser-based profile measurement systems to continuously map the rail profile over the entire corridor, and reviewed Amtrak’s friction management, rail grinding, and wheel re-truing practices. The following paper summarizes the progress made to date by this joint investigative team.

2 The North American high-speed challenge

Amtrak provides its high-speed inter-city rail transport service under one of the most challenging railway maintenance environments in the world. The high-speed service over the Northeast Corridor (NEC) between Washington, DC and Boston, MA travels over a limited number of tangent sections at 150 mph. Along the route the service traverses curves as sharp as 6^o to 8^o with 5 in. cant deficiency at 30 mph. At the higher speed range, the route includes 1^o curves with 7 in. cant deficiency at 130 mph.

High-speed service is provided by the Acela train-sets with 17.5 ton axle-load coaches and 28.1 ton axle-load power cars. Substantial portions of the same track are subjected to heavy haul freight moving up to 50 mph with 35.8 ton axle loads. At one particular section of the railroad where high speed and heavy haul traffic share the same tracks, the annual traffic is 15 MGT passenger and 37 MGT freight. No other high-speed intercity railroad in the world allows heavier axle-load freight service (not to mention heavy haul) to travel over the same tracks as high-speed service. Adding to this harsh loading environment, the same railway line also accommodates trains from six commuter authorities in and around the major cities through which the line traverses. The result of this is a severe limitation in access time for line maintenance.

Planned service improvements by Amtrak, the commuter authorities, and the freight users of the Northeast Corridor will require further increases in train operating speeds, traffic volumes, and vehicle weights. As with most railway businesses, these service improvements must be accomplished under reduced funding levels for both capital and operational expenditures. The technical challenge for Amtrak's managers is to learn how to do MORE with LESS within the age-old competitive environment that exists between train operations and maintenance. To accomplish this, the manager must first have a comprehensive understanding of the infrastructure and its components, how the structure functions and how it deteriorates. Secondly, the manager must use the best available information and measuring technology to determine asset condition and performance to assist in the decision making process. Such information will assist the maintainer to implement preventative practices to apply his limited resources at the right time and place and thereby controlling the infrastructure life cycle and optimally extending the components' life with minimal "maintenance" interference. The prospect of obtaining a better understanding of the wheel/rail interaction under mixed traffic conditions explains Amtrak's enthusiastic participation in this joint program.

3 The wheel-rail interaction

The performance of the wheel/rail system is governed by the interactions that occur between four technology classes - friction management, contact mechanics, metallurgy and vehicle dynamics (Figure 1). Optimizing the wheel/rail interaction is a process of making small adjustments in some or all of those classes, exploiting the synergies that exist between them to multiply or "leverage" those small changes and maximize the net benefits. This "systems" approach is necessary to avoid the all-too-common result of making changes in one element of the system that produces an unexpected (and usually undesired) impact on some other element of the system.

The mixed-traffic environment presents a particularly challenging problem for railway engineers. Superficially, the demands on the wheel and rail system for passenger and freight operations are similar. In both cases, contact stress and wear must be balanced to maximize life, stability of the vehicle must be maintained within safe limits, the potential for wheel-rail related derailments must be minimized, and wheel/rail noise must be controlled. But the devil is in the details…. Table 1 below compares the operating environments for freight and high-speed passenger (and includes rapid transit for comparison purposes. Since the performance priorities differ in each environment, clearly it will not be possible to meet all the needs of both freight and high-speed passenger on the NEC. An obvious example is the selection of rail superelevation. A value is typically used which forces lower speed trains to run at under-balance speed, often overloading the low rail and contributing to fatigue or plastic flow of the low-rail surface. At the same time, high-speed trains are running at over-balance speeds that contribute to passenger discomfort, high flange forces and excessive flange and gage-face wear.

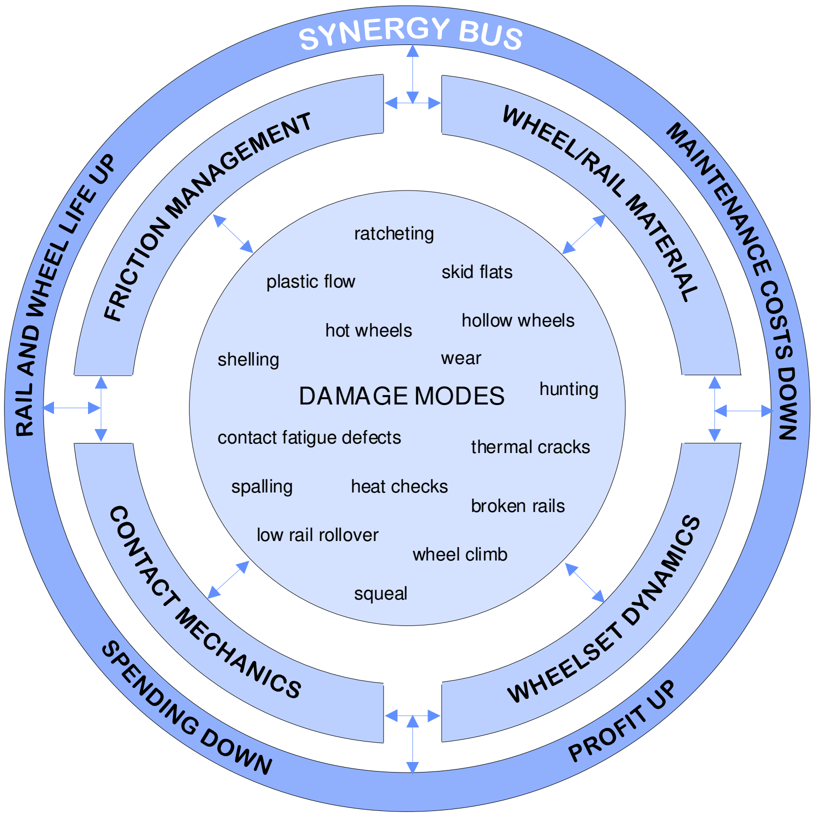

Figure 1: The performance of the wheel/rail system is governed by four key technology classes: friction management, contact mechanics, metallurgy and wheelset dynamics.

Table 1 : Comparison of operating conditions for freight, transit and high-speed passenger.

