Burlington northern Santa Fe preventive gradual grinding initiative

Stanford, John; Sroba, Peter; Magel, Eric

Publisher's version / Version de l'éditeur:

Proceedings of the 1999 annual conferences: communications and signals, Baltimore, Maryland, August 29 - September 1, 1999; track and structures, Chicago, Illinois, September 12 - 15, 1999, 1999

BURLINGTON NORTHERN SANTA FE

PREVENTIVE GRADUAL GRINDING INITIATIVE

by

John Stanford
The Burlington Northern Santa Fe Railway Company
2600 Lou Menk Drive
Fort Worth, TX 76131-2830
Telephone: 817 352 1983
Fax: 817 352 7415
email: john.stanford@bnsf.com

Peter Sroba
Centre for Surface Transportation Technology
National Research Council Canada
160 Arbour Lake Way N.W.
Calgary, Alberta, Canada T3G 3W9
Telephone: 403 208 7063
Fax: 403 241 7272
email:

Eric Magel
Centre for Surface Transportation Technology
National Research Council Canada
3250 East Mall
Vancouver, British Columbia, Canada V6T 1W5
Telephone: 604 221 3122
Fax: 604 221 3088
email:

ABSTRACT

Burlington Northern Santa Fe (BNSF) has over 37 years of rail grinding experience and has utilized all types of rail grinding strategies - from corrective to maintenance to preventive. In the early 1990's, the Burlington Northern Railroad was grinding on a 18 to 40 million gross ton (MGT) interval. They had "caught up" with their rail surface defect problems and the rate of detail fracture defects was declining. In the mid 1990s, however, traffic and tonnage increases, partly stemming from the merger between the Burlington Northern and the Santa Fe railroads, reduced available track time and grinding pass miles, causing the grinding program to fall back into a corrective grinding mode. Rail surface defects and detail fracture rates increased accordingly.

The BNSF commissioned the National Research Council Canada (NRC) in 1997 to assist with a transition back to the favored preventive mode of grinding. A new grinding method called the "preventive-gradual" strategy was developed. This technique allows the immediate adoption of preventive grinding intervals without first restoring the rail to a clean surface condition. The rail gradually returns to a damage-free state as additional metal is removed on each pass.

The preventive-gradual grinding strategy was implemented on the BNSF's 8,000 mile Pacific Northwest territory in February 1998. Test sites were established and monitored to evaluate the economic and performance benefits of the preventive gradual strategy compared to other grinding methods. Results after the first year of the program demonstrate that economic considerations favor the preventive-gradual grinding strategy.

1 INTRODUCTION

The 34,000 mile Burlington Northern Santa Fe Railroad (BNSF) was formed through a merger in 1995 of the Burlington Northern Railroad (BN) and the Santa Fe Railroad (ATSF). This heavy haul coal, grain, inter-modal and bulk commodity railroad extends from the west coast cities of Seattle and Los Angeles, to El Paso in the southwest, Minneapolis in the midwest and Galveston and Pensacola in the southeast. Traffic density, axle loads and speeds have continued to increase over the years as BNSF improves operating efficiencies. At the same time the track component technology and maintenance practices have also improved, reducing operating costs and addressing the increasing demands of traffic. New component technology such as premium rail steel and concrete ties have been installed in high tonnage and sharp curve territories throughout the BNSF system. Rail grinding equipment has also been upgraded to significantly increase productivity.

1.1 Rail Grinding History on BNSF

Rail grinding has been an important component of the BNSF rail maintenance program for the last 37 years [Ref. 1]. In the 1960's and 1970's the BN was grinding to remove corrugations and head flow. In the early 1980's, increased axle loads and subsequent use of harder rail steels lead to deep surface spalling on the low-rail and gage-corner shelling on the high-rail. Grinding hardware and strategies then evolved to address these and other problems. Improved control systems allowed rails to be ground to specific profiles. The BN used a corrective grinding strategy, applying multiple passes with a large production rail grinder to curves at grinding intervals of 35 million gross tons

(MGT), removing defects and producing a central wheel/rail contact band on the rail. In 1986, full time supervisory staff was assigned to the grinders to perform pre-inspections and provide for better planning of the work. Grinding efficiency improved and the total pass miles ground each year increased steadily (Figure 1). By 1987 the rail surface was in much better condition, however the profiles ground produced a strong 2 point contact between the wheel and the rail (§2.2) and resulted in excessive rail-wear rates [Ref. 1].

In 1988 BN modified its grinding policy to introduce a conformal, one-point wheel/rail contact condition. Grinding intervals were lengthened to between 35 and 90 MGT and the grinding speed (Figure 2) increased by 40% in 1989. The rate of detail fractures in 1989/1990 (Figure 1) was markedly greater than previous years. The increased grinding speed, reduced grinding of the gage-corner and the longer grinding intervals were responsible for the increased fatigue damage.

In 1991, BN focussed on implementing a preventive grinding strategy. Grinding intervals of 18 to 40 MGT were introduced on curves and an interval of 35 to 60 MGT on tangent track. Locations with surface defects were ground with additional maintenance passes to apply the rail profile and remove visible surface defects. The NRC BAR Gauge templates were applied to produce a 2 point conformal (mild 2 point) wheel/rail contact condition (§2.2). Under this regimen, the total pass miles (Figure 1) and the average grinding speed increased (Figure 2). Each of the large production grinders maintained approximately 6000 track miles per year. With a smooth and clean rail surface and reduced contact fatigue at the rail gage-corner, the detail fracture rate started to decrease (Figure 1).

The Sante Fe Railway's grinding strategy in the 1990's was to apply a conformal rail profile with corrective grinding intervals of 70 to 140 MGT. The ATSF's detail fracture rate continued to increase throughout this period (Figure 1).

In 1995 the BN merged with the ATSF, creating the 34,000 mile BNSF system. Traffic and tonnage increased, but there was a less than proportional increase in the total grinding pass miles, and the amount of track time available for grinding decreased. Grinding intervals across the entire BNSF slipped to 60-200 MGT. The rail condition deteriorated rapidly, and multiple pass, corrective grinding was required to remove surface defects and restore the rail profile. Detail fracture rates were significantly higher on the combined system (Figure 1). Figures 3a and 3b illustrate typical premium rail conditions in 1997 on the high and low-rail of a 6 degree curve.

Expected rail life of 650 to 950 MGT on sharp curves [Ref. 1] were not being realized. Average rail life of between 370 to 560 MGT was experienced on BNSF in 1997 for curves from 2 degree to 7 degree in curvature. Published figures from other railroads [Ref. 2] indicated that rail life could be increased significantly for premium rail in curves with a preventive grinding program.

2 WHY PREVENTIVE GRINDING?

As demonstrated on the BNSF and many other railroads, even the best premium rail cannot prevent surface fatigue from developing in the uppermost layer of the rail steel under today's traffic and axle loads. The growth of surface (and subsurface) fatigue cracks is governed by the contact stress (§2.3) and slip. From studies conducted by the

NRC, micro-cracks develop at the most stressed portion of the rail surface within 5 to 8 MGT [Ref. 3]. In their early stage, the microscopic cracks grow very slowly. Since cracks grow faster as they get longer, their growth rate accelerates with time. The preventive grinding strategy is designed to address the damaged surface of the rail before the micro-cracks enter their stage of rapid growth. By completely removing all short cracks, the preventive mode takes advantage of the crack initiation phase and period of slow growth. Removing the thin skin of the rail surface that contains the micro-cracks can be accomplished with a single, high-speed pass of the grinder. At the same time, the "optimal" profile is maintained on the rail and a good, protective layer of work-hardened material retained. Under preventive grinding, the rail surface is maintained to control contact stress and promote wheelset steering, while at the same time retaining resistance to crack initiation and growth by virtue of its work hardened layer.

