“Man vs. Machine”: Testing Automated Rail Grinding Pre-Inspection vs. Manual Methods

J. F. Holt, D. H. Isdahl, R. C. Harris, B. J. Koch, D. M. Daftari, C. P. Rudeen, J. M. Carlin
Loram Maintenance of Way, Inc., Hamel, MN USA

1.0 INTRODUCTION

Hundreds of millions of dollars are spent each year by heavy haul railways on rail grinding programs. Rail grinding has been increasingly adopted as an effective method of extending rail and wheel life. This is done by removing fatigued rail metal and reshaping the head of the rail to control rolling contact fatigue (RCF) defects, which in turn, will improve wheel steering, reduce wheel/rail contact stresses, and reduce fuel consumption. However, the question of how best to optimize the grind results is very complex, involving many variables and trade-offs.

With the advancement of technology comes the desire to duplicate and ultimately improve upon the unique skills and talents of the most knowledgeable experts in their given field in order to boost productivity, quality, consistency, and maximize results across a broader scope. Inspectors who truly understand all of the factors to be considered when developing the best grind plan are becoming scarce and in high demand. However, automating the lessons of years of experience and undefined and often unmeasured variables makes for a particularly daunting challenge.

Loram has collected track data for more than ten years on the rail grinders (typically pre-grind and post-grind profiles). In addition, their first rail inspection vehicle (RIV) was commissioned in 2005. The data collected, combined with the results of recent experiments conducted for comparison purposes, can provide insight into advances in the ability to achieve the desired transverse profile and depth of cut through technology improvements in the application of the rail grinder. This paper provides a discussion of these advances as well as the advantages that seasoned inspectors can hold over the technology when applied by those with more limited experience.

2.0 ECONOMIC FACTORS

The benefits of grinding rail have been established in many publications. Studies have shown its significant contribution to a two-fold increase in system rail life and a four-fold increase in system rail fatigue life over the past thirty years [1]. Implementing rail grinding as part of a new program was shown to reduce rail fractures by 45%, lower fuel consumption by 3%, double expected rail life within a four year period, and reduce traffic interruptions and replacement cost accordingly [2].

Since grinding is essentially artificially wearing the rail, it is obvious that removing as little as is required in the proper rail head locations will help achieve the goal of longer rail life. By removing less metal per grind cycle, it follows that fewer grind passes will be required and equivalent results can be achieved at higher speeds, leading to more track kilometers ground in the available track window. While measurement of the possible grinding benefits foregone due to the lack of conformance to the desired rail profile has not been successfully achieved, it stands to reason that these benefits have the potential to be substantial. [3,4] Therefore, in order to produce the greatest value from the program would be, in a macro sense, to remove the smallest amount of metal that is beneficial in the most efficient manner while achieving precise and consistent results to the extent that improvement is no longer cost-effective. This leads to maximum life extension of the rail with the least amount of maintenance (grinding) cost per track kilometer of the rail throughout its life. A common solution suggests efficiency gains by regular pre-inspection of the rail and application of a specific treatment to each condition encountered [3].

3.0 PRE-GRIND INSPECTION

Pre-grind inspection is the act of inspecting the rail and track conditions just prior to the grind cycle to determine grinding requirements for the different rail conditions encountered. Typically on a heavy haul railroad the inspection should be performed two to three weeks ahead of the grinder to ensure that rail conditions do not change. However, the exact duration is dependent upon factors such as tonnage, type of rail, etc. The results of a pre-inspection include the detailed work (number of passes, speed and pattern number) that the grinder must perform on each rail of every curve or track section. It is important to note that since each grinder differs in its pattern set up as well as metal removal capabilities, the results of pre-grind inspections are grinder specific.

3.1 Manual inspections

Manual inspections, for the purposes of this paper, are those performed by personnel riding on the tracks making visual observations, typically with frequent stops to closer observe the conditions. Track inspectors often utilize a õbar gaugeö, õradius gaugeö, or other handheld device to help assess rail profile conditions. These assessments may be made on each curve and at times in tangents to determine the grind plan based on their knowledge of grinding, the generic metal removal curves for the patterns, and the metal removal capabilities of the specific rail grinder for which the inspection is intended.