	Freight	**Transit**	**High Speed Passenger (Amtrak)**
Axle load (tons)	35.8	8	17.5 coach and 28.1 powercar
Speed range (mph)	40-50	30-50	125-150
Cant deficiency (inches)	Often below balance speed, rarely over	Run at balance speed	2”-9”
Wheelbase (feet)	“Short” (e.g. 5’ 10”)	Short to long	Long (e.g. 9’ 5”)
Truck stiffness	Relatively flexible	Flexible to very stiff	“Rigid”
Performance priorities	Maximize asset availability Minimize maintenance expenditures Minimize derailments	Safety Ride quality Noise Wear and fatigue	Safe operations Achieving schedule Minimize unplanned maintenance

Amtrak’s NorthEast Corridor (NEC) is heavily focussed on achieving a favorable environment for high-speed running that accepts limited freight traffic. This is a substantially different scenario than the many other Amtrak routes over track that is maintained for freight trains but accommodates limited passenger traffic. From a performance perspective, the NEC is therefore most concerned with:

Safety: Wheel/rail related safety issues include wheel-climb derailments, low-rail rollover (under heavy axle-loads) and broken rails from surface fatigue and impacting wheels.

Stability: To achieve the desired reductions in travel time for passengers on its premium Acela service, Amtrak aims to achieve 150 mph operation on all supportable sections of the railroad. It is currently limited to 130 mph on curves due to vehicle lateral force exceptions associated with various modes of oscillation in the truck and carbody.

Curving: The current high-speed, high cant-deficiency operation of Acela trains on the NEC is resulting in rapid wheel-flange wear[1].

These performance parameters all have a dramatic impact on component life and comfort, which are measured in terms of ride quality, wheel/rail noise, wheel and rail wear, stress to track components and wear and fatigue of vehicle components. Extending wheel life by reducing flange wear (99% of Acela wheels are re-trued for thin-flange) will minimize the train out-of-service time associated with wheel re-truing. Improving stability reduces damage to bogie components and track alike, and may help Amtrak to achieve the desired operating speeds.

Although issues such as flange wear and stability are the result of interactions between many different properties of the system, this program chose to focus initially on the wheel-profile design. The performance of the current wheel was investigated and analysis conducted to determine whether it is possible to engineer an alternate wheel profile to reduce wear and possibly address some vehicle ride quality issues (especially in curves) without compromising the overall vehicle stability.

3.1 Improved wheel profile

The wheel profile can have a dramatic effect on the performance of the wheel/rail system. Its contribution appears directly in the contact mechanics and wheelset dynamic classes of Figure 1. A wheel profile that simultaneously reduces contact stress and improves curving contributes tremendously to a reduction in wear, fatigue and fuel consumption. Transit examples include Dallas, Los Angeles [1] and Vancouver [2]. BHPIO Railway [3], the Cartier Railway Company [4], Spoornet [5], and the Canadian Pacific Railway [6] are heavy haul lines that have benefited from an improved wheel tread shape.

The wheel profile currently employed by Amtrak for its Metroliner and Acela fleets is called the “Amtrak Standard”. Figure 2A shows that wheel superimposed on the current rail grinding templates for curved rail. The Amtrak wheel has an AAR 1:40 taper shape and clearly exhibits a heavy two-point contact with the high rail. The normal force and frictional work expended at the wheel-flange/gage-face contact are very high for this design. These correlate well with the high rates of wheel-flange wear found in practice, especially in the earliest stages of wheel life.

Starting with the general worn shape of the Amfleet and Acela wheels, NRCC engineered a new wheel profile for Amtrak that will significantly improve curving performance over the current Amtrak Standard profile but should not compromise the wheel stability. The performance of the new wheel profile, dubbed the “AMTK-NRCC”, is shown in Figure 2B. The comparison with the Amtrak Standard is summarized in Table 2.

The AMTK-NRCC wheel profile has also been compared with the Amtrak Standard using the NRCC’s **pummeling** model. The pummeling model performs quasi-static curving superpositions for the leading and trailing wheelsets (joined in this case by a rigid bogie of Amtrak dimensions) for a large number of measured rail pairs. A post-processor accumulates the damage indices (wear, fatigue) for each super-position and displays the results using a vector plot mapped to the profile, where the accumulations are normalized by the total number of wheelset passes. About 300 rail pairs have been used from each of two sharp curves. The 4-degree curve at Mystic runs with 7 inches of cant deficiency (at 65 mph) while trains traverse the 2-degree curve at Elizabeth with 3 inches of cant deficiency at 55 mph.

The accumulated frictional work (sum of tangential force times sliding distance) is a direct indicator of the expected wear. Not surprisingly, the graphs of Figure 3 indicate that the Amtrak Standard wheel will suffer very large flange wear rates. The accumulated fatigue index of Figure 4 shows similarly the distribution and amplitude of fatigue damage applied by that wheel to the rail (and vice versa). Clearly, the shape of the AMTK-NRCC wheel is more compatible with these measured rails than the existing Amtrak Standard.

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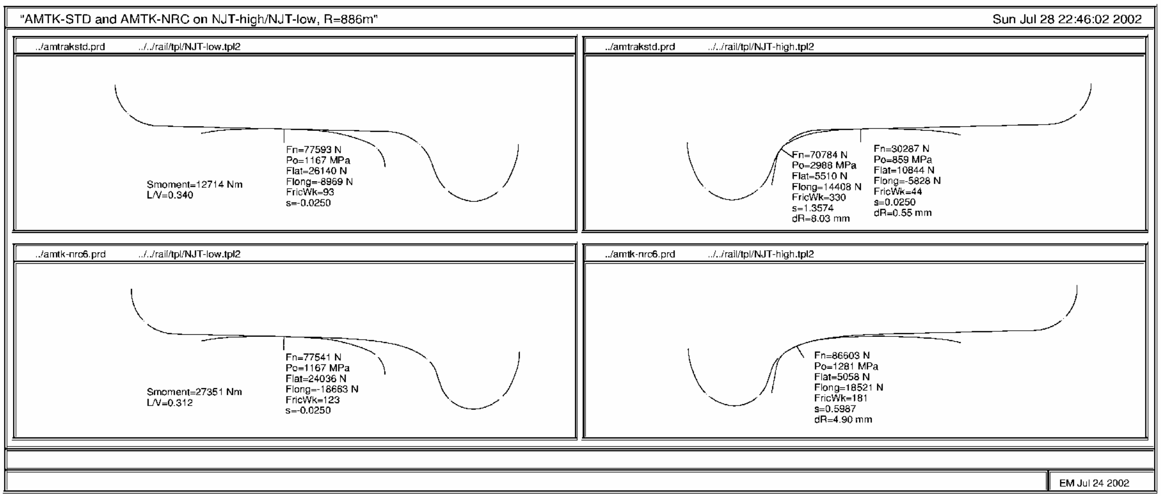
[1] Note that since Acela tonnage amounts to a relatively small fraction of total tonnage, the impact on the rail is not as noticeable.