Corrective grinding results in the rail being subjected to higher contact stresses for longer intervals. Even the toughest premium rail cannot withstand this assault. Corrective grinding therefore must apply many passes at low speed to address very deep cracks. This heavy metal removal from the rail strips away the work hardened layer, while at the same time usually fails to eliminate the deepest cracks. Corrective grinding is thus associated with larger overall metal removal rates, and therefore contributes to shorter rail life. In addition, the failure to regularly address the profile results in greater lateral forces to the track structure and trucks, leading to excessive strain on fastening and truck components. The potential for truck hunting also increases considerably. Failure to regularly address welds and other surface irregularities contributes to ballast and tie deterioration.

Table 1 provides a comparison of the preventive and corrective grinding modes.

2.1 Wheel and Rail Profiles

Contact fatigue of the rail surface is the result of excessive contact stress and creepage. Both contact stress and creepage are governed by the wheel/rail contact geometry, which in turn depends not only on the initial, unworn geometry of each component, but also the changes in geometry that result due to wear, fatigue and plastic flow [Ref. 4]. As an example, plastic flow tends to cause rail metal to creep into the high-rail gage-corner and the field side of the low-rail. This plastic flow generally results in a larger number of higher stress contacts that contribute to further overstressing of the component. Large traction forces between the wheel and rail associated with poor friction control, high adhesion locomotives and braking on downgrades further exacerbate surface flow.

2.2 Conformity

The NRC uses the term *conformal* to refer to the general condition where (as per the Webster's definition) the wheel and rail profiles have "similar shapes". Figure 4 shows NRC's definitions for conformity between the wheel and high-rail profile at an L/V of approximately 0.6, for various new and worn rail profile combinations. One and two-point contact conditions are shown. .Be it a 1 point or two-point contact scenario, a contact is *closely conformal* if the gap *d* or *s* between the undeformed wheel and rail is approximately 0.1 mm (0.004 inch) or less. Upon loading, elastic deformation of the wheel and rail will cause that gap to be closed, resulting in a wide contact ellipse that spans an appreciable portion of the wear band, e.g. 1.0 to 1.5 inches. A larger gap, up to 0.4 mm (0.015 inch), provides a contact that is still conformal but only becomes closely conformal after appreciable wear or plastic flow. For values of *d* or *s* exceeding 0.4 mm (0.015 inch), the contact is considered *non-conformal*, since the profiles are now fully separated and do not take advantage of the reduced contact stresses available by employing more conformal geometries.

2.3 Rail Stresses and Pummeling

The objective of preventive rail grinding is to control wheel/rail contact stresses and maintain favorable steering of the wheels, while also minimizing the metal wastage through the grinding process. The analysis of a population of typical worn wheel profiles allows the necessary rail profiles to be selected to establish an optimal contact geometry.

Profile overlays and stress analyses may be carried out to determine the wheel and rail contact stress and distribution on typical preventive and corrective profiles. The accumulated normal contact stress between wheel and rail for the population of wheel profiles analyzed may be plotted in a Pummeling Diagram. Figure 5 shows photographs and pummeling diagrams for typical preventive and corrective rail profiles. The rail surface cracks are highlighted with the use of dye penetrant.

Figures 5a and 5b are of a 6.5 degree curve, with a track gage of 0.47" wide, maintained at preventive intervals of 15 MGT to NRC templates H2 / L2. (§3.6.1) The rail surface condition shows visible but very shallow cracks. The distribution of fine cracks is from the gage-corner to within 1 inch of the field side of the rail. From the pummeling diagrams we see a low stress loading on the high-rail gage-corner and low-rail field side. The wheel/rail contact band is 1.5 to 2 inches. These cracks can be removed and the profile restored to the NRC template in one pass at a speed of 8 mph using a high-production rail grinder.

Figures 5c and 5d are of a 6.5 degree curve, with a track gage of 0.87" wide, maintained at corrective intervals of 60 MGT to NRC templates H4 / L2. The rail surface cracks on the high-rail gage-corner and low-rail field-side are very deep. These cracks are caused by high contact stresses from a large percentage of wheels contacting the high-rail gage-corner and false-flange contact on the field side of the low-rail. This surface condition requires multiple passes of the rail grinder. Typically, three to eight passes on the high-rail and five to nine passes on the low at 6 mph will restore profile and remove the cracks. As the amount of metal removal from the rail is high, this method removes a significant amount of work hardened metal from the rail surface.

2.4 Lubrication

Rail surface fatigue cracks grow fastest when contaminated by water and somewhat slower when contaminated with a mixture of water and lubricant [Ref.5]. On the other hand, lubrication substantially reduces the tractive stress at the wheel/rail surface and therefore reduces the number of contact cycles that contribute to fatigue. For this reason, preventive rail grinding (where surface cracks are eliminated) in combination with lubrication can significantly increase rail life. Conversely, the application of lubricants to damaged rail can increase the rate of crack growth. Since lubrication also significantly reduces the gage-face wear of the high-rail and reduces the lateral forces in the curve [Ref. 6], an effective lubrication program is essential to a successful preventive grinding program as well as to maximize rail life.

2.5 Track Gage

Maintaining track gage is important to the success of any grinding program. Where wide gage exists in curves, the false flange on hollow wheels can contact the field side of the low-rail. Surface defects develop rapidly on the low-rail due to high contact stress (Figure 6d) and wheelset steering is severely compromised. Additionally, high lateral forces that develop under poor steering conditions [Ref. 6] lead to further deterioration of the fastening system and further widening of the gage. Wide gage in excess of 1/2 inch begins to pose problems with low-rail fatigue. If track gage exceeds 1 inch wide, the single-pass preventive grinding strategy is unable to eliminate the surface defects that are generated by false flange contacts.

3 THE PACIFIC NORTHWEST GRINDING INITIATIVE

The Pacific Northwest territory (PNW) on BNSF consists of 8000 miles of track and a variety of climatic conditions, from the temperate climate of the Washington coast line to the snow covered Cascade Range and Rocky Mountains, to the hot summer climate of the Columbia River Gorge from Pasco to Vancouver, Washington. The main type of traffic is grain and inter-modal freight. Annual tonnage over the core routes varies from 30 MGT to over 80 MGT. A significant proportion of the track structure consists of concrete ties with elastic fastenings. The rail in sharp curves is primarily 136-lb/yd, deep head-hardened premium rail.

The grinding strategy prior to 1996 on this territory was to perform a one to three-pass maintenance grind on all curves at 30 MGT intervals and a one-pass grind at approximately 60 MGT on tangent track. Because of traffic increases at the time of the BNSF merger, and the resultant decrease in track time available, grinding intervals then increased from 30 MGT to 60 MGT in the PNW. As a result, the grinding effort changed to a corrective strategy, where the program focussed on addressing all mainline rails once each year. Even this target quickly proved unattainable, rail condition and budget restrictions limited the number of miles ground to about 80% of the target. One Loram 88 stone rail grinder served this entire territory.

BNSF contacted the NRC in 1997 to manage, monitor and evaluate a small test section of track according to the best practices of preventive grinding to demonstrate the cost effectiveness of the preventive grinding process. It quickly became clear however that the single machine would not be able to return to the test site on preventive grinding intervals without accumulating a prohibitive amount of dead-heading. Faced with this reality, NRC was tasked to formulate a strategy for transitioning an entire territory from a corrective to a preventive grinding mode. BNSF specified that any strategy must:

- *Prove its economic benefits over current practices* - a number of test curves were to be maintained with a variety of different grinding strategies and the wear rates and defects monitored.

- *Produce rapid results* - a two-year (120 MGT) duration was judged to be sufficient for demonstrating the program's benefits.

