Preventive-Gradual On-Cycle Grinding: A First for MRS in Brazil

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Summary: MRS Logistica S.A. operates a 1674 km railroad in southeastern Brazil. Loads are primarily unit iron ore trains running from mines in the Brazilian mountains of Minas Gerais to tidewater harbors at Rio de Janeiro. Located in a region that concentrates 65% of the gross national product, MRS Logística S.A. has experienced tremendous growth since privatization in the later part of 1996. Since that time the annual revenue tonnage more than doubled from 71 to 146 mmgt - metric millions gross tonnes (from 78 to160 mgt - millions gross tons) in 2003. Future plans call for another doubling of capacity to 304 mmgt (335mgt) by 2009.

Prior to 2002 there were no rail grinding services at MRS. Under the strains of rapid growth, rail breaks and replacement due to RCF related surface defects were a daily occurrence, resulting in train traffic interruptions and significant increases in maintenance costs. Attempts were made to address the RCF conditions with a rail planer but in the end, rail replacement was the only alternative.

This paper describes the strategies and actions taken to implement a cost effective, state-of-the-art grinding program at MRS in only 2 years. A partnership between MRS, Loram Maintenance of Way, Inc. and the National Research Council Canada was established to face the challenge. Specialized rail profiles for curve and tangent track were developed and implemented under an accelerated Preventive-Gradual grinding program using a Loram RGI-48 stones rail grinder machine. The benefits of the rail grinding program will be detailed in terms of significant reductions in rail purchases, extended rail life, and reduced rail failures, fewer train delays and a 3% increase in fuel economy.

Index Terms: accelerated preventive-gradual, rail grinding and RCF.

1. INTRODUCTION

MRS Logística is a privately owned company operating one of the most important railways in Brazil. Its network is located on the southeast part of the country, covering the three states of Minas Gerais, Rio de Janeiro and São Paulo. The main products hauled on the railway are: iron ore, steel products, cement, bauxite, coal, agricultural products, coke and containers with iron ore representing 68% of the hauled tonnage.

Since privatization in 1996 the amount of capital investments in the former government run company have exceeded US$458 million. This level of investment combined with the implementation of modern operational procedures and technologies have allowed the railroad to grow at an extraordinary pace. As shown in Figure 1 the annual production has more than doubled from 42 metric millions net tonnes, (78mgt) in 1996 to over 98 metric millions net tonnes (183mgt.) in 2004 with the expectation of once again nearly doubling by 2009.

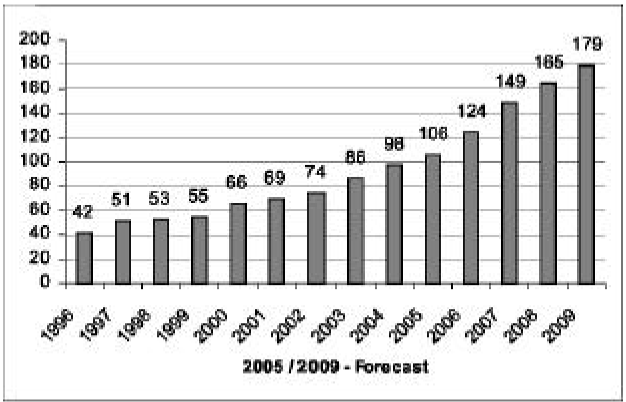

Figure 1 - MRS Annual Production (Metric Millions Net Tonnes)

At the same time train accident rates have dropped from a high of 58 accidents per million train kilometers to less than 16 in 2004. Locomotive and car availability, employee productivity and gross revenues were also improved throughout this time period. All of these factors combined to make the company "The Best Freight Railroad in Brazil" [1] for the years 2000, 2002, 2003 and

2004. The support of this explosive growth along with the accompanying detrimental effects on the railroad infrastructure is the challenge of the MRS Track Specialists. The most important component within the infrastructure is the rail, representing the major expenditure of maintenance of way. It has long been acknowledged [2] - [13] that rail wear and fatigue cannot be eliminated, making this the main concern of the track engineer who must develop methods and procedures to control and minimize their harmful consequences.

2. THE MRS NETWORK

The MRS network is constructed as a broad gauge, 1,600 mm (63") railway and consists of three primary routes and a connecting branch, all with differing characteristics. These routes are depicted in Figure 2 and are referred to as follows:

Linha do Centro (Central Line) 566km (354miles)

Linha de São Paulo (São Paulo Line) 306km (191miles)

Ferrovia do Aço (Steel Line) 350km (219miles)

Saudade to Guaiba section 157km (98miles)