A)

B)



Fn: normal load carried by that contact point
Po: Peak normal contact stress
Smoment: steering moment
Flat: Lateral creep force
Flong: Longitudinal creep force
L/V: net lateral force divided by net vertical force
FricWk: frictional work
s: slope at the contact point
dR: rolling radius difference compared with low rail contact

Figure 2: Wheel/rail contact conditions for a free wheelset (angle of attack, friction conditions etc. typical for the Amtrak system) with the A) Amtrak Standard and B) AMTK-NRCC wheel profiles on the nominal rail grinding templates.

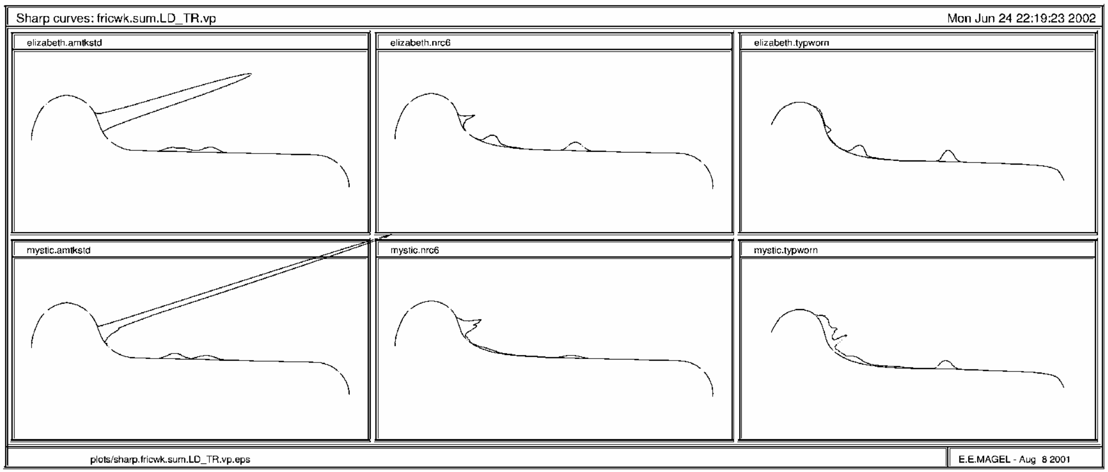
Table 2: Comparison of Amtrak Standard and AMTK-NRCC wheel profile when running on Amtrak's current rail grinding templates.

	Amtrak Standard	AMTK-NRCC
Contact type	Non-conformal 2-pt	Conformal one point
Contact stress at gage corner (Po)	100%	≈50%
Total wear (FricWk), high rail	100%	48%
Steering moment (Smoment)	100%	215%
L/V (low rail)	100%	92%
Effective conicity	100%	Unchanged

A major concern with implementing a higher effective conicity wheel is that is may make the wheel/rail system more vulnerable to instability. The AMTK-NRCC wheel possesses the same 1:40 taper of the Amtrak Standard wheel, and in normal tangent running will theoretically be as stable. The issue arises as to what happens when the wheelset experiences a strong enough lateral excursion (for example at a lateral alignment defect) that causes it to run into the flange root in tangent track or mild curves. Dynamic modeling is currently being undertaken to assess this scenario, but in the meantime, a "common-sense" approach has been taken. A comparison of the AMTK-NRCC profile with existing worn profiles shows that about 7-10% of the Amfleet and 2% of the worn Acela wheels have (or had) effectively the same profile, including the width of the flange. Since no ride instability problems have been reported for the in-service wheels that have worn to the AMTK-NRCC shape, the risk of ride problems for new wheels with the AMTK-NRCC shape is very low.

A

B

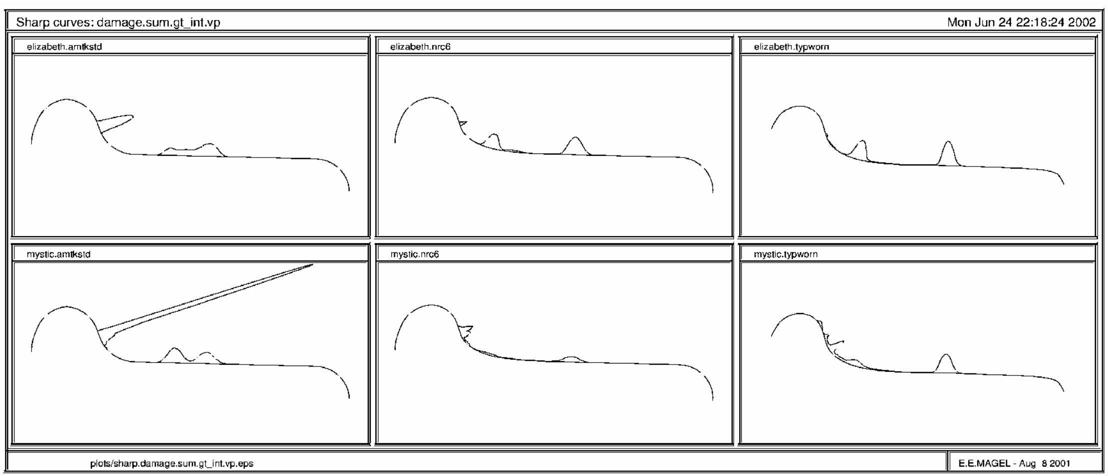


Amtrak Standard AMTK-NRCC Typical worn wheel

Figure 3: Accumulated frictional work for the Amtrak Standard, AMTK-NRCC and a typical worn wheel on Amtrak sharp curves at A) Elizabeth, and B) Mystic.

A

B



Amtrak Standard AMTK-NRCC Typical worn wheel

Figure 4: Accumulated index of fatigue damage for the Amtrak Standard, AMTK-NRCC and a typical worn wheel on Amtrak sharp curves at A) Elizabeth, and B) Mystic.