- *Manage the risks* - a comprehensive program of rail condition monitoring and teleconference meetings was proposed.

- *Be accomplished without any increase in the annual grinding budget* - in fact, the money to pay for the NRC's efforts would be taken from the existing grinding budget.

3.1 The Preventive-Gradual Grinding Strategy

In November 1997, NRC presented to BNSF a series of technical arguments in favor of undertaking a "preventive-gradual" grinding strategy on the whole territory. In its simplest terms, this technique involves embarking straight onto preventive grinding intervals and practices from a current corrective scheme, without first undertaking the expensive task of "cleaning" all the rail. The rail is then transitioned to the desired profile and crack-free state on a gradual basis, hence the name. This strategy starts with frequent one-pass grinding, as is associated with the preventive mode, but with additional metal removal each pass - a method that only becomes feasible with today's modern high production grinding equipment. The objective was to immediately give BNSF the benefits of an optimized preventive grinding strategy while gradually catching up to the profile and surface cracks.

Figure 6 shows the staged profiling and crack removal process. The proper NRC rail profile is achieved in Stage 1 of the strategy with one to three passes. Generally tangent track and shallow curves are on profile after the first cycle while the rails in sharp curves, greater than 3.5° curvature, (Table 2) take three grinding cycles. Stage 2 includes the next one to three cycles, which gradually stop the initiation of new cracks. The final stage, Stage 3, consists of a further one to three cycles (usually 9 total on sharp curve low-rails) which remove the remaining inactive cracks to produce a clean rail surface.

3.2 Planning Stage

The Pacific Northwest territory was selected since it was judged to be the most demanding of the BNSF's four grinding territories, and thereby most likely to demonstrate positively (or negatively) the effects of the modified grinding scheme.

To implement a preventive-gradual grinding strategy on the PNW, the physical constraints of the territory had to be considered. The grinding machine had to be capable of returning to each sharp curve at preventive grinding intervals. This interval was selected as 15 MGT for the PNW. The logic behind the selection of this frequency were two fold:

1) Recent studies by the Association of American Railroads [Ref. 7] suggest that the newer premium rails can survive longer in track without developing surface fatigue and plastic flow due to improved steel cleanliness.

2) Previous generation premium rails required preventive intervals of 8 to 10 MGT on sharp curves [Ref. 3]. In the past ten years hardness of premium rail has increased from 360 Brinell to 380 Brinell, and today's deep head-hardening penetrates further into the rail-head than previous processes. The new generation rails were believed capable of withstanding a 15 MGT grinding interval.

The planning process for the grinding program had to consider the following:

- Grinding intervals of 15 MGT on sharp curves (2.5 degrees or greater), 30 MGT for mild curves and 45 MGT for tangent track
- Historical track time available to do the work
- Grinding machine metal removal capability per grinding pass at a pre-determined grinding speed
- Grinding machine cost per pass mile to plan the territory size to be covered by the annual budget.
- Rail condition (profile and surface defects) at the start of the process.

3.3 Project Team

A project management team (Core Team) was established to implement the preventive-gradual grinding program. The team consisted of representatives from BNSF engineering and field departments, Loram Maintenance of Way Inc. (the grinding contractor), and NRC.

The team established the initial grinding schedule, developed training programs for the field personnel (§3.4), and selected the monitoring and testing sites for the project (§3.8). The team also established several Key Performance Indicators for the project . These measures compare target to actual values to monitor performance of the grinding equipment against the plan, and include:

- Average Track Time per Day
- Track Time Utilization
- Average Time per Work Block
- Pass Miles Ground
- Average Grinding Speed
- Passes per Finished Mile
- Equipment Availability (down time)

The team set a schedule of bi-weekly conference calls for the duration of the project to monitor the following:

- Progress of the grinding equipment
- Key issues affecting smooth implementation with the field representatives
- Grinding program changes to take into account varying rail conditions
- Key Performance Indicators

- Monitor and Test site results
- Any other issues affecting the program

3.4 Implementation Training

All members of the team were trained so that they were aware of the overall project goals and the intended strategy for applying the rail grinder. Most importantly, the expected and desired results on the rail after each grinding cycle, when the rail was in "catch-up" mode, were explored.

Half-day seminars were conducted at the BSNF division level to ensure the understanding and support of the program from field personnel. The seminars emphasized three points:

1. It is critical to maintain the specified tonnage-based intervals with the preventive and preventive-gradual approaches.
2. The lubrication of curves must be maintained to a high standard.
3. The track gage must be maintained to less than 1/2 inch wide.

Field supervisors had to understand that since a preventive-gradual approach does not initially address visible surface defects, they were not going to see the type of clean rail surface they were accustomed to seeing after a corrective grind. The difficulty at the outset of the program was that one pass of the Loram 88 stone grinder would not, for example, "fix" a flat, center-spalled low-rail. The intensive corrective work was not going to be done in one cycle. As a result this approach required understanding, discipline, commitment, patience and a little faith.

The field training sessions included NRC working with the two BNSF Grinding Supervisors dedicated to the rail grinder (§3.7) and the Loram Data Technician ahead of and behind the grinding machine.

3.5 Grinding Equipment

Grinding machine technology has changed dramatically in the last few years. The Loram RG314 Rail Grinder working in the PNW has 88 thirty-horsepower grinding motors, and the metal removal rate per grinding pass is substantially higher than previous generation machines. The optimal metal removal capability of this highly productive machine had to be determined in sharp curves, mild curves, shallow curves and tangent track.

The Loram Data Technician and the NRC representative collected metal removal data ahead and behind the grinding machine to evaluate and refine the grinding patterns. The patterns were fine-tuned into a 'V' configuration at tighter angles to maximize performance for a predominantly forward-pass operation. Grinding patterns and speeds used on the various curve classes and tangent track were selected for their efficiency in producing the rail profile while simultaneously working to remove surface defects. Also, the on-board software was modified to allow grinding patterns with horsepower variations from rail to rail. This machine configuration optimized the one pass preventive-gradual grinding process.

The Loram Rail Grinder has an on-board electronic profile measurement system (VISTA) which is capable of recording the rail profile before and after grinding. This tool was used to assist the BNSF Grinding Supervisors with decisions on pattern selection at the designated speed.

3.6 Wheel Profile Analysis

NRC conducted a survey of the typical wheel profiles from the PNW territory. The optimal rail profiles were selected on the basis of analysis undertaken on 800 measured wheel profiles from heavy axle-load vehicles operating over the PNW. Profile overlays and stress analyses (§2.3) were carried out using proprietary NRC software to determine the wheel and rail contact stress and distribution on typical preventive profiles.

3.6.1 A new rail template standard

The wheel profile analysis permitted new profile standards to be recommended. Table 2 shows the new standard for the BNSF-PNW alongside the conventional recommendations of the Loram BAR gauge manual [Ref. 8]. Instead of using H4/L2 in curves sharper than 3.5 degrees, a H2/L1 pair is used (Figure 7). These profiles require less metal removal and provide for better steering in curves, thereby increasing the grinder productivity and helping premium steels to last longer. The importance of track gage is demonstrated by template selection. More metal must be removed from the field side of the low rail to compensate for potential wheel false flange contact. The effectiveness of the new template standard may be seen in Figures 5a and 5b.

3.7 Application of Preventive-Gradual Grinding

BNSF implemented the preventive-gradual grinding strategy on the PNW territory in February 1998. Planning and training aspects were completed and a rigorous quality assurance program was established.

BNSF has two Grinding Supervisors dedicated to each rail grinder. They perform many tasks, including: pre and post inspection of the rail to monitor the grinding process, selecting the proper NRC BAR Gauge profiles, supervising the grinding operation, ensuring high production of the grinding machine by selecting the best one pass grinding patterns and speed, maintaining a safe operation, coordinating the BNSF field staff to control right of way fires, ensuring the grinder is supplied with water and fuel, and working with the dispatcher to get good work blocks.