3.2 Automated inspections

With advances in technology, automated inspections such as those performed by Loramœs Rail Inspection Vehicle (RIV) have become more common. This standard vehicle is equipped with a laser-based device that measures the rail profile, track gauge, rail cant and head loss. Additionally, there is a camera system to show the surface of both rails from within the vehicle with the ability to store and retrieve snapshots as desired. The vehicle is capable of operating at 50 kilometers per hour, frequently gathering data and identifying the most accurate representation of a profile on that segment of rail. Manual inputs also indicate the severity of surface conditions such as corrugation, spalling, shelling and other defects. These inputs are then synthesized into a central program that through a series of algorithms determines the best approach to grind the rails to a pre-defined ideal template. An expected Grind Quality Index (GQI) is determined based on all assumptions being correct and the machine functioning at 100% of its capability.

4.0 GRIND PLAN DEVELOPMENT EXPERIENCE

To produce the optimal grind plan through pre-inspection, a number of factors must be considered, such as:

- Existing Profile Shape: The profile is not the same throughout the entire curve or tangent. A representative profile must be selected before choosing the grind pattern(s) and grind speed(s) to approach the desired grind template most efficiently. While this involves perhaps choosing a particular location to be assumed representative, automation allows a mathematical solution.
- Metal Removal: Generic pattern sheets commonly used only approximate where the metal will be removed. Actual removal depends upon the pre-grind shape of the rail (See Figure 1). Furthermore, each rail grinder is different. An inspection grind plan is made with a specific rail grinder in mind. There are times when the rail grinder performing the work will be changed.
- Efficiency / Speed: Due to the high number of kilometers of track ground and increasing speeds of rail grinding, the inspections must be fast and efficient.
- Safety: Employee safety cannot be compromised in the inspections. Some railroads do not allow employees to get on the ground to manually inspect the track.

- Track and Grinding Knowledge: Knowledge and experience is required to relate track conditions, such as track gauge, tie conditions and rail cant to RCF in order to make wise grinding decisions.

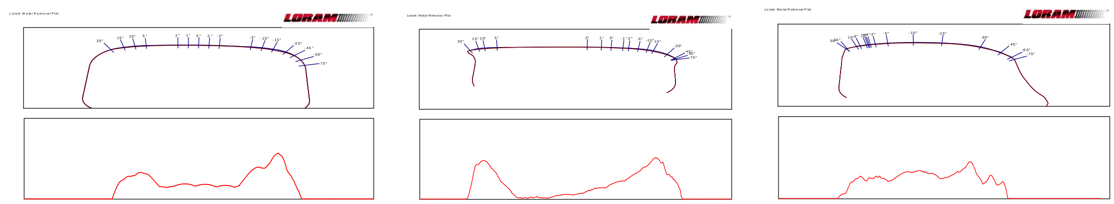

Figure 1: Metal removed by the same pattern on a new rail, a flat low rail, and a curve worn high rail respectively

The following sections provide a summary of the results of automated and manual pre-inspection and experiments conducted with the intent of learning more about the benefits and drawbacks of each. It is divided into location, as it has been found that applications should be tailored to each unique situation.

5.1 North America

While the ability to collect and view rail profiles and grind data has been available for a number of years, Loram began utilizing an automated inspection process to determine the best grind plan (grind patterns and speeds) to most efficiently achieve the desired profile within the constraints of the inputs and algorithms available in 2006. Since then, more than 230,000 miles (380,000 kilometers) of track have been inspected in North America utilizing eleven rail inspection vehicles. In 2012, more than 60% of the pass miles ground in North America were inspected by these vehicles. That figure is expected to continue to grow. The remaining grind plans are created through either a manual pre-inspect, existing data assessment, or an estimate based on typical requirements with dynamic adjustments as the rail is ground. This provides a great deal of historical data and trending information to compare the progress.

5.1.1 Profile Conformance to Pre-defined Template

A great deal of research and a number of publications have been devoted to the proper templates to which rails should be ground to achieve optimal results [4,5,6]. These usually asymmetric templates are independently developed based on many factors including curvature, rail cant, MGT, desired running band, and typical worn wheel profiles found throughout the system. In some cases, different wheel shapes are specific to territory, such as those found on heavily loaded coal trains. They are often further segregated by degree of curvature. Indicators have been developed to characterize conformance of the rail head profile to the desired template, sometimes referred to as the GQI (Grind Quality Index) or the RPQI (Rail Profile Quality Index), and can vary depending upon the package used. The index referenced in this paper will be Loram's version of the Grind Quality Index (GQI), where higher priority areas of the rail head radius are given more weight in the score. A score of 100 would indicate perfect conformance to the desired template (within the tolerances chosen) on the scale of 0 to 100. As an example, new rail in North America would typically score between 20 and 30 on this scale before grinding is performed to achieve the desired asymmetric templates.