3.2 January 2002 curved-rail profiles

A pressing concern for this study was the annual rail-grinding program conducted on Amtrak at the beginning of each year. Past practice was to grind a single pass to the two high-speed main tracks, using the existing legacy rail templates as a guideline. A pre-grind field inspection in November 2001 by NRCC, Amtrak and Loram found that the worn and as-ground (in previous grinding programs) high-rail profiles showed considerable deviation from the legacy high rail template, with the shape difference being greatest for milder curves (Figure 5). This indicates that the legacy grinding templates are not stable and that the rails are being shaped in-service through wear by the passing wheels. Most of the rail exhibited very good surface condition with satisfactory running bands. It was believed that the future design of optimized rail templates in 2002 might require entirely different contact band locations than those shown by the legacy templates. Any grinding before then might increase the cost of future grinding programs. Accordingly the selective grind would not use the legacy high rail template but instead take advantage of already established wheel/rail contact bands and leave the as-worn profile on the rail. Using measured rail profiles and the wear, gage and cant information provided by the Advanced Rail Management measuring system (a task supported by the FRA), NRCC developed for Amtrak two high-rail profiles, one each for sharp and mild curves.

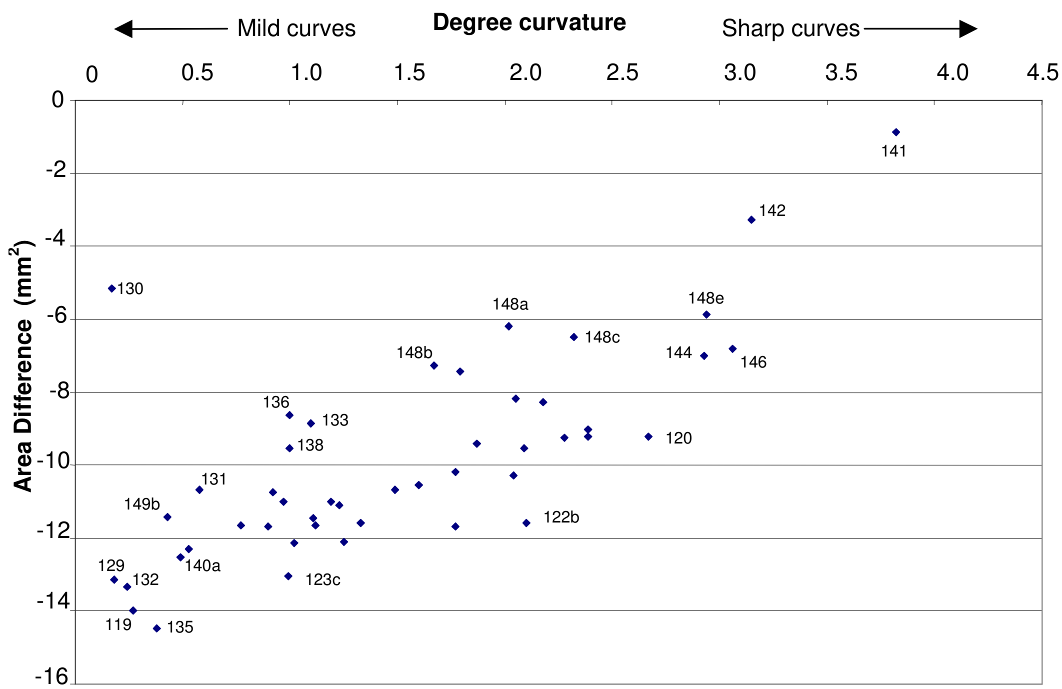


Figure 5: Plot of the area difference ("metal-removal") between existing worn high rails and Amtrak's legacy high rail template, as a function of track curvature. Mild curves (low degree curvature) showed a large gap at the gage side while the gap on higher curvature high rails is less. Several points are labeled with Amtrak curve numbers.

The new sharp-curve and mild-curve high-rail templates (called the Amtrak-HS and Amtrak-HM, respectively) were based on typical worn profiles from the Boston to New Haven line. The mild-curve template has 0.014 inches greater gage corner relief than its sharp-curve counterpart. Both templates were found to fit well to the worn curve rail shapes before grinding, and the designed patterns successfully maintained that shape with 1 pass at 9 mph.

3.3 Developing site specific rail profiles

Amtrak's Northeast Corridor is a large mixed-traffic system with a wide range in annual MGT and vehicle types over the various track segments. Ten to 200 MGT of mixed traffic (Amtrak Metroliner and Acela, mixed freight, MBTA, Metro North, SEPTA and several others) is split between 2-4 tracks. Matching the wheel/rail shapes to promote safety, improve vehicle performance and extend rail and wheel life will require detailed wheel profile, vehicle characteristic and track data to account for the site-specific traffic and MGT patterns. The NRCC's pummeling approach is ideally suited to this task, since it incorporates many relevant vehicle and track specific parameters including wheel profiles, friction conditions, track characteristics (super-elevation, gage, dynamic rail rotation) and vehicle characteristics (bending and shear stiffness, wheelbase, wheelset torque etc.). Much of this data is already available in some detail, including the rail profiles collected by the ARM system and very detailed track configuration, layout and geometry measurement information warehoused in Amtrak's Maintenance Management system (see Section 4).

Amtrak is also putting into place systems for automated measurements of wheel profiles, wheel impact loads, L/V forces and wheelset angles of attack. This data will be utilized in NRCC's pummeling model to develop site-specific rail profiles matched specifically to the wheel distribution that a given section of track encounters.

Although NRCC's pummeling approach is an effective tool for evaluating wheel/rail performance, it is a computationally expensive process that may not be the most practical approach all cases. The NRCC is working on techniques for rationally condensing the very extensive wheel and rail profile data - *on an updateable, site-specific or fleet-specific basis* - to a smaller, but still representative sample of wheels and rails. Sensitivity analysis is being performed to ensure that the proxy distribution does not overly compromise the accuracy of the pummeling results. But besides the pummeling approach, the NRCC is developing other techniques to more quickly characterize the wheel/rail interaction. One example is the "conformality analysis".

Conformality is a measure of the "closeness" of shape of the wheel profile to the rail profile. The definition of conformality is shown in Figure 6 for a) single point contacts and B) two point contacts [7]. The conformality analysis consists of superimposing many wheels on a particular rail section (or one wheel profile over many rail sections), determining whether the contact is single- or two-point, and evaluating the separation. These are then plotted as a histogram with at least three bins for separations less than 0.1 mm (closely-conformal), from 0.1mm to 0.4mm (conformal), and greater than 0.4mm (non-conformal). An example of the results is shown in Figure 7. The probability of Acela, Amfleet, and freight wheels having conformality values in each bin are shown as stacked bars - the sum of all the bar heights is 300%.