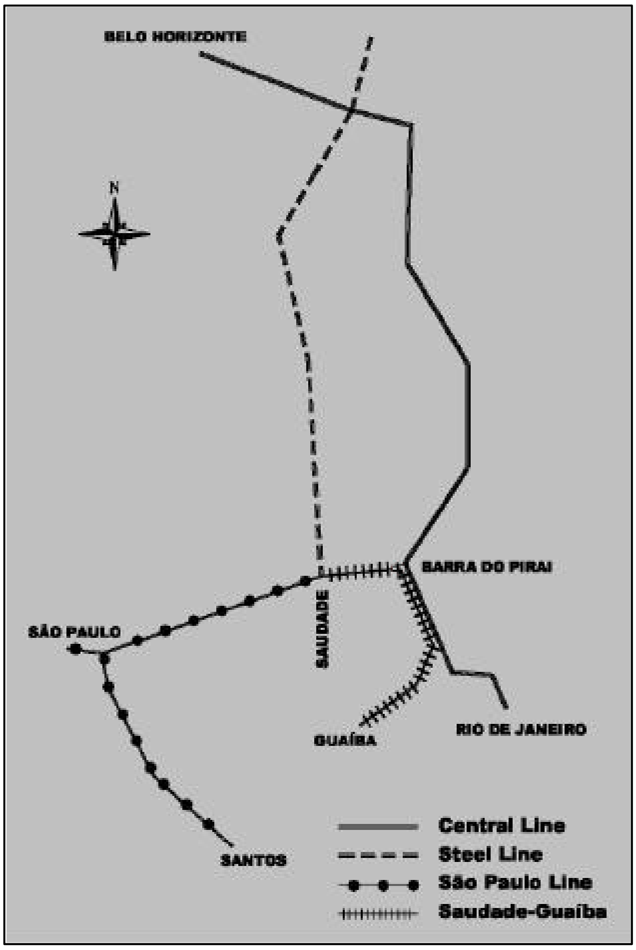

Figure 2 - MRS Network

Most of the trains operated are unit trains, consisting of 3 3,000 HP locomotives and 132 gondola iron ore cars. In areas of large ascendant grades, 2 or 4 locomotive helpers are temporarily added to the consist. Each loaded gondola car weighs 120 tonnes, laden with 101 tonnes of ore, resulting in 30 tonnes per axle on 914 mm (36") wheels. The loads on the network are quickly moving to 33 tonnes per axle (and after 2008 up to 36 tonnes/axle).

The layout of the system is such that the primary iron ore loads are hauled from the mining region near Belo Horizonte to the port terminal at Guaiba through the Steel Line with the empties returning on the older Central Line.

2.1 Central Line

Construction on the Central Line began in 1861 and was completed in 1919. High curvature, heavy ascendant grades, poor infrastructure and drainage make this section difficult and expensive to maintain. 58% percent of the track is comprised of sharp curves of less than 300m radius (6 degrees) and the maximum grade against loaded trains is 2%. The track is laid originally with premium 136 AREMA section CWR Japanese rails with hardwood ties and Pandrol clips. Annual tonnage on the Central Line is 20 mgt and it is the preferred route for general freight trains and empty iron ore trains returning to the mining region.

2.2 São Paulo Line

The São Paulo Line is a 306 km single-track route used by a limited number of iron ore trains and intermodal freight trains carrying 28 mgt annually. It was built between 1877 and 1972 and was originally constructed with French designed twin-block concrete ties and RN fastenings.

The track is laid with 115 RE standard carbon CWR rails. It has mild curves and long tangents with good ruling grades. Over time, MRS has been replacing the concrete ties with hardwood due to the general deterioration of the concrete ties under the increasing loads.

2.3 Steel Line

The Steel Line, built by the Brazilian government, is the most modern railway section in the MRS network with construction of the single-track line completed in 1989. The line carries an annual tonnage of 106 mgt.

Although the line runs through some very demanding geographic regions the minimum curve radius is only 900m (2 degrees) and the maximum track grade is limited to 1%. Maintaining these mild characteristics while traversing the mountainous region of Serra da Mantiqueira required the construction of 74 tunnels and 108 high concrete bridges. As a consequence the design of the line incorporates undulating grades and many sags.

The Steel Line was built with 136 RE intermediate strength Brazilian rails (Nb alloy) and high strength, fully heat-treated Polish rails.

The Steel Line was also constructed with high drainage standards incorporating good, clean ballast and sub-ballast, select roadbed materials and foundations with hardwood ties with Pandrol clips. All of these design and construction features make the Steel Line the most productive track segment of the MRS network.

2.4 Saudade-Guaiba Section

Originally, most of the Saudade-Guaiba Section was part of the old Central Line and has many of the same characteristics with the exception of a portion through the Serra do Mar region, where double track was built to traverse a heavy mountain region, resulting in very sharp curves of 170m radius (10 degrees) and a maximum gradient of 2.3%.

The Saudade-Guaiba Section forms a portion of the main iron ore route and reaches the Guaiba, Sepetiba and Rio de Janeiro maritime ports.

