Reducing Rail Surface Defect Service Failures on the CSXT Railroad

Bill Bell – Manager Rail Services; CSX Transportation
Ron Bright – Director Track Testing; CSX Transportation
Dennis Witt, PE – Engineer Standards and Testing; CSX Transportation
Bob Harris – Chief Engineer Rail Quality; Loram Maintenance of Way, Inc.

Summary: CSXT has used rail grinding as a part of its rail maintenance program since the mid 1980's. Toward the end of 2000 steps were taken to transition the grinding program from a corrective grinding strategy to a preventive approach. In January 2002 a statistical study was launched to analyze rail surface defect service failure rates over a select group of curves on the system that had previously been subjected to a corrective method of grinding and were then maintained using preventive grind cycles. A 65% year to year reduction in rail surface initiated service failures were found on the selected curves. A system wide study of CSXT's rail grinding program was also initiated as a part of CSXT's Six Sigma program and found similar reductions where a preventive method of grinding had been performed.

Index Terms: Preventive rail grinding, Railhead surface defect reduction, Service failure reduction

1. INTRODUCTION

CSX Transportation, a unit of CSX Corporation, provides rail transport and distribution service in 23 states, the District of Columbia, and two Canadian provinces, serving every major population and industrial center east of the Mississippi river. CSXT railroad consists of 37,499 km of main line track covering over 31,380-route km, carrying an average of 1700 trains per day.

CSXT is comprised of five operating regions and one business unit. The traffic throughout the railroad is varied. Loads range between heavy haul coal and bulk phosphate to inter-modal, merchandise freight and passenger service. Annual tonnage on some routes reaches a maximum of 132 million gross tonnes (mgt) (145 million gross tons) (MGT). The total distribution of track by annual tonnage is detailed in Table 1. Terrain on the system varies between the relatively tangent, level areas of Florida to the mountainous regions of the Appalachians with severe curvature and grade.

An objective of any rail grinding program is to extend the useful life of the rail, which includes reducing the incidence of rail surface defects and resultant service failures. This paper outlines the historical grinding practices on CSXT through a transition from corrective[1] to preventive[2] grinding. A correlation between preventive grinding and a reduction in rail surface initiated service failures is established. Also, a relationship between no grinding, corrective grinding and preventive grinding is given in terms of defect rates normalized to track miles and traffic.

Table 1: Track kilometers by annual tonnage

	0 to 13.6 mgt (0 to 15 MGT)	13.6 to 27.3 mgt (15 to 30 MGT)	27.3 to 54.5 mgt (30 to 60 MGT)	Over 54.5 mgt (60 MGT)
Track Kilometers	15,039	9,655	11,298	1,508
% of Total	40%	26%	30%	4%

2. RAIL GRINDING PROGRAM

2.1 Historical CSXT Grinding Program 1997 to 2000

Prior to 1999, CSXT utilized a single Loram 84 stone, 22.4 kw (30 hp) rail grinder to service over 30,000 km of track. The grinder was used exclusively in a corrective method of operation to address major traffic corridors. Average tonnage accumulations of 36 mgt (40 MGT) between grinding cycles were typical. The accumulated tonnage between grinding intervals resulted in the rail shape deteriorating to such a degree that curves would require between 3 to 9 passes each grinding cycle. Tangent track,

[1] Infrequent, low speed, multiple pass grinding to address visible and often severe rolling contact fatigue damage.[1]

[2] Frequent, high speed grinding in a predominately single pass operation.[1]

ground when time and budget permitted, required 1 to 3 passes. Even in a corrective mode the grinding of rail on the CSXT system was recognized as a beneficial track maintenance operation with in house studies confirming a significant positive return on investment.

In 1999 CSXT contracted the services of a second production rail grinder for 6 months of work. This machine was operated in a similar corrective fashion. Also, in June 1999 CSXT acquired a portion of the Conrail contracted rail grinding service as part of the acquisition of that property.

In 2000, as a result of the increase in track kilometers due to the Conrail acquisition, CSXT expanded its production rail-grinding program to include two Loram rail grinders for the entire year. The original CSXT track continued to be maintained in a corrective fashion while steps were taken to keep the Conrail portion in a preventive state.