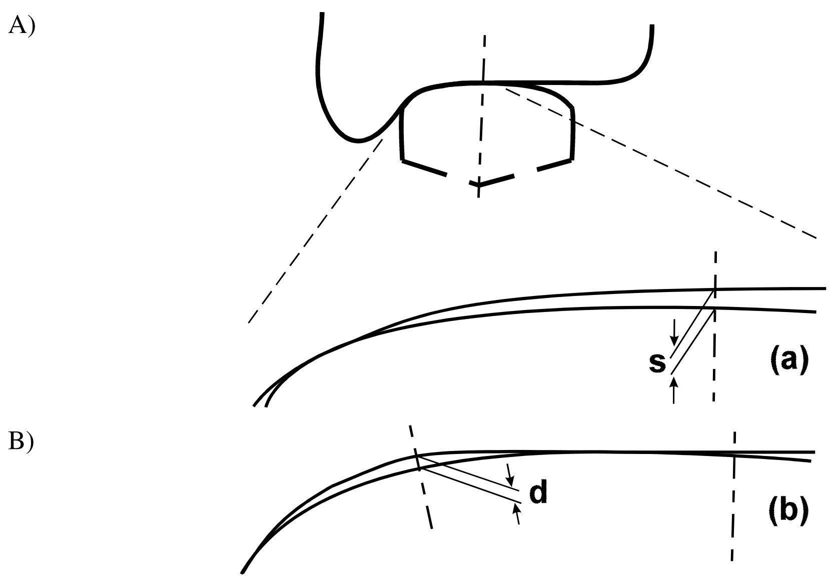


Figure 6: Definition of conformality for A) single- and B) two-point contacts.

Figure 7 shows that of the closely conformal wheels, i.e. whose shape is within 0.4 mm (0.016") of the rail, most are from Acela and Amfleet vehicles. While a few freight wheels do have the shape of the rail, the bulk is non-conformal. In this example, more than two thirds of all contacts are 2-point and non-conformal, with the freight being especially non-conformal. Since (non-conformal) single-point contacts contribute to contact fatigue, while (non-conformal) two-point contacts are responsible for gage face wear, the conformality distribution is a direct indicator of how well the rail profile matches the wheel profiles. The wheels running over Aberdeen Track 4 are unlikely to pose a hazard with respect to high-rail gage-corner fatigue (like that which led to the Hatfield incident in the UK) but gage-face and wheel-flange wear will be quite severe. Indeed, the existing Acela wheel profile, through nearly all its life, exhibits a non-conformal two-point contact, and so exhibits high wear in virtually all of the NEC curves.

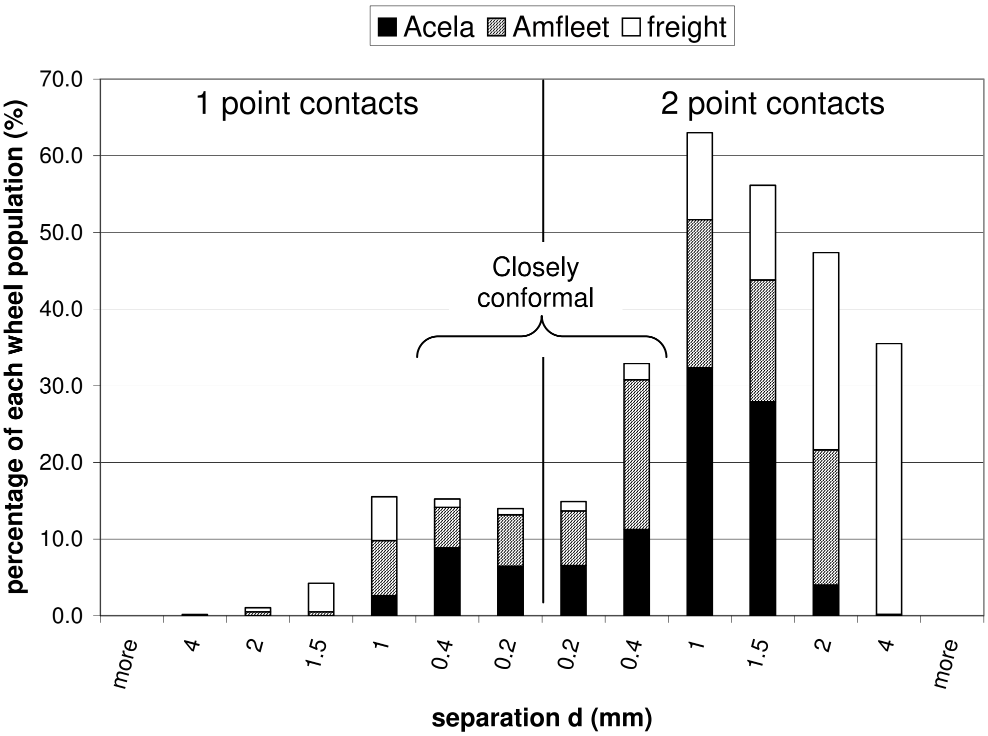


Figure 7: The results of a conformality analysis for Acela, Amfleet and freight wheels on a sharp curve at Aberdeen, track 4.

3.4 Assessing and addressing friction management practices

Although the project has to-date focussed on the wheel and rail profile designs, the next major effort will be friction management. Friction management is the process of controlling and maintaining the friction coefficient across the wheel/rail contact bands to values most appropriate for optimal performance of the wheel/rail system. Most often this is translated to consider only wayside lubrication of the gage side of the rail or vehicle mounted oil sprays or sticks applying a lubricant to the wheel flange. But top-of-rail friction control can be a powerful tool for addressing problems not treatable by gage side lubrication, including some forms of wheel/rail noise and corrugation, high lateral forces, and possibly vehicle instability. Friction management may in fact be even more powerful than profiles in treating problems of wear, fatigue and vehicle stability. Profiles and friction management, working synergistically, can be a powerful and cost effective antidote to a number of wheel/rail performance issues.

4 Maintenance Management

Amtrak's fixed infrastructure maintenance approach is to introduce condition-based preventive-maintenance practices at the rate that measuring technology becomes available. At present, Amtrak's track-maintenance is based on a 2-week cycle of geometry condition assessment using maintenance intervention levels to pro-actively address problem sites before conditions develop into safety level exceptions. The AMM decision support system provides the maintenance management information required to accommodate this preventive track maintenance activity.