3. HISTORIC RAIL PROBLEMS ON MRS

The large population of sharp curves combined with ineffective lubrication, only performed by obsolete wayside mechanical lubricators (~150 units) on the Central Line resulted in premature rail replacement due to high lateral wear and shelling defects. The Steel Line, because of its mild track curvature, saw very little lateral wear in the first 3 years, 144mmgt (130mgt), even without any lubrication. On the other hand every manner of surface defects began to appear on both the Brazilian and Polish rails. It has been shown [16] that the gauge corner of the standard 136-12**"** AREMA rail profile section, under the influence of AAR-1B and worn wheel profiles produces high contact stresses, especially in high rails and tangent track with rail plastic flow induced tight gauge**.** With no natural wear mechanism, and one-way traffic of loaded trains the phenomenon of contact fatigue was accelerated.

In 1993, head checks, spalling, corrugation and plastic flow were found everywhere on the Steel Line, which started to cause problems for the maintenance personnel and the operations department. Rail surface defects were responsible for an increase in other maintenance activities as well, such as tamping and re-surfacing. On the operating side, detail fractures caused by RCF (Rolling Contact Fatigue) were responsible for frequent train delays and losses in productivity.

At that point, the contact fatigue phenomenon was not completely understood by the track maintenance personnel. After all, it was the first time those defects had occurred with such intensity and speed on the network.
Many times when this happens, a common reaction for the Track people are to blame the rail manufacturer rather than trying to understand the proper mechanism behind the rail defects.

3.1 Use of Rail Planer Machine

The former Government Railroad Company, RFFSA, with a very tight budget and slow purchasing procedures, wasn't able to provide new rails for the worst locations. A Plasser SBM-200, a large Rail Planer-Cutting Machine was used in a corrective basis [15] by cutting out the fatigued metal and re-profiling the rails. This machine worked from 1993 to 1996, and despite the high costs and low productivity, many tonnes of rails were saved. Defective RCF rails were able to be in service for more than 275mmgt (250mgt), until 1997 when the RFFSA - Government Railroad Company was privatized. The final shape of railhead was treated to get an asymmetrical rail profile with many severe cuttings, some on the field side of the high rail with light relief on its gage face and other severe cuttings on gage side of low railhead on all curves. The final wheel and rail contact band was between 25mm (1") and 32mm (1½"). The rail contact radii crown was difficult or impossible to control. No records of the final true figures of the rail contact radii crown were made available. The tangent track was skipped due to lack of production time. We tried to save the rails laid on 100% mild curves, Radius = 900m (0.5 Degree), with 1% maximum ascended / descended track grade.

The average operation cost of the rail planer-cutting machine reached US$ 6,000 per finished kilometer (0.625 finished mile) of track, it started using 10 passes/km (~6 passes/mile). The work speed was around 3.5 km/h (2.2 miles/h) and the monthly production was only12 km (7,5 miles) of finished track. To completely remove the surface and subsurface RCF defects of many of the worst track sections using the planer-cutting machine, most of the curves demanded 50/60 passes; the monthly production came down to only 2km (1.3miles). And that job was really eating the rail cross section by up to 8% wear out of the total railhead area and losses in useable vertical railhead height of approximately 4mm (0.160") for each one finished track kilometer (0.625 finished track mile).

By 1997 the growing traffic on the Steel Line made track maintenance windows difficult to obtain. In addition, acceleration of RCF defects caused by the increased tonnage had been verified as the cause of rail failures. In this environment, like heavy haul operations, the single Planer-cutting Machine, with such low productivity, was not able to keep up with the growing maintenance needs. The total costs reached an unaffordable level and the rail cutting machine job was abandoned forever. On the end first quarter of 1997, the SBM-200, the large rail planer-cutting machine was back to its owner.

3.2 Weld Failure Incident on the Steel Line

In the middle of 1991, just 20 months after the Steel Line was open, an alarming number of flash-butt weld breaks occurred. The breaks were primarily in tunnels and were occurring at a rate of almost one broken weld per day. The cracks began near and above the neutral axis and cut the weld collar horizontally and up and down in an "H" shape. Very high residual stresses (400 Mpa) and a bad-shearing operation were found to be the cause of the failures. All 12,000 of the flash-butt into tunnels were suspect and presumed ready for failure. A "shot peening" relief method was developed and implemented by MRS [14] and successfully solved that problem definitely.

3.3 Summary of Rail Surface Defects on the Steel Line by 1998

During the year of 1998, a 132 service failure rail breaks occurred. Train delays related to those fractures were common. A rail replacement program had started on the worst spots, mainly in tunnels and bridges of the Steel Line. At that time, accumulated tonnage over the originally 136 AREMA section laid rails was 517mmgt (470mgt). A summary of the rail conditions on the system that could be remedied by a large rail planer-cutting or large rail grinder machines are listed in Table 1.