Table 2 summarizes CSXT rail grinder productivity statistics for the period between 1997 and September 2002. The ratio of pass kilometer to finished track kilometer from 1997 through 2000 was in excess of 2.0 and in some cases approached 4.0 and highlights the corrective nature of the grinding program.

Table 2: Historical CSXT grinding statistics

	1997	1998	1999	2000	2001	2002 (thru Sept)
Pass Km's	8,923	9,480	17,753	21,336	23,657	18,945
Track Km's	3,360	2,463	7,833	12,262	17,388	15,055
Ratio	2.66	3.85	2.16	2.09	1.36	1.26

2.2 Historical Conrail Grinding Program

In the early 1990's the former Conrail grinding program was transitioned to a preventive method of grinding. Table 3 details the Conrail grinding statistics for the years 1992 through a portion of 1997. As can be seen, the ratio of grinding pass kilometers per finished track kilometer had stabilized near a level of 1.1, indicative of a preventively maintained system. Approximately 6735 km of main line track that had been included in the Conrail grinding program was added to the CSXT system as a result of the 1999 acquisition.

Table 3: Historical Conrail grinding statistics[2]

	1992	1993	1994	1995	1996	1997 (partial year)
Pass Km's	14,088	18,517	12,059	16,414	14,593	2,911
Track Km's	7,557	12,872	10,439	14,542	13,266	2,644
Ratio	1.86	1.44	1.16	1.13	1.10	1.10

2.3 Transitioning to a Preventive Grind (2001 – 2002)

Toward the end of 2000, CSXT management began investigating approaches to transition its grinding program to a preventive mode of operation. At that time a single individual in the CSXT organization managed the entire grinding program. This person was responsible for all aspects of the rail-grinding program including overall planning as well as day-to-day scheduling of the 2 grinders. The grinding contractor assisted CSXT on-board the grinder to assure the final product met CSXT specifications and expectations. This arrangement was adequate in a corrective mode. At the time, most other North American Class 1 grinding programs relied on in-house field staff to perform this function and other additional tasks required of a preventive program[1],[3].

One aspect of a successful preventive rail-grinding program is the need to perform a pre-grind inspection of the work to be done prior to the arrival of the grinder [4], [5]. In a corrective mode of grinding where multiple passes are needed the first grinding pass is generally an extreme shaping pattern. On-board railhead measuring equipment is then used to assist the grinding operator in selecting subsequent patterns to attain the desired shape. In a preventive mode of grinding where a single pass is utilized it is critical to select the most appropriate patterns and speed for each curve. If an incorrect pattern is applied due to invalid assumptions about the rail conditions the opportunity to correct any mistakes won't occur until the next grinding cycle, which is generally months away. The need for pre-inspection meant that additional personnel with a specialized knowledge of rail grinding would be required.

A comparison of the CSXT system with other railroads of similar size with grinding programs in a preventive mode showed that additional grinding capacity would also be needed during the transition period. It was determined that the use of a 3rd grinder for a portion of the year would be needed. Also, the nature of a steady state preventive grinding program requires a long-range financial commitment to fully maximize any benefits. In an ideal case each piece of rail is ground at the exact time it is needed. Any disruptions in the grinding program, either through a lack of funding or equipment availability, will be felt almost immediately throughout the system. Picking up where you left off is not easily done, as many portions of the system will have lapsed into a corrective state.

With the commitment of CSXT management to go forward with the implementation of a preventive grinding program, funding was obtained to support the additional grinding capacity and acquire the necessary personnel. In a unique arrangement with the grinding contractor, CSXT chose to utilize the expertise of trained Loram personnel for the pre-grind inspections. CSXT management then negotiated guarantees from the contractor to insure the required equipment was available to do the work.

As part of the arrangement with Loram, semi-annual planning sessions were instituted to produce and refine a grind schedule that would allow the system to be brought into a preventive mode in the most expeditious manner. The scheduling process also included monthly conference calls to monitor statistics to compare actual machine performance against the planned schedule and to discuss any other areas of concern regarding the grinding program.