As a next step, a wheel/rail management system will be designed and developed to link the fixed infrastructure information with the vehicle information to service the wheel/rail interaction modules. A number of challenges exist with this endeavor, the most fundamental being the successful linkage of moving asset information to the fixed tracks over which that asset travels.

The rest of the maintenance management discussion will give a description of the AMM system, its use and a conceptual description of The Wheel/Rail Management System.

4.1 Fixed Infrastructure Information Management System (AMM)

The AMM System [8] consists of an infrastructure information database and various applications that access the information in the database to manage the railway's infrastructure. *All information components of the database are referenced to the physical location of each asset and its functional relationships with other assets, therefore all information is relational via asset location and function.* Asset information components consist of:

- LAYOUT defines the railway network with accurate definitions of asset and component location, descriptive attributes, and network relationships.
- CONDITION of the fixed infrastructure assets based on quantitative measurements and tests, qualitative visual inspections, and failure records.
- A history of maintenance WORK required to provide a serviceable railway as well as the future programmed maintenance work to ensure future availability.
- UTILIZATION of the railway in terms of train operating speeds and cumulative tonnage over the layout.
- FINANCES needed to ensure profitable operations measured in terms of revenue and expenses. This set of data will also be used to determine book value/depreciation of fixed assets, level of capitalization, fair allocation of maintenance expense and state of good repair.

To facilitate the development of new applications and tools for the AMM System, either through contracts with third party developers or through collaborative efforts between Amtrak and others, the AMM Database has an open structure, which is owned by Amtrak. This structure provides open, standardized access to the data for the development of new applications and tools for the System and it avoids "ownership" issues with the information in the database or the structure of the database. This approach also accommodates the protection of intellectual property rights and commercial interests in the development of independent applications for The System. This sharable database will be made available to the industry in a collaborative manner in order to encourage standardization of asset information format and to facilitate information sharing.

"Applications" refer to AMM System applications, which include software modules to import data into the database from various information sources as well as applications that access the information in the database to visualize the information, analyze and model performance, conduct "what-if" analyses, and draw up budgets. Applications include the queries and unique tables specifically created to connect the database schema to the application.

The most commonly used application is the AMM_{TRACK} Viewer. The value of the AMM_{TRACK} Viewer is its ability to pull together the various maintenance management data elements and relate the information to an electronic track chart. Through this graphical visualization, correspondence between infrastructure assets, measured conditions, work input, traffic characteristics and resulting maintenance costs becomes readily apparent. This allows more informed decision-making and better management of the fixed infrastructure.

A good example of the use of the AMM system to present maintenance management information related to rail decision support is shown in Figure 8. The railroad layout is shown in the first window and the curvature of track 2 is shown in the second window. The ARM rail profile/wear measurements are shown in windows 3 to 6. The rail flaws detected and removed on the west rail are shown in window 7, which is date based, gage measurements are shown in window 8, and the maximum authorized speed over track 2 is shown in window 9.

At mile 91 plus 4299' the west rail shows a spike in the gage and head wear. By investigating the rail profile measurements on either side of the spike and the rail flaw data, it can be seen that an unworn rail plug was welded into the worn section to remove the Head and Web Separation flaw. This causes an abrupt change in the running band on the rail. Making these types of information sets available to the forces in the field can substantially reduce the instances of mismatch and ride quality issues. It also increases the awareness of the workmanship.

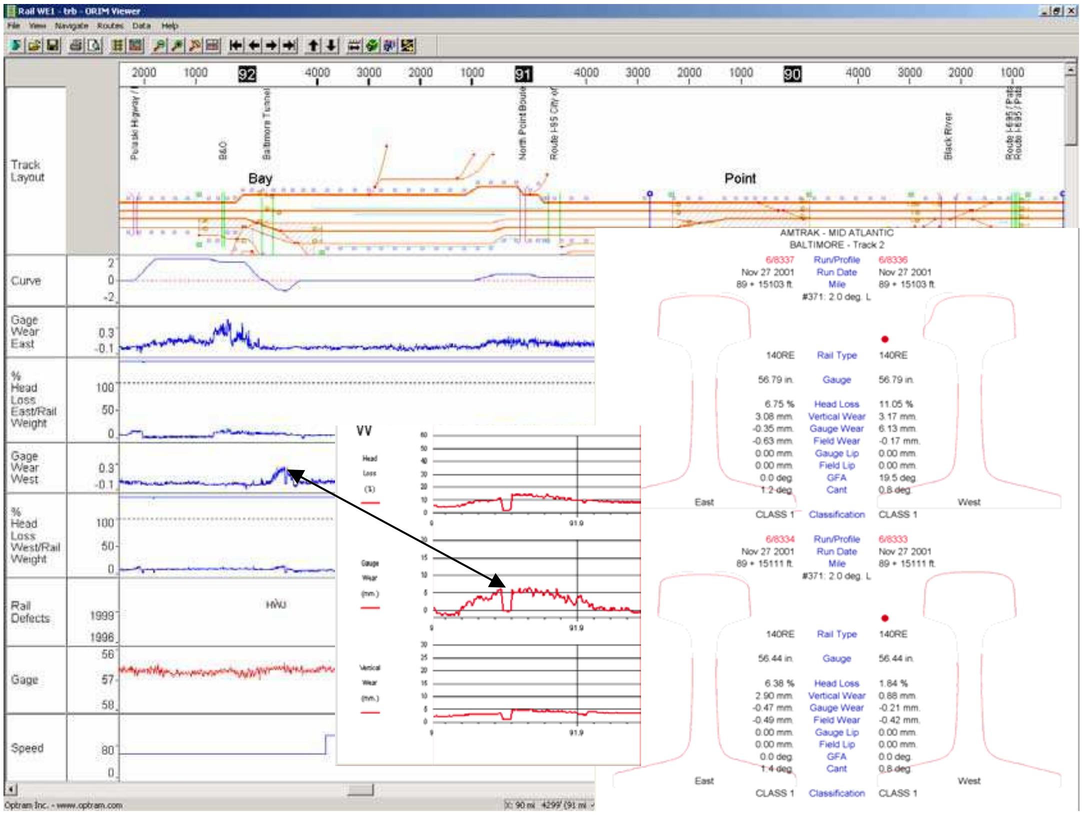


Figure 8: A typical graphical screen from the AMM$_{TRACK}$ Viewer.