Table 1 - Summary of Rail Surface Defects on the Steel Line

Rail Condition	Description	Distribution
RCF CORRUGATION	RCF defect initiated and propagated by a combination of non-uniform RCF crack growth, plastic flow in combination with wheelset/track dynamic phenomena	Primarily on low rails
HEAD CHECKS	RCF cracks that penetrate into the rail head caused by high wheel/rail contact stresses	Gauge corner of high rails and tangents
SPALLING	Caused when multiple head checks meet and pop out at the rail surface	Gauge corner of high rails and tangents and center of low rails
FLAT RAIL	Extreme areas of plastic flow on the rail head	Low rails and some tangents
DIPPED WELDS	Associated with changing steel metallurgy at the HAZ (Heat Affected Zone) and exacerbated by inaccurate setup of the rail welding machine	Primarily on the Steel Line
DETAIL FRACTURES	Rail failures under service caused by RCF.	Throughout the system
ENGINE BURNS	Areas where the locomotive wheels lose traction and spin on the rail.	Areas of ascending grades

3.4 Looking Beyond 1999

By the end of 1999 it was apparent that something must be done to help prolong the life of any rail that was still in service. The growing demand on traffic and the limited infrastructure capacity made the resulting rail problems a serious threat to the company business plan.

MRS Logistica S.A., which has operated the system since privatization in December 1996, began an action plan to introduce a rail grinding program as expeditiously as possible to the network in order to deal with the rising defects. The main goals of this initiative were:

a) Reduce the increasing number of train delays and rail breaks. Internal studies at the time predicted over 500 occurrences per year by 2002/2003.

b) Extend the life cycle cost of approximately 50,000 tonnes of fatigued damage rails on the Steel Line. The economical and operational impact of having to replace that too much steel rails in a short term would have a drastic, negative factor on the cash flow of MRS company.

c) Bring and introduce to MRS the latest advancements in rail grinding technology, with a completely new rail engineering maintenance, a well-proven performance and efficient management equipment techniques.

4. ADOPTED STRATEGY

From the lessons learned with the use of the rail planer-cutting machine it was obvious a new approach was needed. Corrective grinding, with multiple passes, in use by some railways in Brazil, was not a viable solution at MRS due to the heavy traffic patterns and limited maintenance work windows. In addition, a more efficient method of dealing with all aspects of the entire system (rail and wheel) was required. As others heavy haul railroads and dedicated rail researches had already discovered [16]-[28], a solution could not afford to remedy only a small portion of the system or be limited to a few sections of track.

4.1 Loram/NRCC Involvement

During a previous collaboration, Loram Maintenance of Way, Inc. and NRCC (National Research Council Canada) had proven the benefits of the preventive-gradual grinding approach on a North American heavy haul railway, and both parties were confident that the same approach would be successful at MRS. Preventive-gradual grinding is a three-stage process, which involves performing a single-grinding pass over the rail at frequent grinding cycles, removing only a thin skim of metal across the railhead. In this way, the rail profile is gradually (within two or three cycles) brought to the desired shape without removing the high hardness (ratcheting resistant) portion of near surface work-hardened layer of steel. Once the profile's shape has been corrected, the rate of crack initiation will decrease.

Continued grinding in the second stage (another two or three cycles) will remove any cracks which initiated after the last grind, before they penetrate the rail surface to a depth greater than what the grinder is capable of removing in a single pass. Grinding in the final stage of the program (another two or three cycles) will remove any inactive cracks (ones whose growth rates are less than the metal removal rate from grinding), and the rail surface will be free of cracks (those that are obvious to human eye).

At this point, the railroad is grinding in a preventive mode where subsequent grinding cycles take place at the same frequency as during the preventive-gradual stages and controls the RCF damage of rail by removing any visible cracks before they get a chance to grow deep into the railhead.

As part of the wheel-rail interaction analysis, over 1300 MiniProf wheel profiles were collected from hopper cars, flat cars, coal gondolas and tank cars. NRCC used its proprietary software tools to determine the geometric characteristics of this population of wheels, as the worn wheel shapes are a reflection of their interaction with the rails. In addition, NRCC and Loram performed a detailed track inspection, and recorded over 130 rail profile sections with the EZ-2 laser rail-profiling instrument unit.

Through this analysis, it became evident that the wheels were wearing uniformly across the tread, and that hollowing was virtually non-existent (85% of the wheels had no hollowing and 13% had hollowing of 1mm or less). The lack of wheel hollowing is consistent with the extensive plastic flow and flatness of the rail. Most of the flanges had an angle of between 71° and 74°, which is approximately the same as the angle on the unworn wheel.

This was a positive indication that the flanging forces and angles of attack on the leading wheelsets were lower than anticipated. The cars from which the wheel profiles were measured generally had well maintained trucks, which contributed to the uniform state of profile wear.

The flat rail profiles and the type and frequency of rail defects at MRS dictated that a change be made to the preventive-gradual strategy. Loram and NRCC developed a modification of the "Preventive-Grinding" approach named "Accelerated On-cycle Grinding", which involves performing several successive single-pass grinding cycles on the track, to treat the entire track over a shorter grinding period (as compared with regular preventive-grinding period). Every single "Accelerated On-Cycle Grinding" pass removed an average of 20/100 mm (0.008 inches) of metal across the railhead.