The schedule for 2001 was developed based on the following set of criteria

1. Any track ground in 2000 and had not yet accumulated more tonnage exceeding the preventive tonnage limits would be maintained in a preventive mode.
2. The former Conrail track would be kept on a preventive cycle.
3. No track would be scheduled for grinding that could not be re-scheduled for a return visit within a preventive cycle time frame.
4. Preventive cycles, based on other preventive programs [6], were established at 13.6 mgt (15 MGT) for sharp curves, 27.2 mgt (30 MGT) for mild curves and 40.9 to 54.5 mgt (45 to 60 MGT) for tangents. Sharp curves were considered as being less than or equal to 699m (greater than or equal to 2º30').
5. Additional routes brought into the program would be ground in a modified preventive immediate approach. That is, the rail shape would be ground close to the desired template but some amount of surface irregularities could remain. This would involve somewhat less effort than if the rail was ground to traditional corrective standards.
6. Track requiring multiple passes would be ground to the existing rail templates currently in use on CSXT. Those templates were the original NRC low rail and tangent templates, circa 1991 and the NRC-Loram Bar gage H1 template for high rails.
7. As was demonstrated in the BNSF PNW initiative [6], any rail corrugations would be removed even if additional passes were required to do so.
8. In each subdivision 1/3 of the tangent track was to be ground each cycle so that after the 3rd cycle all of the track within a subdivision would be ground at least once.

A few exceptions to these criteria were made for various reasons. Some areas with heavy tonnage are geographically isolated from similar routes so that it is not feasible to run the grinder out of the way to service these isolated cases. Those areas continue to be ground but cycle frequency is based on the needs of the surrounding territories, typically pushing the sharp curves beyond the preventive state. On some routes with a limited number of sharp curves it was found to be more beneficial to extend the grinding cycles beyond the sharp curve interval and grind the track out-of-face on each cycle. The few locations that reacted adversely to the extended cycle were ground correctively.

At the end of 2001 a rail grinder had passed through some subdivisions 5 times. Table 4 summarizes the total kilometers of track ground based on grind cycles through September 2002. Since grind cycle records were not kept prior to 2001 any track ground for the first time since transitioning to a preventive mode at the beginning of 2001 was considered as cycle 1. As discussed earlier, some of this track was actually a preventive pass since it was last ground toward the end of 2000 and had not yet deteriorated to a corrective state. As can be seen, the majority of track ground in 2001 was ground for the first time that year while roughly 1/3 of the track saw a return visit from the grinder. For the year 2002 an additional 3,016 kilometers of track was added to the grinding program, including many areas that had not seen a rail grinder in several years, if ever. The added track represents 20% of the total track ground for 2002. As shown in Table 2 the pass kilometer to track kilometer ratio has continued to drop since instituting the preventive grinding program. A steady state condition has not yet been reached as additional track continues to be brought into the program.

Table 4: 2001 and 2002 track kilometers ground by cycle

Grind Cycle	2001	2002 (through September)
1st cycle	12,103	3,016
Preventive cycle	5,285	12,039
Total	17,388	15,055

In 2002 the cycle interval for many subdivisions was extended in an attempt to find the optimum tonnage interval. Some subdivisions reacted favorably to the extended cycles while others were quick to drift away from a preventive state. The differences between territories continue to be monitored and are being used to fine tune the schedule and help predict the work required for each individual subdivision with greater accuracy.

2.4 Pre-Grind Inspection

Since the beginning of 2001, 95% of track ground, excluding predominately tangent track territories, had been pre-inspected prior to the arrival of the grinder. The grinding inspectors arrange to get on track with local CSXT roadmasters or track inspectors. In this way they can discuss any special needs and prioritize the grinding effort prior to the arrival of the machine. Also, each grinding inspector is assigned a specific territory to assure

that any knowledge gained during one cycle can be applied to the next.

Initially, grinding inspectors were provided with basic track information including curve lengths, degree of curve, etc. In addition they were given the accumulated tonnage since the last grind, the date of the last grind and the number of passes ground on each rail during the previous cycle.