The bi-weekly Core Team conference call allowed the process to be dynamically managed. Changes were made to the program, from time to time, based on rail condition and machine cycle progress on the PNW.

The progression of the profile and surface defect removal from the corrective state to the preventive state was rigorously monitored in 4 audit sites by NRC (§3.8)

VISTA profile measurement data was also used to analyze the progress of profile improvement at a number of specific locations in the PNW. This information was use to verify the performance of the preventive-gradual strategy. The Loram Data Technician visited the rail grinder frequently to ensure the patterns were working correctly and machine performance was maximized.

3.8 Test Areas

To manage the risk of potential rail failure, specific rail monitoring sites (§3.8.1) were established to review the progress of profile shape and surface crack removal. A more comprehensive site was also established on the Lakeside Subdivision (§3.8.2) for a detailed analysis of rail performance and to verify the economic benefits of the preventive-gradual grinding process against other options.

3.8.1 Monitoring Sites

The rail monitoring sites were established in 3 mountainous sub divisions with sharp curves and high tonnage. These sites are monitored before each grinding interval of 15 MGT for: rail profile, the progress of surface defect removal, lubrication standards, and wide gage influence on surface defect removal. The Loram VISTA collected rail profiles from the audit sites each cycle.

3.8.2 Lakeside Test Site

A test site was established on the Lakeside Subdivision at Connell WA, located 30 miles north of Pasco. The test area is 5 miles long with predominately sharp curves. Train speeds average 30 mph, at under balanced speed, on concrete tie track. The rail in curves consists of predominantly 136 lb/yd, Japanese, deep head hardened premium rail. The annual tonnage on the test site was 61 MGT in 1998. The previous grinding history for the rail was a corrective grind once per year.

The main objective of the intensive rail-monitoring site was to manage the risks of implementing the preventive-gradual grinding process on the whole PNW territory. If any serious failure of the strategy was to take place, BNSF, Loram and NRC would see it happen here. Also, BNSF specified the requirement for an economic analysis to prove the benefit of the preventive-gradual grinding process against various other rail maintenance strategies, including: lubrication versus no lubrication, no grinding, corrective grinding, maintenance grinding and preventive-immediate grinding. This would allow BNSF to determine the most economical strategy to employ, in the short term and the long term, for the rest of the BNSF system.

The test area was split up into two zones: a non-lubricated zone of 3 miles and a 2 mile lubricated zone. The test curve distribution is shown in Table 3. The following measurements were performed at each 15 MGT interval:

- rail profile using the MiniProf and EZ-2
- dye penetrant to enhance surface cracks
- track gage measurement
- lubrication samples and friction values

4 PREVENTIVE-GRADUAL GRINDING STRATEGY – FIRST YEAR RESULTS

At the conclusion of the first year of the preventive-gradual initiative in February 1999, BNSF had completed four grinding cycles with the Loram RG314 Rail Grinder across its PNW territory. Preventive cycles were maintained at 15 MGT on sharp curves, 30 MGT on mild curves and 45 MGT on tangent track.

The results show that in general:

- VISTA monitoring sites and field hi-rail inspections revealed that an estimated 98% of the rail had been restored to the desired NRC template profiles at the end of the third cycle (45 MGT).
- Rail surface condition (visible surface defects) had significantly improved across the territory.
- The high production rates of the Loram Rail Grinder and the improved rail surface condition allowed additional sub-divisions to be ground. Also an extra 1 to 2 passes were ground on a small percentage of severely deteriorated low-rails in sharp curves.

4.1 Test Site Observations

The following observations were made in the Test Site on the Lakeside Subdivision (§3.8.2) between February 1998 to February 1999:

- To align the test curves to same starting point, all were correctively ground except for the preventive-gradual curves. The initial corrective grind on the Lakeside test curves required approximately 3 to 5 passes on the high-rails, many of which had gage corner shelling. The flat center-spalled low rails required 5 to 9 passes . Grinding at 6 mph, this initial work established appropriate rail profiles and removed all visible surface defects and cracks. After grinding, there was a significant reduction in the depth of the work hardened surface layer and plastic flow occurred within the first few trains over the curves.

- The preventive-gradual curves were ground with single passes at 6 mph. The high-rail profile was restored and surface defects eliminated in 3 cycles of 15 MGT interval. The low-rail required more cycles. Low-rails in curves with track gage greater than ½" wide were still flat at 61 MGT.
- No-grind and corrective curves developed surface spalling on the low-rail and deep gage-corner fatigue cracks on the high-rail within 61 MGT (typical defects are shown in Figures 3a and 3b).
- Lubrication on the curves was difficult to maintain with the use of hi-rail vehicles alone. Two fixed in track lubricators were added mid-way through the first year.
- The non-lubricated zone was difficult to maintain lubricant free. Tests are being conducted on the fixed lubricator settings to achieve the dry state in this zone.

4.2 Test Site Results

At the end of the first year (61 MGT), the various grinding options were evaluated to determine the economic benefits to BNSF. The following information was compared: total wear from grinding and traffic on the high-rail gage-face, the top of the high and low-rails, the severity of surface defects and the total grinding cost per track mile over a projected 3 year period.

The wear data is shown in Figure 8 and the results are summarized as follows:

- Although the no-grind scenario exhibited the lowest rate of vertical wear, it is not a practical option for BNSF due to the development of severe rail surface defects.

- Preventive-gradual curves exhibit the least gauge-face wear and second lowest vertical wear overall. It should be appreciated that this was achieved despite the aggressive grinding each cycle to profile the rail and remove cracks. Less grinding will be needed in the second year and even better wear results are expected.

- Maintenance grinding is a distant second to the preventive gradual strategy with especially poor low rail performance.

- Corrective grinding was third best for vertical wear, however had the second worst gage-face wear rate. The correctively ground rail developed severe surface defects on both the high and low rails.

- Preventive-Immediate exhibits high first-year wear-rates due to the large grinding effort made at the outset to correct the rail. In subsequent years, wear rates will be much lower (similar to the preventive gradual) and the overall results will look more attractive.

The grinding cost data is shown in Figure 9. The grinding costs for the first year include the initial corrective grind of all curves. The preventive-gradual curves were ground with one pass. The grinding costs are then projected for the second and third year. The results are summarized as follows:

- Preventive-gradual is the most cost effective way to start a new territory towards the best practice preventive grinding strategy

- Preventive-immediate is expensive in the first year however at the end of the third year is the second best option
- Corrective grinding is more expensive than either of the preventive options (and at the same time will contribute to increased maintenance costs through fastener, tie and ballast deterioration).
- Maintenance grinding is most expensive grinding strategy.

4.3 Benefits of Preventive Gradual Grinding

Comparisons between the various grinding strategies ((§4.2) show clearly the benefit of starting out with a preventive-gradual grinding strategy.

In the first year on the PNW, the preventive-gradual grinding strategy has proven to be a substantial improvement over the previous corrective grinding strategy. The program has demonstrated its ability to restore 98% of the rail to preventive profiles within 45 MGT. BNSF field supervisors have stated the rail to be in better condition than it has been for a long time. Compared to the previous 60 MGT intervals the rail surface is cleaner, which improves ultrasonic rail flaw detection equipment's ability to detect sub-surface fatigue defects. Track maintenance costs are minimized in general due to reduced wheel/rail impact loads on surface defects.

The first-year benefits to BNSF of this new grinding effort on the PNW territory are listed in Table 4. Most importantly:

- More track miles and pass miles can be completed each year with the same machine, with no increase in grinding budget.
- The rail life has been increased due the reduction in grinding passes (metal removal) on curves each year. Savings have been estimated at $3.3 million in the first year.