Based on available data, a comprehensive six month rolling average shows post grind GQI values consistently scored higher by using a Rail Inspection Vehicle versus a manual pre-inspection method, with the differential increasing over time. The RIV-inspected data represents four Class I North American railways, while the manually inspected data represents two Class I North American railways (see Figure 2).

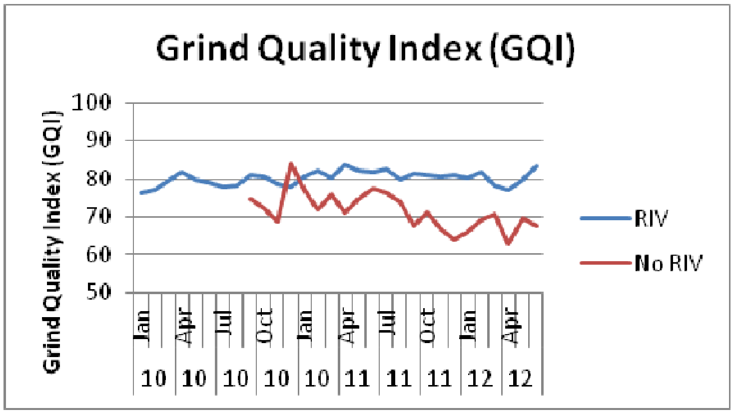

Figure 2: GQI after grind with and without RIV inspection

To further understand the ability of the automated grind plan development algorithm's ability to efficiently improve the profile, an experiment was conducted in 2012 involving the Rail Inspection Vehicle on a territory where only manual inspections had previously been conducted before grinding. The grinder then ground according to the grind plan generated by the RIV. The results showed a significant increase in the GQI in all conditions, including low rails, high rails, and tangent rails (see Figure 3).

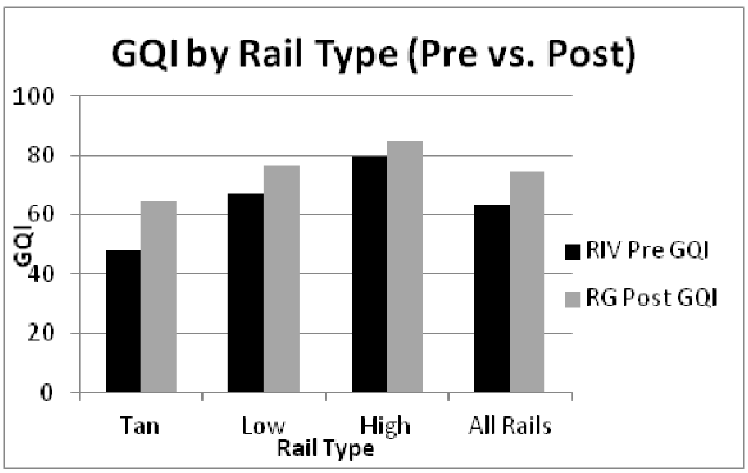

Figure 3: GQI improvement with RIV inspection

Interestingly, one of the manual inspectors rode along with the RIV on the inspection and had the chance to observe the patterns, speeds, and number of passes selected by the RIV in various situations. His next manual inspection resulted in higher post-grind GQI values versus the post-grind GQI values witnessed on previous manually inspected track. This indicates that the RIV program may have in fact educated the manual inspector on how to better develop a grind plan to achieve improved profile conformance.

On another North American railway, a test was conducted on track previously inspected manually only. The regular inspector first inspected the track and developed a grind plan in the usual manner. An RIV was used to then inspect the same territory and produce a grind plan. The grind plans were then merged with the manual and automated plans interspersed without indicating their origin to the grinder. The post-grind GQI of segments ground using the automated grind plan was nearly 15% better overall than segments ground using the manual grind plan (see Figure 4).