The rails get new profiles quickly in order to limit damage caused by (existing) poor profiles. As in the preventive-gradual strategy the single "Accelerated On-Cycle Grinding" pass does not remove the work-hardened layer. By preserving the high hardness of near surface (ratcheting resistant) work hardened layer the rail does not undergo rapid plastic flow before the start of the next grinding cycle. This allows all the old and damaged rails to be treated in a relatively short period of time, so that it can then be successfully maintained using **"**Preventive On-cycle Grinding"**.**

Despite the generally satisfactory condition of the wheel profiles, NRCC determined that some of the curve rails had transverse profiles that resulted in high contact stresses with the average-worn wheel, and other curve rails produced poor steering performance and thus suffered high rates of gauge face wear.

Some tangent rails had crown radii that were approximately the same as the concave tread radii of roughly 10% of the wheel population, a situation that increases the risk of hunting for empty cars.

Consequently, NRC-CSTT developed a family of five new rail profiles that were to be implemented on the MRS network [9]. Two high rail profiles for mild and sharp curves, two tangent rail profiles which could also be used on the high and low rails in curves of 1300m radius and greater (curve degree< 1.3º), and a low rail profile to be used in sharp curves.

The benefit of using asymmetric profiles in curves is that steering can be improved and contact position can be varied on the wheel tread. Multiple high-rail profiles protect the gauge corner in sharp curves by relieving it through grinding, and reduce occurrences of on-flange curving in milder curves by shaping the gauge shoulder to enhance rolling radius difference. On tangent track, grinding to more than one profile can spread wear over more of the wheel tread, control wheel hollowing that could be caused by any over-profiled rail and extend the interval between wheel turnings.

Other goals of the rail profile design process included controlling contact stresses by matching the rail crown radii to the radii on the average-worn wheel in the areas where contact will occur. Proper management of contact stresses plays an important role in reducing the rate of RCF cracks on the rails, particularly in curves.

To implement the "Accelerated On-cycle Grinding"**,** the MRS network was divided into tangent track (including curves with R>1300 meters (Curve degree< 1.3º), mild curve (1300m < R< 500m (3.5 >Curve degree> 1.3º) and sharp curve R< 500meters (Curve degree> 3.5º) segments, which directly corresponds with increasing severity and growth rates for RCF damage. On the first cycle, the first third of tangent track, and all of the curves would be ground. On the second cycle, the second third of the tangent track, half of the mild curves and all of the sharp curves would be ground. On the third cycle, the last third of the tangent track, the remaining half of the mild curves and all of the tangent curves would be ground.

This grinding schedule would then be repeated for another three cycles. After completion of the sixth cycle, tangent track would have received two grinding passes, mild curves would have received four passes, and sharp curves would have received six passes. Most of the rails would have profiles that closely matched the desired shapes, and the worst of the RCF damage would have been removed.

Having the proper shapes on most of the rails slows the development of new RCF damage, and the grinding strategy can now move to the "Preventive-On-Cycle Grinding" mode.

Each curve category has specific rail profiles for low and high rails depending on the track gauge. The primary area of treatment was to cover the route traversed by the loaded iron ore trains from the mines to the port. Achieving the new rail profiles in these areas would improve the wheel set steering and reduce the contact stresses, thereby reducing the deterioration rate and achieving the preventive mode in a shorter period of time.

5. GRINDING PROGRAM IMPLEMENTATION

One of the “keys of success” of any grinding plan is the tool to be used to perform the operation, the grinder itself. The machine needs to have the capacity for the level of production and quality to match the strategic plan.

The decision made by MRS was to purchase a high production 48 stones Loram rail grinder, which arrived in Brazil in February 2002. The main characteristics of the second RGI-48 (Rail Grinder International) machine are:

- 2 grinding cars, 1 support car, one water tank with 80,000 litres (21,000 gallons) capacity.
- Fully computer controlled 48 electrical independent 30 hp grinding motors
- 2 x 1350 HP Cummins power motors
- Maximum grind speed 15 kph (12 mph)
- Redundant fire fighting system

To perform single-pass grinding, the machine must be able to not only re-profile the rail but also have sufficient metal removal capabilities to remove the surface cracks initiated since the previous grinding cycle. As there is only one opportunity to get this right on each grinding cycle it is important to have totally position independent grinding motors with sufficient power. In addition, the grinding stones used must have sufficient life and metal removal characteristics to support an economical application of the machine.

No matter how many precautions are taken to contain sparks created from the grinding process there is always the need to have adequate fire fighting capabilities on the machine. All of the money saved on rails can be wasted on the replacement of burned wood ties or from losses associated with a right-of-way fire that extends into the surrounding neighborhood. In dry and hot seasons it is not unusual to consume the entire 80,000 liters (21,000 gallons) of water in a single grind shift. In some instances MRS has constructed wells and reservoirs at the machine storage locations in order to meet this demand.

After conversion of the machine to broad gauge wheelsets and bogies and final machine commissioning activities the machine began work in May 2002 in the Saudade-Gauiba segment, specifically in a double track section. Despite the original plans to attack the entire system in a single-pass mode it was decided that some locations would benefit more from multiple passes to remove extremely bad surface defects. In some cases up to 6 passes were applied where there were extremely flat rails or severe corrugation or engine burns were present. It was a logistic decision, and helped to save many tonnes of rails that were about to be scrapped, without losing the general idea of the grinding program.