4.4 Future Direction

BNSF is very confident of the success of the preventive-gradual strategy. So much so, that they are now implementing the process with another Loram machine in the high-tonnage Coal Loop territory. The Loop includes the Powder River Basin coal fields, and spans from Billings MT to Denver CO to Kansas City MO. Grinding intervals have ranged between 60 and 180 MGT on this territory in the past three years.

To further improve the preventive grinding process in the PNW the optimal wear rate for premium rail in this environment will be established. The optimal wear rate is the rate of wear to control rail surface fatigue. With lubrication, rail grinding provides the controlled artificial wear needed to prevent fatigue. If the wear rate is too low, rail surface fatigue cracks develop. If the wear rate is too high, surface fatigue problems do not develop, but the rail life is reduced. The optimal wear rate will vary with differences in rail metallurgy, track curvature, environment / season, track gage, and rolling stock.

The program for determining the optimal wear rate can be outlined as follows:

- Rail samples will be analyzed to determine the fatigue crack growth rates and direction of propagation.

- Rail grinding patterns used for 1 pass grinding in the test site will be fine tuned to accurately produce the optimal wear rate. Rail surface fatigue cracks between grinding cycles and the actual metal removed from the rail to control the profile will be analyzed.
- The trends in rail sub-surface fatigue defect rates will be studied for the PNW.

To improve the productivity of the preventive-gradual grinding program, several key initiatives are being addressed:

- Improve the management of lubrication
- Reduce the number of curves with wide gage greater than 0.5"
- Increase the work block time to improve grinder production

For the PNW territory the NRC test program will continue to 120 MGT (February 2000), at which time there will be an update to the economic analysis.

5 CONCLUSIONS

BNSF has a long history with rail grinding. Their past experience showed preventive grinding to be a better strategy than their current, system wide corrective grinding practice. BNSF commissioned NRC to manage the transition from corrective grinding to preventive grinding. The scope of the project was to prove the economic benefits over current practice, produce results in 2 years and manage the risk of implementation, all without increasing in the annual grinding budget.

BNSF introduced in February 1998, with the assistance of NRC, a preventive-gradual grinding program on the 8000 mile Pacific Northwest territory. As the name implies, this is the immediate implementation of one pass grinding to gradually catch up to the rail surface damage and produce the preventive profile. The grinding intervals were set at 15 MGT in sharp curves, 30 MGT in mild curves and 45 MGT in tangent track.

To manage the risk and measure the economics of various grinding strategies, BNSF, Loram and NRC rigorously monitored several audit sites with one intensive test site.

The preventive-gradual grinding program was successful in the first year of the program (61 MGT). On 98% of the rail, the desired NRC preventive profiles have been achieved. The rail surface condition (visible surface defects) is better than it has been in the preceding several years under a corrective grinding program. The Loram 88 Stone Rail Grinder now grinds at an average speed of 8 mph compared to the previous year's average of 5.7 mph. This allowed the incorporation of extra track to the schedule and additional passes on poor quality rail that would not otherwise last until the regularly scheduled interval. The annual grinding budget did not increase in the PNW. The Lakeside test site has verified in the first year that the preventive-gradual strategy reduces rail wear, and that the grinding cost per mile of curved track is less than corrective, maintenance and preventive-immediate grinding strategies. And while the no-grind strategy minimizes rail grinding costs, it permits the rail in sharp curves to develop severe surface defects.

BNSF is now introducing the preventive-gradual strategy into another high tonnage territory, the Coal Loop. The preventive-gradual grinding program will be further improved by determining the optimal wear rate, improving lubrication, maintaining gage less than 0.5” wide and increasing work block time available for grinding.

6 REFERENCES

1. Linn, S., Abell, D., Kalousek, J., Sroba, P., “**Planning of Production Rail Grinding on the Burlington Northern Railway**," Proceedings of the Fifth International Heavy haul Conference, Beijing, China, June, 1993.

2. Stone, D.H., Sawley, K., Kelly, D., Shust, W., **“ Wheel/Rail Materials and Interaction: North American Heavy Haul Practices”** International Heavy Haul SST Conference, Moscow, Russia, June, 1999.

3. Kalousek, J., Sroba, P., Hegelund, C., “**Analysis of Rail Grinding Tests and the Implications for Corrective and Preventive Grinding**," Proceedings of the Fourth International Heavy haul Conference, Brisbane, QLD, Australia, September, 1989.

4. Kalousek, J., Igwemezie, J., “**Shell-Like- Defects and Microgeometry of Grinding**", Proceedings of the International Symposium on: Rail Steels – Developments, Manufacturing and Performance. Montreal, Quebec, Canada, October 26-27, 1992.

5. Kalousek, J., “**Wear and Contact Fatigue Model for Railroad Rail”**, NRC Canada Technical Report TR-WE-50, October 1986.

6. Wolf, G.P., "**Rail Grinding, Rail Lubrication, & Lateral Rail Restraint – Effect on Gage Spreading and Rail Rollover from a Practical Viewpoint**". Roadmasters and B&B Association, Chicago, Il, September 1996.

7. Sawley, K., "**Grinding Trial Results on Canadian National and Norfolk Southern Railroads.**" Technology Digest , 98-033, December 1998.

8. Kalousek, J., Sroba, P., "**LORAM BAR Gauge Operators Manual**" 1993. Instruction Manual issued with the BAR Gauge.

Table 1: Summary of differences between preventive and corrective rail grinding strategies

	Preventive Grinding	Corrective Grinding
Grinding frequency		
Sharp curves	8 to 20 MGT	40 to 80
Mild curves	16 to 40 MGT	60 to 120
Tangent track	24 to 60 MGT	80 to 200
Grinding speed	6 to12 MPH	2.5 to 6 MPH
Grinding passes	1	3 to 9
Characteristics	grinding interval depends on curvature	usually out-of-face
	interval depends on traffic levels (MGT)	usually time based (e.g. annual grinding)
	grind even if there are no visible surface defects	grind rail with visible/severe deterioration
	all surface cracks removed	Deepest cracks not removed
	crack initiation period available	Existing cracks start to propagate immediately
	work hardened layer retained	work hardened layer removed by many grinding passes
	optimal profile always maintained (lower contact stresses, better stability in tangent track and steering through curves)	profile deteriorates within about 20 MGT.
	welds addressed regularly	welds addressed infrequently. Weld dipping leads to fastening, tie and ballast deterioration.

Table 2: Comparison of revised NRC grinding templates on BNSF in 1998

High Rail	Template		Low Rail		Template	
	Old	New	Curvature	Gage	Old	New
Sharp Corrective	H4	H3	≥ 3.5°	>1”	L2	L3
Preventive >7°	H4	H2	≥ 3.5°	½” – 1”	L2	L2
Preventive 3.5° to <7°	H4	H2	≥ 3.5°	<½” wide	L2	L1
Preventive 1.5° to <3.5°	H2	H1	<3.5°	<½ wide	L2	TT
Preventive < 1.5°	H2	TT	<1.5°		L2	TT

Table 3: BNSF Lakeside test area – rail grinding layout

	BNSF LAKESIDE TEST AREA – RAIL GRINDING LAYOUT				
No. of Curves	**Lubri-cated**	**Grind Test Type**	**Curve Degree**	**Rail Type**	**Type of test**
1	NO	Preventive Gradual	3º 04'	CF&I NKK	1 pass Preventive-Gradual Intervals of 15 MGT
1	NO	Corrective	5º 00'	NKK	Corrective Grind then Intervals of 61 MGT
1	NO	Preventive Immediate	6º 06'	Nippon	Corrective Grind then 1 pass Intervals of 15 MGT
2	YES	No Grind	4º 00' 6º 31'	CF&I Nippon	Corrective grind then No Grind
2	YES	Maintenance	6º 08' 5º 51	Nippon NKK	Correct Grind then Intervals of 31 MGT
2	YES	Preventive Gradual	6º 30'	NKK Nippon	1 pass Preventive-Gradual Intervals of 15 MGT
2	YES	Corrective	6º 30'	NKK Nippon	Corrective Grind then Intervals of 61 MGT
2	YES	Preventive Immediate	6º 06' 6º 23'	Nippon	Corrective Grind then 1 pass Intervals of 15 MGT