The grinding inspectors select the appropriate grinding patterns and machine speed based on their observations of the current rail and track conditions. Factors such as the wheel path, traffic patterns, lubrication, rail head radius, visual rail surface irregularities, track geometry, the anticipated time until the next grind and the work done during the previous grind cycle are all considered when determining the specific work to be done on each curve and tangent. Each of the grinding inspectors has extensive experience with the production capabilities of the rail grinders and they use this experience to match the work required with the appropriate grinding pattern and machine speed.

In the middle of 2001 additional information with regard to rail surface defects was added to the grinding inspection sheets. Any curve with 2 or more defects, requiring removal, in either the high or low rail within the previous 12 months was highlighted so that the inspectors would pay special attention to those curves.

By the middle of 2002 the manual inspection sheets had evolved to a computerized form for collecting information and passing it along to personnel onboard the grinder. Specific notes about the track conditions and rail defects can be stored and recalled during the next inspection cycle. This information along with the actual work done by the grinders is accumulated in a database so that specific questions regarding the grinding program can be answered as cycles progress.

After the inspection a grind plan is formulated and passed on to the machine with specific detail on the work to be done for each curve and tangent section along with any special instructions.

3. CURVE STUDY

3.1 Rail Flaw Detection Program

CSXT inspects 104,650 test km annually. The rail test vehicle fleet is comprised of 13 contracted hi-rail test vehicles. Inspection intervals are performed at 31, 62, 92, 123, 182 and 365 day cycles. Test cycles are determined by rail defect history, tonnage and type of traffic. Table 5 describes the types of defects and rail service failures that can be positively affected by production rail grinding. [7], [8].

Table 5: Rail defect and failure definitions

Defect or Failure Type	Definition
Detail Fracture from Shelling[9]	A progressive fracture starting from a longitudinal separation, whether visible or internal, close to the running surface of the railhead, then turning downward to form a transverse separation substantially at right angles to the running surface.
Detail Fracture from Head Check[9]	A progressive fracture starting at the gage corner of the railhead and spreading transversely through the head.
Shelling[9]	A progressive horizontal separation that may crack out at any level on the gage side, generally at the upper gage corner. It extends longitudinally, not as a true horizontal or vertical crack, but at an angle related to the amount of wear.
Rail Surface initiated Service Failure	Formation of a detail fracture from shelling and/or head checking failing in service
Rail Service Failure	An undetected rail that breaks in service.

3.2 Curve Selection and Monitoring

There are over 28,300 total curves on the CSXT railroad with a distribution shown in Table 6. In August of 2001, CSXT selected 140 sample curves from the total population of curves for monitoring rail surface initiated service failures. Past experience had shown that rails in curves with excessive detected defects would continue to produce such detectable defects and would be likely to cause rail surface initiated service failures until the rail could be removed from service. In other words, once a rail started to shell it continued to do so, increasing the likelihood of a service failure. Figure 1 shows a typical rail surface initiated service failure caused by shelling. Curve selection criteria was based upon past defect history in heavy axle load territories (32.4 tonnes per axle) where a preventive grind cycle had not yet been completed as of August 2001 (§ 2.3). The 140 curves were distributed in 26 subdivisions throughout the railroad. On average there were 2.4 defects in either the high or low rails in each curve over the previous 12 months. The curves ranged in radius from 3493m to 134m (0°30’ to 13°0’) with an average radius of 437m (4°).

Table 6: CSXT Curve distribution by radius

	Greater than 699m (less than 2°30’)	699m to 175m (2°30’ to 10°)	Less than 175m (10° or greater)	Total
Kilometers	6,130	4,331	216	10,677
Number	14,376	12,955	1,031	28,362
% of Total	51%	45.5%	3.5%	100%
Average Length (km)	0.43	0.33	0.21	0.38

Between September 1, 2001 and August 31, 2002, 56 of the curves out of the initial 140 had been relayed or not ground preventively. Data from these curves was not considered and were removed from the study. Of the remaining 84 curves the total number of rail surface initiated service failures had decreased to 19 as compared to 54 during the previous 12-month period between September 1, 2000 and August 31, 2001. This amounted

to a 65% reduction in rail surface initiated service failures over the same time frame.