The first concern was to re-shape the rails in order to slow down degradation. The machine’s ability to grind rails using different patterns to get a good profile was essential and proved to be a real asset. The MRS and Brazilian Contractor grinding supervisors, assisted by Loram specialists, quickly developed the ability to pre-inspect the rails and choose the best grinding patterns for each situation.

By the end of 2002, after only 7 months of operation, the fourth cycle had been completed on 670 km of track, with a total of 3,250 pass-kilometers, average of 1.2 pass-km per finished track kilometer (2,030 pass-miles, 1.2 pass-miles per finished mile. This work was completed on the Steel Line, Saudade-Guaiba and Central Line North, covering the entire route of loaded iron ore trains. During only the first year 2,000 tonnes of rail that were to have been replaced were saved and are still in service today. The grinding program was off to a very encouraging start.

The grinding program continued into 2003 with much the same strategy. Single-pass grinding proved to be an effective way to utilize in the high production-grinding machine, especially in a heavy traffic environment with limited track time available for maintenance. As the program progressed it was found that some of the tangent track could be skipped, as it presented good shape and a clean, crack-free surface. The production time saved on the tangents was applied to the curves, where the benefit of receiving a pass at a shorter cycle was clearly apparent.

As the program progressed experience was also being gained in determining which situations needed immediate attention and would require multiple passes to rectify. Certain curves with extremely bad profile shape, severe corrugation or other detrimental surface conditions would be in just as bad, if not worse, condition on the subsequent grind cycle if they received only one pass. It was learned that if the time were taken to rectify those situations with multiple passes, the curves would be in an acceptable condition the next time through and would then only need a single pass.

It was also learned that the grind cycles and machine scheduling could not focus on the worst curves but rather on the majority of the curves in a certain territory. A balance between sacrificing a few curves to benefit the overall system was soon found to be a good strategy, as it is not possible to have the grinder in all places at all times.

In some territories on the Steel Line, the operating rules were changed to allow the dispatcher to give the grinder permission to follow a passed train, rather than waiting for the train to clear the block, which could be 16 km further down the track. This technique further increased the productivity of the grinder while still maintaining a safe work environment.

In 2003 a total of 5,095 pass-kilometers (3180 pass-miles) had been ground, ending the eighth grind cycle with an average ratio of 1.9 pass-km per finished track-km (1.9 pass-mile per finished-mile). The increase in the pass-km to finished track kilometer ratio (pass-mile to finished track mile ratio) over the previous year was believed to have served the system well and allowed the planning for 2004 to be done with a serious attempt at achieving the desired single-pass method of grinding. The unexpected increases in traffic along with the reality of dealing with severe conditions were lessons well learned and allowed the program to look ahead to the coming year. By year-end, the specially designed NRCC templates had been applied on the majority of the rails and the results, in terms of slowing down the fatigue process and extending the rail life cycle cost, were quickly being realized.

In 2004, after 8 complete cycles, the program began to operate in a truly preventive mode. The single-pass method of operation could become a reality. As outlined in Table 2 the system was divided into different sections that allowed the scheduling of the grinder to be best applied based on the anticipated tonnages, track curvature dependent grinding intervals, production requirements and other conditions. Each of the six sections had similar characteristics and could be treated as a separate entity within the overall schedule. In general the grinder was operated following the route of the loaded iron ore trains from the mines to the port to avoid working against traffic and lost time due to travel from one location to another.

Table 2 – Summary of 2004 grinding program by section

Section	Monthly Tonnage (mgt)	Preventive Cycle (months)	Typical Cycle (mgt)
Central Line North	3	5	15
Steel Line North	4	6	25
Steel Line South	9	3	30
Serra do Mar	7	2	15
Saudade à Barra do Piraí	8	3	25
Ramal Brisamar	5	3	15
Grinding Speed	10 kph	10 kph	10 kph
Number of Passes	1	1	1

One of the factors affecting the grinding interval is the ability of the rail to hold up between grind cycles. MRS typically uses high strength premium rails of 370 BHN. An attempt was made to use some rails with an intermediate hardness of 320 BHN but it was found that the performance was completely different and the higher degradation rates would have upset the grinding intervals to the point of being unacceptable.

6. RESULTS

6.1 Effects on Rail Fractures and Life

If a picture can say a thousand words then the graph outlined in Figure 3 should be all that is needed to tell of the extraordinary results obtained through a well managed rail grinding program at MRS. Had remedial action not been taken, the rail fractures on the Steel Line would have continued to follow the trend outlined in Figure 3 and the company would have faced a nearly insurmountable task of rail replacement and purchases. Our experience has been similar to that of other railroads [29]-[35], in that from the onset of grinding in mid-2002 there have been measurable, positive results and every indication is that this will continue.