Table 4: Comparison of 1997 corrective grinding vrs 1998/1999 preventive gradual grinding on the PNW (subdivisions with annual tonnage >= 20 MTG)

Item	**1997**	**2/16/98-2/15/99**
Work Days	256	250
Track Miles	2440	2990
Curve Miles	740	900
Pass Miles Ground	4690	5120
Pass Miles / Track Mile	1.9	1.7
Pass / Curve	4.1	2.9
Track Miles / Day	9.5	12.0
Grind Speed (mph)	5.7	8.0
Grinding Cost / Track Mile	100%	82%
Curve Pass Miles Reduction	0	890
Rail Savings	$0	$3.3M

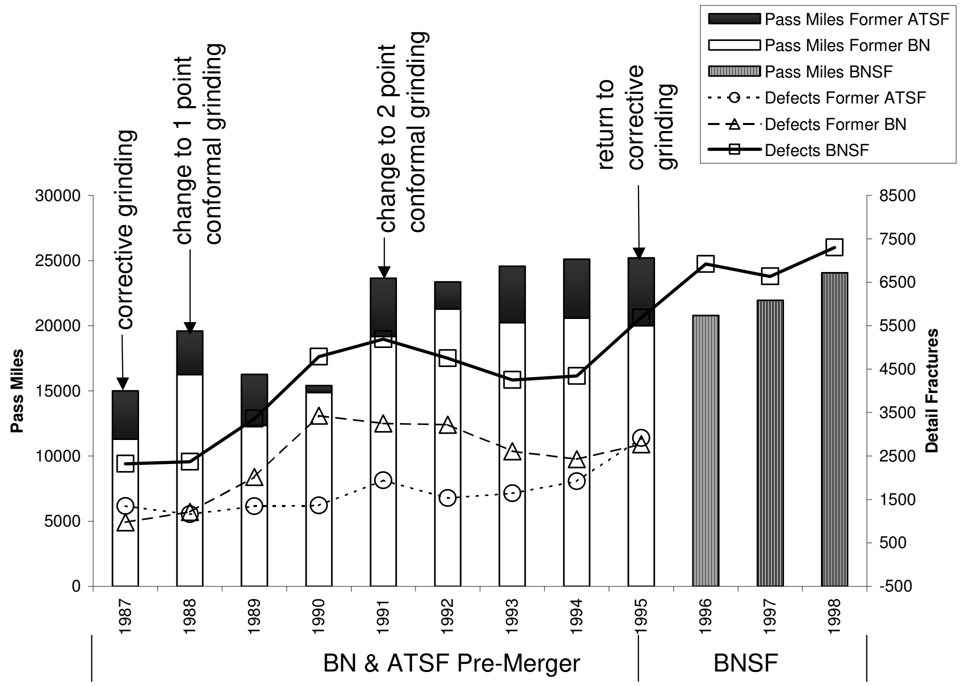


Figure 1: Total grinder pass miles and detail fractures (main tracks) per year on the BN, ATSF and BNSF from 1987 to 1998.

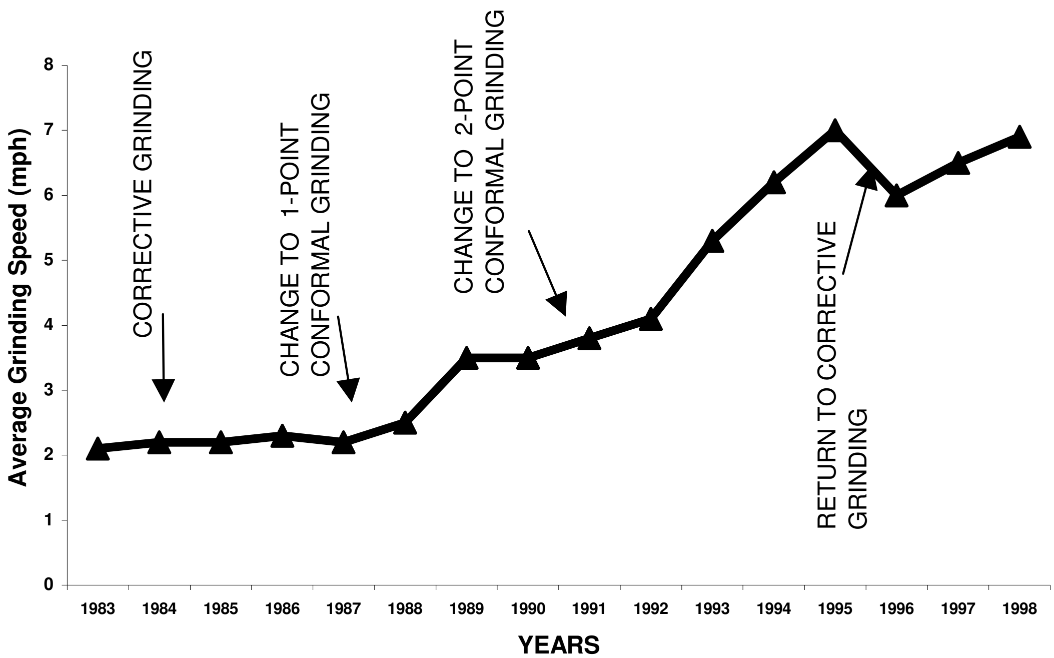
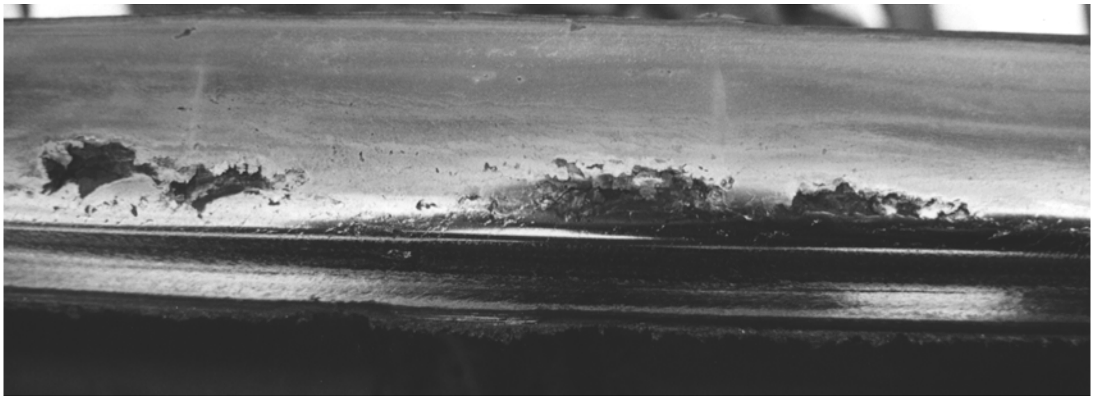


Figure 2: Average system grinding speed on BN and BNSF between 1983 and 1998



a)

b)

Figure 3: Typical defects on premium rail (6° curve 1997) a) high rail gage corner shelling b) low rail center spalling