4.2 Wheel/rail Management System (W/R)

The W/R system integrates all data streams on traffic, vehicle characteristics and the track over which it travels as well as the financial aspects that impact those assets. With the processed data and reports presented, both track and rolling stock managers are given a system view of their assets, their deterioration rates and root causes. The system is based on predicting wear trends and life spans of the key vehicle and track components with the capability of performing extensive “what if” analyses of maintenance interventions. Its objective is to promote a cross-functional approach to continuous improvement in both asset life and service levels.

The performance of the vehicle cannot be evaluated without consideration of the track traversed, just as the performance of the track depends on how it interacts with the thousands of wheels that pass over it. The profiles to which the wheels and rail wear are interdependent (Figure 9), as are the locations, severity and rates of deterioration. The FRA sponsored project to better understand the wheel-rail interaction at Amtrak is providing valuable insights into the parameters that govern the high-speed rail/wheel interaction and the maintenance management information that must be compiled to optimize the wheel and rail life. Amtrak and the National Research Council of Canada are working together to encapsulate the data, relationships, analysis, and intervention recommendations into an integrated wheel/rail management system.

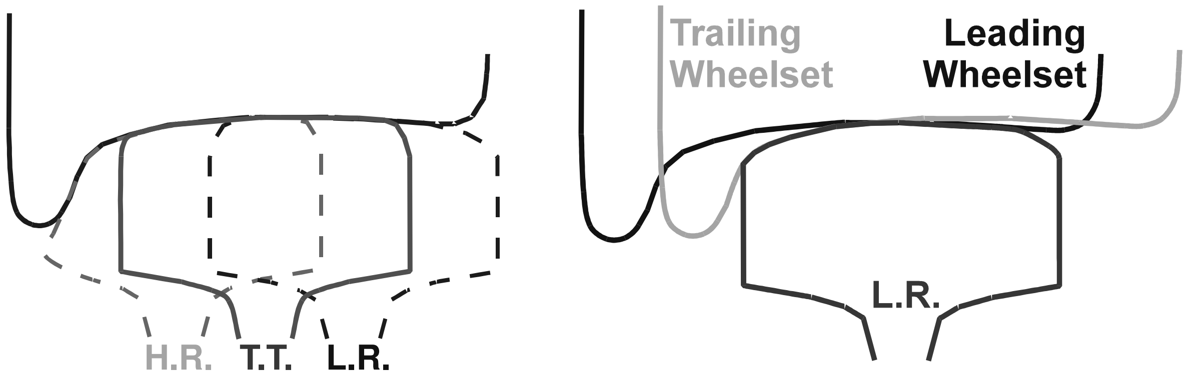


Figure 9: The worn wheel shape is an envelope of all the rails that it runs over, while the worn rail shape is an envelope of all the wheels that run over it.

The W/R management system will consist of vehicle database, fixed infrastructure (AMM) database and management applications that tie the wheel information to the rail over which it travels in order to support maintenance decisions on these two components. The rail information resides in the AMM database while the wheel database remains to be designed. *This database will have all information components recorded based on vehicle identification and axle numbers*. The wheel information components consist of:

- VEHICLE NUMBER and TYPE and axle configuration
- Measured CONDITION of the wheels (axle and journal box information, as well as other subjective inspection results can also be recorded)
- WORK conducted on the trucks e.g. wheel truing date and metal removed, truck maintenance work.
- Vehicle routes and mileage – TRAFFIC.
- FINANCES - revenue generated and expense incurred by each vehicle.

The NEC consists of primarily 2-track territory between Boston and New Haven, 4-track territory between New Haven and Wilmington and 3-track territory between Wilmington and Washington. The most important first step in building the W/R database is to track the routes that each train takes. This will tie each train to the set of consecutive track segments (point of switch to point of switch) it traverses. This will enable Amtrak to apportion the deterioration caused by each service over each segment of track, and assess the fair allocation of the maintenance cost to each user of the NEC. This information, as well as revenue generated over the track segments, will play a major role in determining maintenance prioritization. The train route information is available in the operations records and the revenue information is available in the reservation system. These informational components need to be combined in the W/R system. To assist in verification of the train movements as well as obtaining the induced loads, speed, train make-up and routes, measurements being gathered at wayside impact and hotbox measurement sites can be used.

While the AMM system greatly facilitates preventive maintenance activities for track, there remain several activities at Amtrak that are not condition based. Rail profile maintenance and rail grinding are addressed through an annual grinding program. The management of wheel condition is based on a fixed inspection cycle using standard go-no-go gauges. Lubrication is still practiced in a relatively de-centralized fashion with varying rates of success. But the progressive investment in on-line inspection systems throughout the NEC makes feasible greater management of the track and vehicle condition than has ever been possible previously. As an example, the Acela train-sets are inspected about *every four days* using a Hegenscheidt laser-based measuring system that assesses wheel conditions such as profiles, flange thickness, height, diameter mismatch etc.

Several other sources of vehicle data will soon be on-line. Amtrak is starting a campaign to monitor vehicles operating on the NEC territory, with the aim of limiting damage to the infrastructure and reducing the risk of catastrophic events. The strategy is to identify and remove any hazardous vehicles on the NEC right-of-way, thereby preventing them from affecting the operations of the railroad. It is anticipated that at least 10 sites along the NEC will be prepared in the next couple of years. As these sites are brought on-line, the information gathered will contribute to the complete representation of vehicle movement and traffic characteristics in the W/R database.

Monitoring sites will comprise of the following measurements:

1. Weigh-in-Motion measurements are used to identify over-loaded and unbalanced loaded vehicles, and protect against:
   - Structural failure from the overloaded car.
   - Over-turning or derailment of the unbalanced car.
   - High wheel loads that cause accelerated deterioration of the infrastructure.
2. Wheel Impact Detection to identify dynamic impact loads that could cause catastrophic failures such as broken rails, fractured wheels, and broken axles.
3. Vehicle Dimension measurements to detect oversize cars for the intended route, and shifted loads to prevent side swipes and collisions.
4. Car Identification to be incorporated into each site to pinpoint and monitor specific bad acting vehicles.

Amtrak is also developing a special research site at Midway, NJ for assessing additional methods for evaluating wheel/rail interactions. Besides the standard weigh-in-motion testing, the site will evaluate the shape of the measured vertical accelerations in order to obtain more information on wheel defects. This wayside research instrumentation site will also include Angle of Attack measurement equipment to detect "bad-actor" trucks and provide vehicle performance information. An additional site is being prepared at the Sunnyside yard for the installation of automated wheel-profile measuring equipment. All the aforementioned information will be kept in the W/R database and be made relational to train number, which will additionally provide train-consist make-up information.