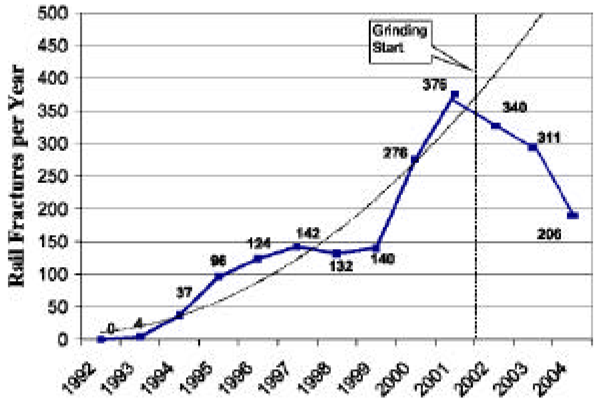

Figure 3 - Steel Line Rail Fractures per year

In addition to the time and expense saved in having to deal with fewer rail breaks there has also been a dramatic increase in the anticipated rail life on the Steel Line as is outlined in Figure 4. After the grinding program began the average rail life expectancy on the lines running loaded iron ore trains has gone from 750 mgt in 2002 to 1,200 mgt in 2004 and is expected to be as much as 1,500 mgt in 2005. MRS is not only realizing economic gains from lower rail purchases but it is also benefiting from fewer traffic interruptions and reduced replacement costs in terms of manpower and other materials.

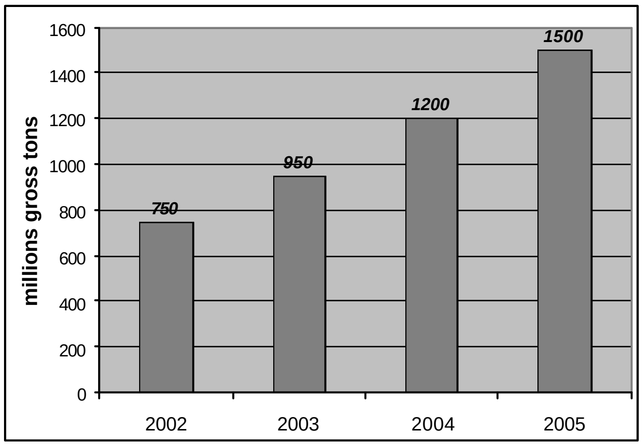

Figure 4 – Average MRS Expected Rail Life

6.2 Decrease in Fuel Consumption

As with every railroad one of the major expenses is the cost of fuel for the locomotive fleet that can be as much as 11% of the total operating expenses. The Transportation Department within MRS monitors the use of fuel very closely and, over the years, has taken several measures to improve the cost of operating the locomotives. In January 2004 the MRS Transportation Department was pleasantly surprised by an unexplained decrease in the fuel consumption rate as no any other fuel consumption reducing measures have been taken by MRS. After only four grind cycles, the new shape of the ground rails on the loaded train route was having a positive effect on train handling. The new rail shapes and resultant improved steering had the effect of lowering the fuel consumption by about 3%. Even though some surface defects were still in track there had been enough reduction of curving resistance due to improved rail profiles to have a noticeable impact on the operation of the trains. These results can be seen in the chart in Figure 5.

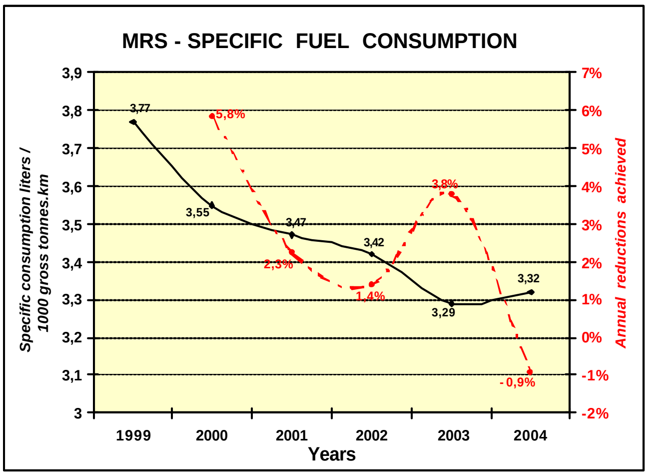

Figure 5 - Annual MRS Fuel Consumption

6.3 Rail Purchases

Figure 6 shows the amount of rail purchased by MRS for track maintenance since 2002. The savings reached 30,000 tons of rail, which represents an economy of approximately US$25 million.

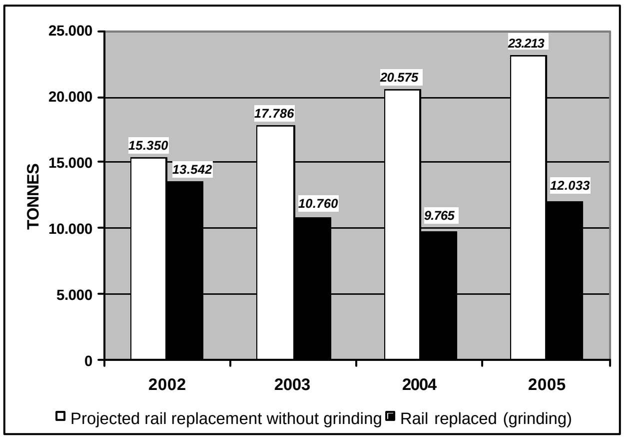

Figure 6 - MRS Rail replacement

6.4 Modifications to Original Plans

A number of issues have arisen since the rail profiles were designed and the grinding program has begun. These issues have had an impact on how effectively the profiles can be implemented in track, and on how long the grinding interval needs to be in order for the grinding program to remain ahead of the RCF damage.