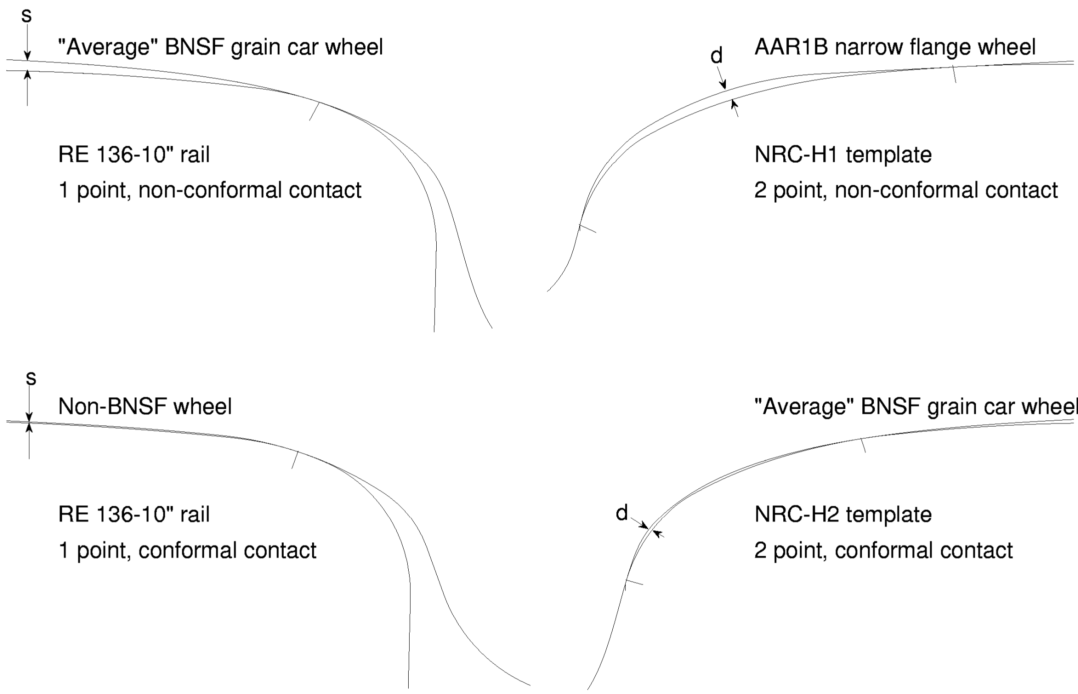


Figure 4: Conformity between the wheel and high rail profile at an L/V of approximately 0.6 (slight rail rotation)

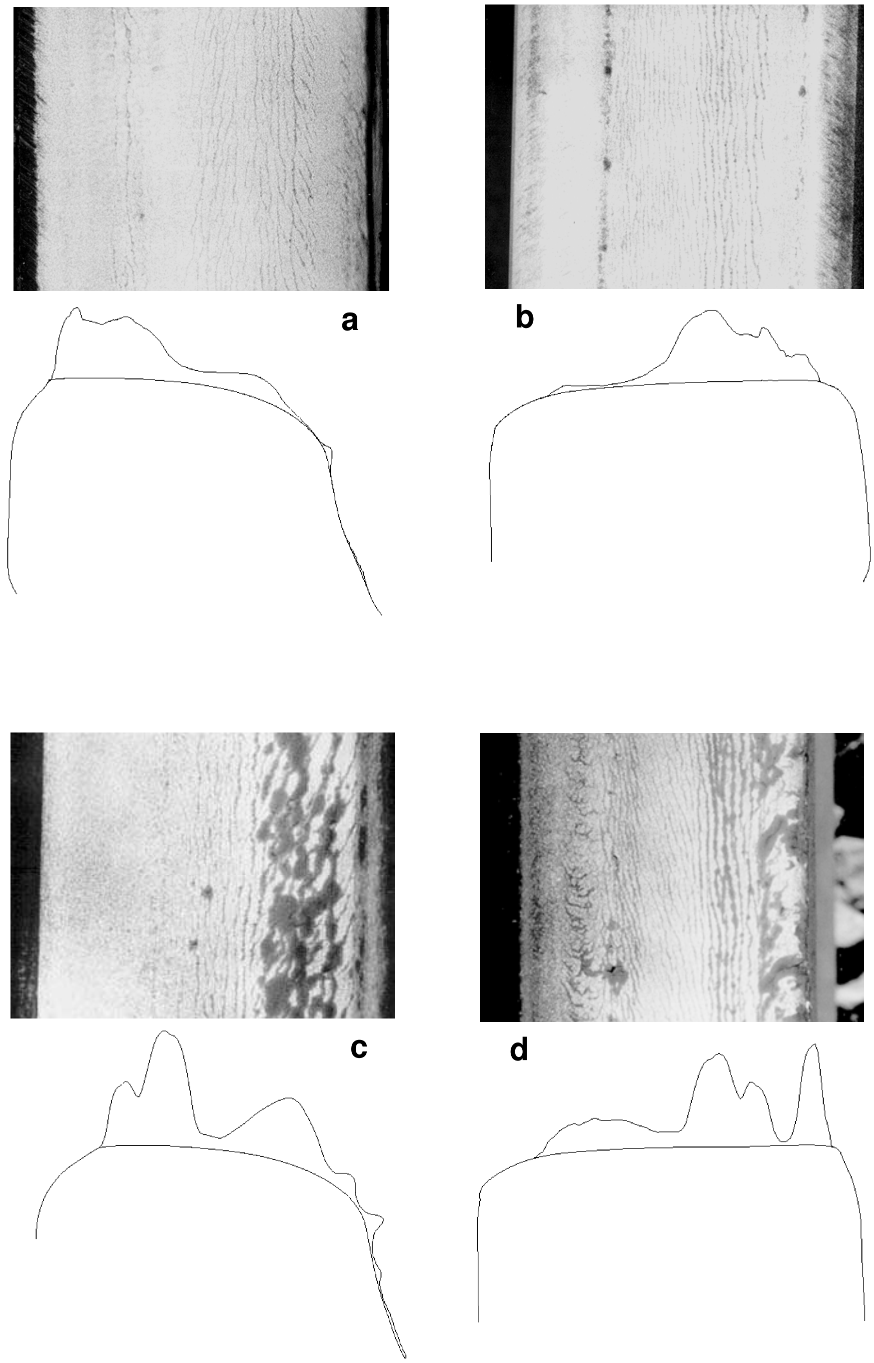


Figure 5: State of rail surface cracks and pummeling diagrams on preventive (a and b) and corrective (c and d) ground rail in the Lakeside test site.

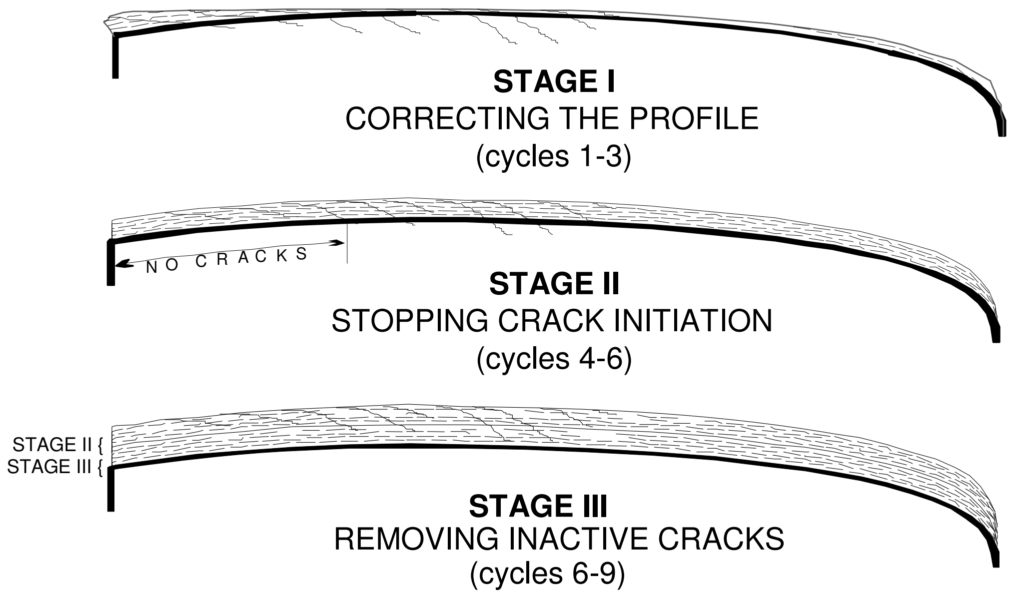


Figure 6: Staged profiling and crack elimination with the preventive-gradual strategy.