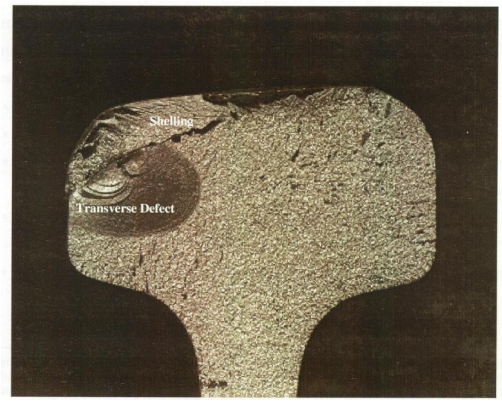

Figure 1: Typical Rail Surface initiated Service Failure from Shelling

4. SIX SIGMA STUDY

In January of 2002 CSXT began a study of railhead fatigue caused derailments under its Six Sigma initiative. A statistical analysis was performed in five significant areas. These areas were track, territory, rail, maintenance frequency and loading, Figure 2. The initial results of the study indicated a significant statistical variation under the category of maintenance frequency. Further examination of the data showed a high level of correlation between the rail grinding program and the rate of railhead fatigue defects.

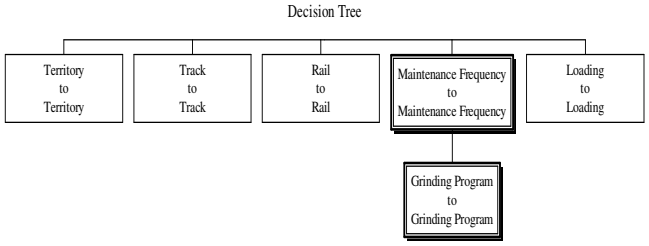

Figure 2: Railhead Fatigue Defects Decision Tree

The data set used for the Six Sigma study included 800 km of track over 6 subdivisions on a major corridor with heavy axle loads. The track involved in the study was subjected to a period of no-grinding or a corrective grind followed by at least 2 cycles of a preventive grind.

Assumptions made for the Six Sigma study are as follows:

- Analysis includes all curves <= 699m radius (>= 2º30')
- Analysis excludes tangent track and curves > 699m radius (<2º30')
- April to August 2000 vs. April to August 2001
- Analysis includes rail surface initiated service failures and detected defects
- Analysis includes only territory monitored by rail test cars
- Analysis excludes territory which had not seen at least one preventive cycle

The data included under the rail grinding program heading is further broken down to include statistics by categories of preventive grinding, corrective grinding and no grinding. Table 7 includes the data for the curves included in the Six Sigma study. A Chi-Square test, a statistical test for independence, conducted on the data provides further support to the conclusions of this study.

The column labeled Observed RHF Defects in Table 7 contains the actual number of rail surface initiated service failures and detected defects for the different grinding treatments over the relevant sample sections and time frames. The column labeled Basis (MGTM) is the actual number of MGT Miles for the associated sample territories. Based on these two numbers the values in the column labeled Expected RHF Defects are calculated by distributing the total observed defects over the sample sections in proportion to the MGTM for the sample sections and time frames.

Table 7: Six Sigma data and Chi-Squared calculation

Grinding Program	Observed RHF Defects	Expected RHF Defects	Basis (MGTM)	MGTM Rate	Chi-Square $(O-E)^2/E$
No Grinding	109	51.230	695	0.156835	65.143
Corrective Grinding	160	172.783	2344	0.068259	0.946
Preventive Grinding	56	100.987	1370	0.040876	20.040
Total	325	325	4409	0.073713	x=86.129
3 Levels			Chi-Square with 2 Degrees of Freedom		
			P(X<=x) = 1.0000		
			P-Value = 0.0000		

A graphical representation of the actual defect rates per MGTM (million gross ton miles) is shown in Figure 3 and is calculated by dividing the Observed RHF Defects in Table 7 by the Basis (MGTM).