One difficulty is that traffic on the network has increased significantly since the profiles were designed, increased again after the start of the grinding program, and is expected to increase again so that by 2007, the annual tonnage will be double what it was during the summer of 2001. This will rapidly make the designed rail profiles obsolete, unless the grinder is able to maintain the grinding interval that was settled upon in 2001. The tonnage increase is in the form of more trains, rather than longer or heavier trains, which reduces the track time available to the grinder and makes it extremely difficult to maintain the desired grinding interval.

Two of the designed rail profiles have proven difficult to implement, due to their high metal removal requirements, particularly when grinding them into rails with large crown radii. The intent of these two designs (one is a tangent profile, the other a low rail profile) was to shift contact further towards the field side of the rail, particularly for the low rail profile. This would add a small increase to the maximum rolling radius difference achievable in sharp curves, and would help to ensure that contact was spread across as much of the tread as possible.

NRCC is in the process of reviewing the profiles to determine if the tangent and low rail designs can be improved to achieve their original objectives with reduced metal removal requirements. If this can be done, it would help to reduce the grinding effort on low rails in sharp curves, and on approximately half of the tangent track. This may increase the efficiency of the grinding process by reducing the number of passes (cycles) required to re-profile the rails which are most dissimilar to the target shapes.

There have been some reliability issues with the original design of the second RGI-48 machine that have been addressed by MRS and Loram. The need to, at times, take the machine out of service has highlighted the importance of the grinding program as a maintenance process at MRS as the condition of the track quickly deteriorates in times when the machine is absent.

These difficulties illustrate the point that all parties must work together to solve any issues that arise. Rail profile design and implementation involve a complicated set of processes, and expert help supplemented by local knowledge is needed for a successful result.

7. CONCLUSIONS AND RECOMMENDATIONS

The grinding strategy employed at MRS referred to as "Accelerated Preventive-Gradual Grinding" allowed MRS to implement a state of the art grinding program in only a few years time. The grinding program has given MRS the ability to control and manage the detrimental effects caused by RCF and extend rail life, the most valuable asset of any railroad.

Throughout this relatively short duration of time all parties involved have learned many valuable lessons. First and foremost is the fact that the story of any maintenance strategy will be told most clearly and directly by the rail itself. A close and personal interview with the rail, asking such questions as:

1) "What can I do for you?"

2) "Did you like what I did to you last time?"

3) "Is this template what you really want or should I go back to the drawing board?"

Are all answered by visual signs told by the rail. Although the long term answers to these questions will be told by future charts and graphs depicting the relative merits of these individual decisions, when grinding in a preventive mode, the most beneficial time to ask them is during a pre-inspection prior to the arrival of the grinding machine.

When operating efficiently in a single-pass mode there is only one chance to apply the right grinding pattern to each curve or tangent segment during each grinding cycle. Once the machine has arrived on-site it is too late to begin asking those questions.

The rail grinder at MRS is applied so that it removes an average of 20/100mm (0.008 inches) of metal across the railhead in one single pass. This means that surface cracks are allowed to grow up to this maximum depth at which point the rail is cleaned up and re-shaped.

Many variables, such as rail metallurgy, machine productivity, grinding intervals, track geometry and a myriad of other issues must be taken into account to arrive at the most efficient and cost effective application of the grinder. Many times these variables are not constant, changing over time, and the program must remain fluid and adapt to these changes.

Rail grinding is a very expensive process and requires a complex logistic operation. A complete understanding of the entire phenomenon of rail surface deterioration and wear is absolutely necessary. The enlistment of experts in the field of grinding and rail management is essential to getting any grinding program off to a good start and helping to direct it along the way, allowing the railroad to reap the benefits without wasting shareholders money due to re-inventions and failed attempts. Everything must be reviewed, from the selection of the proper grinding stones to examining the operating rules of the railroad.

Rail grinding is an absolutely necessary rail maintenance process in a Heavy Haul Railroad and the engineers and managers at MRS learned this lesson in a very short period of time.

Even the best rails in the world, on some of the best track structure, need to be maintained by grinding, otherwise the optimum life cycle cost will never be achieved and the most expensive asset in track maintenance will be scrapped prematurely.

Fuel savings up to 3%, a doubling of rail life, increased traffic potential and a 45% reduction in rail breaks are welcome results. The managers at MRS are fully satisfied in their decision to bring a high production rail grinder, along with professional expertise, onto their property.

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