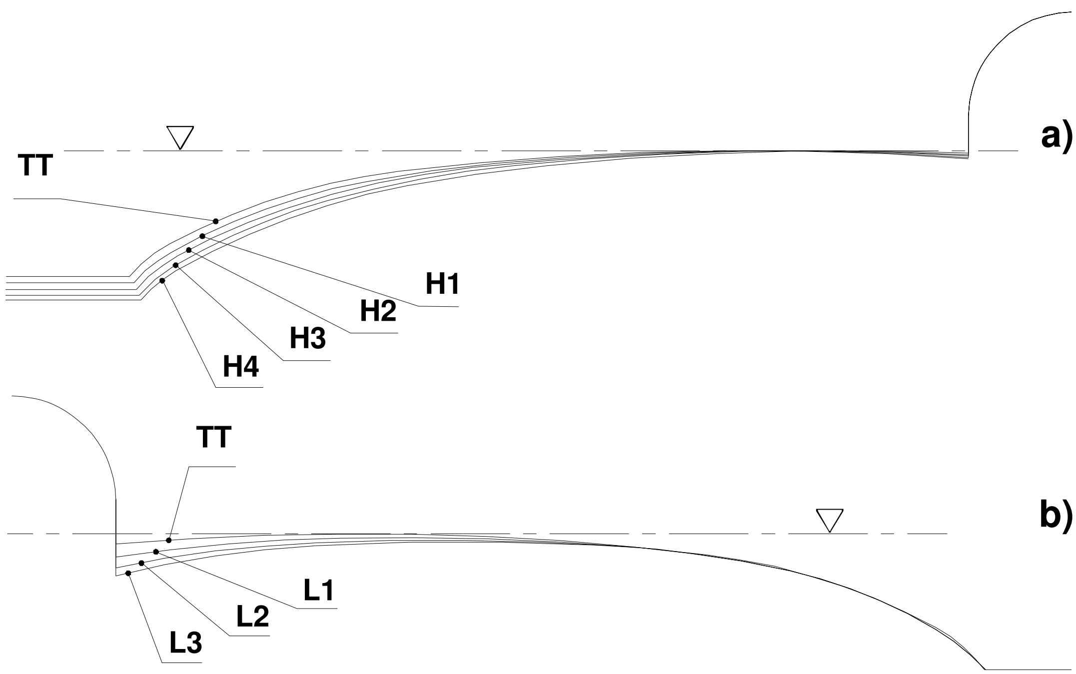


Figure 7: NRC bar gauge template comparison.

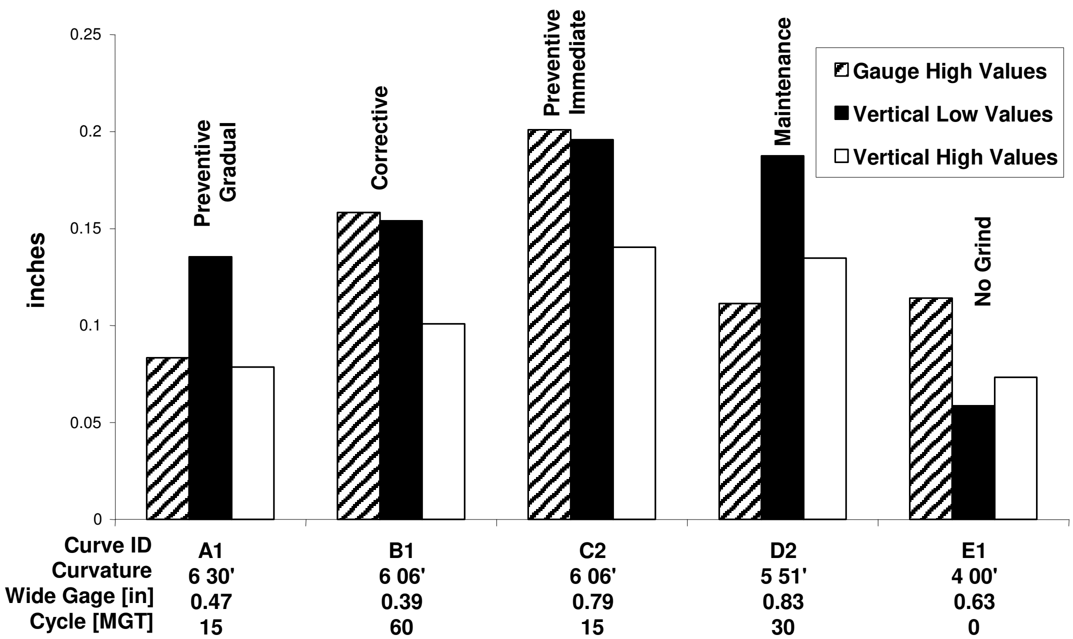


Figure 8: Grinding strategies in the Lakeside test site, showing total wear from grinding and traffic after 61 MGT.

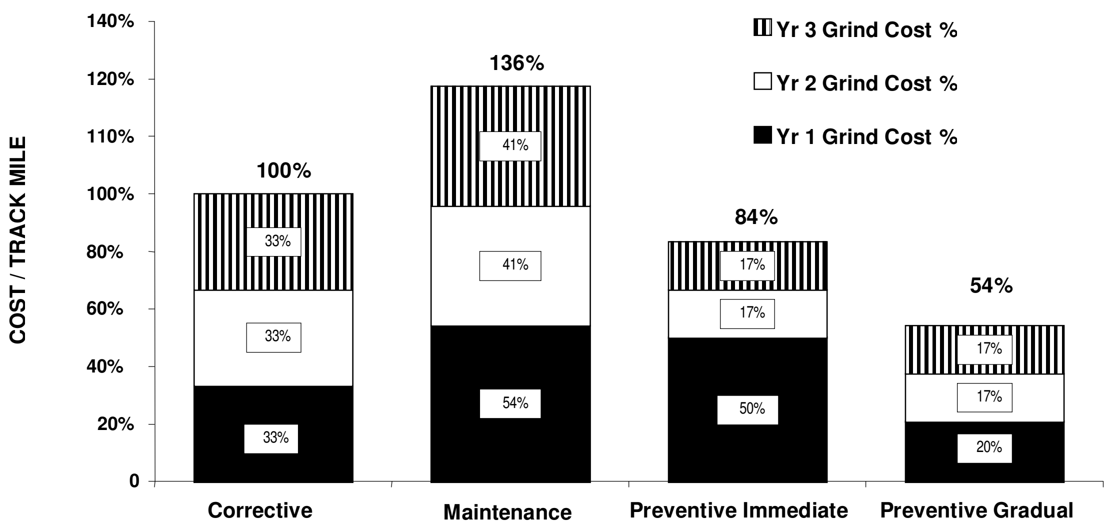


Figure 9: Various grinding strategies on the Lakeside test site, showing grind cost % for one mile of curves over 3 years.

LIST OF TABLES

LIST OF FIGURES