The availability of accurate and up-to-date information from both vehicles and track greatly facilitates the construction of a system to characterize and manage the wheel/rail interface. Analytical techniques, such as the conformality analysis described in Section 3.3 can be automated and readily applied to each track-segment if the traffic distributions and wheel profiles are known. Other techniques for assessing contact stress, wear and stability are under development. As knowledge accumulates through analysis of the physical data collected from the Amtrak monitoring sites, the wayside instrumentation site, and the angle of attack system, additional techniques will be developed, refined and validated. Track and vehicle databases can then be linked with a wheel/rail management system to assist maintenance and intervention decisions based on indices related to safety and cost.

An example of what the W/R management outputs might look like is shown conceptually in (Figure 10) for the track parameters. The format is very similar to that already provided by AMM. By linking the track data to the population of wheels that is running over that track, various performance indices are evaluated and displayed on a mile plus foot basis. Shown in Figure 10 are indices for wheel-climb, wear and contact fatigue. Correlating those parameters to rail-defects, wear rates and measured track data such as geometry irregularities (e.g. track twist, lateral alignment) makes the cause and effect relationships much more visible.

The system will provide numerous benefits for the mechanical department as well. Wheel geometry parameters generated from the measured wheel profiles can be tracked and the estimated date of wheel removal projected. Unusually rapid wear rates, which may point to hunting or maintenance problems, can be automatically flagged. Hot box readings, wheel impact data, angles of attack and L/V measurements can be processed statistically to provide measures of the current state, the variation about that value, and the probability of exceeding a threshold in a predefined time interval. Consistently large angle of attack readings correspond to a greater risk of wheel climb. Pummeling analysis of the wheels using rail profiles characteristic of the route it travels provides the stress distributions over the tread to indicate the risk of wheel climb and wheel fatigue. Simultaneously, the pummeling analysis will identify track locations with highest wheel climb and L/V indices and assess the damage that the wheel is inflicting on those rails. For both track and vehicle, areas of highest risk or greatest cost can be identified for priority attention through user defined threshold setting and filters. Recommended treatments for these detected problems and extensive what-if analysis will be available via an integral reporting system (Figure 11).

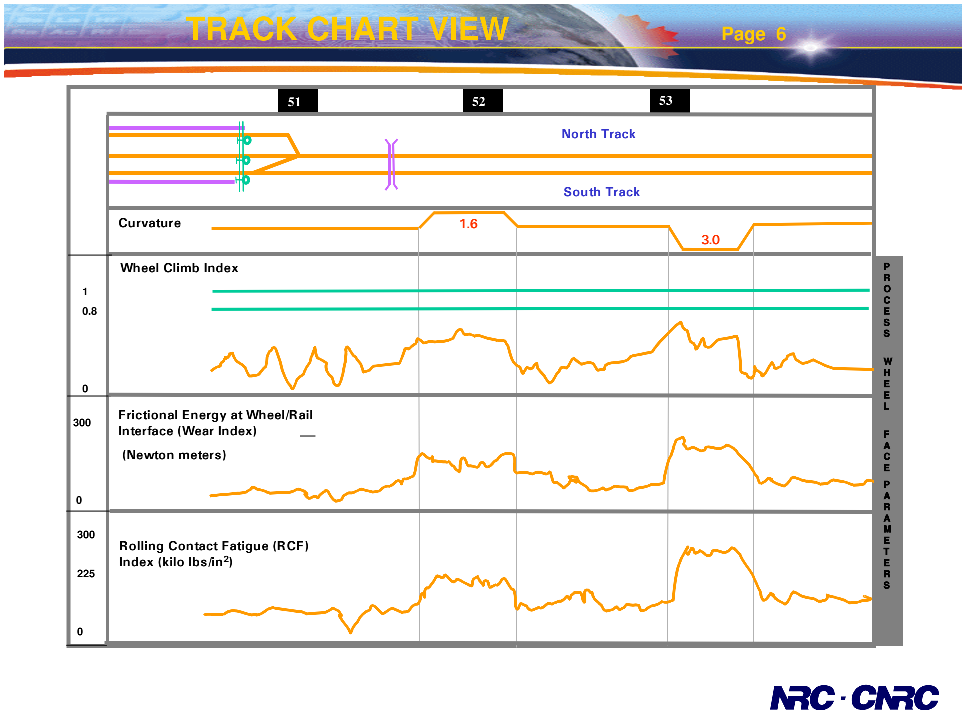


Figure 10: An example of the expected output from the V/T management system - track performance and indices of risk are plotted on a mile+foot basis.

RAIL PLANNING REPORT

CURRENT CONDITION		WHEEL RAIL DIAGNOSTICS		RECOMMENDED INTERVENTION		
MILE from	51+3273	Wear Index	70	Grinding		
				Action	New Replace yr.	Benefit /cost
MILE to	52+2640	RCF Index	225	Reduce to 25mgt interval, Pattern 10	2004	4
RAIL Wt.	140RE 370BHN	Max. Unbalanced Elevation	5.0	Lubrication		
Deg. of Curvature	3.0	Lubrication Index	0.25	Action	New Replace yr.	Benefit /cost
Current % Wear	35%	Max. L/V Predom. Vehicle	0.8	NONE		
Accum. Tonnage	293			Geometry		
Vert. Wear Rate	0.007"/mgt			Action	New Replace yr.	Benefit /cost
Lat. Wear Rate	0.015"/mgt			NONE		
Fatigue Rate	1.5def/mi/yr			Wheels		
Replacement year (No intervention)	2003			Action	New Replace yr.	Benefit /cost
				Reduce Wheel Impact Threshold for Truing	2005	2.5

REPORTS

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Figure 11: A sample report from the V/T management system – recommended interventions are based on available inputs and "what if " scenarios will be available to aid in decision making.

Since several elements of The Wheel/Rail Management system have only recently emerged from the conceptual stage, the system is obviously not yet ready for production. But both Amtrak and the National Research Council of Canada, firmly believing in its applicability and value to not only Amtrak but to railroads everywhere, are forging ahead to put the necessary personnel, hardware and software prerequisites in place. The W/R management system, by providing the information and reporting tools necessary to identify track, vehicle or maintenance practices that are contributing to the highest cost and risk, is expected to be of tremendous assistance in many of Amtrak's maintenance and risk mitigation activities.

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