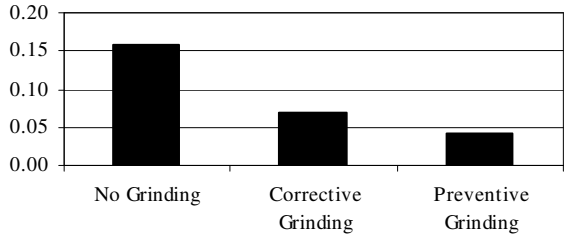

Figure 3: Defect Rate per MGTM vs. Grinding Program

5. CONCLUSION

CSXT has used rail grinding as a rail maintenance tool since the mid-1980's. Though the benefits of the corrective only type of grinding being utilized were positive, the railroad sought to maximize those benefits with a more comprehensive and highly managed rail grinding program. Prior to 2001 CSXT was only able to treat a small portion of its rail due to the nature of corrective grinding. Adapting already successful preventive grinding programs from other North American Class 1 railroads to its own property became a priority. Lacking a large dedicated rail maintenance staff, CSXT chose to rely on its primary rail grinding contractor, Loram Maintenance of Way, Inc., to assist with the staffing necessary to support a preventive grinding philosophy. Loram provided trained personnel to do the pre-grind inspection to assess the rail condition and prescribe the correct grind patterns and optimum grind speeds for this largely one pass operation. Key designated railroad and contract personnel met at scheduled intervals to evaluate the program, share input regarding rail condition and rail defect trends, and recommend alterations to the overall program as field conditions changed and the preventive program continued to evolve.

As stated previously, one of the primary goals of the railroad in transitioning to a preventive rail-grinding program is to further extend rail life. Included in this is a reduction in rail surface initiated service failures as well as an overall reduction in defects, which cause interruption to train traffic and are very costly in manpower and material to repair. An internal defect-monitoring study initiated by CSXT and based on selected curves throughout the system showed a 65% reduction in rail surface initiated service failures. Also, as part of its Six Sigma program for railhead fatigue caused defects, a lack of rail grinding was found to be a key causal factor.

CSXT continues to refine and evaluate the preventive grinding program. As the program becomes more effective in reducing railhead defects, the program will be expanded to include more of the CSXT system. To date, the results have been very encouraging.

6. REFERENCES

[1]. Stanford J., Magel E. and Sroba P., **"Transitioning from Corrective to Preventive Rail Grinding on the BNSF Railroad"**, Proceedings of the 7th International Heavy Haul Conference, Brisbane, Australia, June 2001.

[2]. Palloni M., **"Examining the Benefits of Switch and Crossing Grinding"**, Advanced Rail Management Rail/Wheel Seminar, Chicago, Illinois, May 1997.

[3]. Noiles N., **"Grinding Practices on Canadian National"**, Advanced Rail Management Rail/Wheel Seminar, Chicago, Illinois, May 1999.

[4]. deVries R., Sroba P. and Magel E, **"Preventive Grinding Moves into the 21st Century on Canadian Pacific Railway"**, Proceedings of the 2001 Annual AREMA Conference, Chicago, Illinois, September 2001.

[5]. Sawley K. and Robinson J., **"TTCI R&D – Rail Grinding on CN"**, Railway Track and Structures, December 2000, pp. 15-17.

[6]. Stanford J., Sroba P. and Magel E., **"Burlington Northern Sante Fe Preventive-Gradual Grinding Initiative"**, Proceedings of the 1999 Annual AREMA Conference, Chicago, Illinois, September 1999.

[7]. Kalousek J., Igwemezie J., **"Shell-Like Defects and Microgeometry of Grinding"**, Proceedings of the International Symposium on: Rail Steels – Developments, Manufacturing and Performance, Montreal, Canada, October, 1992.

[8]. Grassie, S.L., Kalousek, J., "**Rolling Contact Fatique of Rails: Characteristics, Cause and Treatments"**, Proceedings of the 6th International Heavy Haul Conference, Capetown, South Africa, April 1997.

[9]. Sperry Rail Service Corporation, **"Rail Defect Manual"**, 1999.