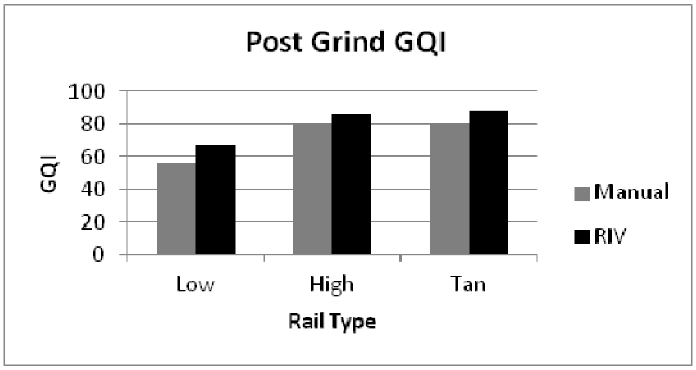

Figure 4: Post Grind GQI Experiment, Manual vs. Automatic

5.1.2 Grind Speeds

The pre-grind shape of the rail head affects the depth of cut that can be achieved. For example, a flat rail head will require more grind effort to reach the same depth of cut as one with a smaller radius. By specifying the precise depth of cut required across the surface of the railhead and what it will take to achieve that depth, safety factors can often be reduced or eliminated in the creation of the grind plan. This most often results in a reduced number of grind passes required and/or increased grinding speeds. Efficiency models can be integrated to optimize the total work effort (and cost) that is required to remove the desired amount of metal. While other factors also come into play, the grind speeds on the rail grinders that use RIV grind plans have averaged almost 3 kilometers per hour faster than those that do not (see Figure 5).

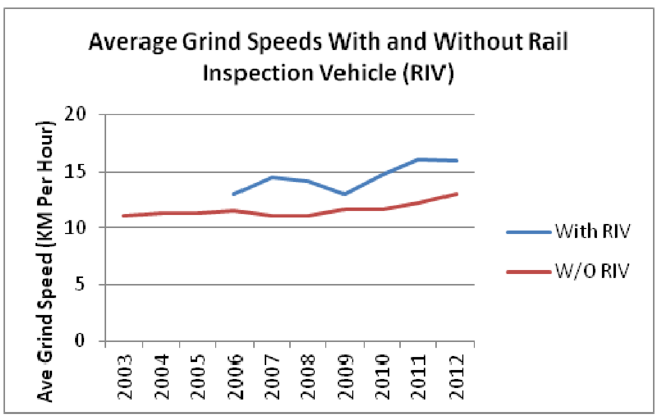

Figure 5: Average grind speed with and without automated inspection

5.1.3 Consistency

In the development of the automated grind plan algorithms, the attempt was made to incorporate the best practices of the most experienced manual inspectors. Consideration was made to weigh each and every measurable factor in determining the best approach for each section of rail. Surface conditions and corrugation are factored into the equation as well. Additional measurable criteria that have the potential to alter the grind plan are the track gauge, track availability, and rail head loss/tonnage since the last grind. However, at this time, these factors still require manual intervention. Variables generally measured such as the wheel running path and other track conditions are components that an experienced inspector may take into account.

To test the consistency in the development of the grind plan by manual inspectors, an experiment was conducted in July of 2012. Three seasoned inspectors with combined experience in rail grinding of over 50 years inspected a portion of a track that had already been inspected by an RIV, but not yet ground.

While data is still being collected and analyzed, initial results showed a significant amount of variation in the inspections and amount of grinding requested. Time spent grinding would be more than 120% more from one plan to the next, resulting in a significant difference in metal removed.

Total of All Tracks	Grind time Mins	Pass KM	Speed KPH
Inspector A	73	24.18	11.7
Inspector B	53	26.05	11.2
Inspector C	117	26.05	11.7

5.2 Australia

In 2009, Queensland Rail began operation of two rail inspection vehicle in conjunction with their acquisition of two rail grinders. One of these vehicles is equipped with a rail corrugation analyzer in addition to the standard features. Their intent was to transition to single pass grinding as much as possible, making it more critical to be as accurate as possible on that pass. One of their contractual requirements involves the requirement to achieve an improvement in the grind quality index versus that which is expected. The GQI has improved over time and as of 2011 was at an average of 85 on the Goonyella subdivision [7]. More recent information reports all networks automatically inspected are over 80, with most between 80 and 90 on the GQI scale. They report safety improvements by avoiding the need to get on the ground, a low pass kilometer / track kilometer ratio and increased productivity of the grinder while keeping visual defects to a minimum. A side benefit has been the available rail wear data, which has been used extensively for rail replacement decisions.

5.3 United Kingdom

A demonstration was conducted on the UK to determine the effectiveness of the grind planning software, including a comparison of automated versus manual inspections. It was found that while the manual inspectors were doing a good job of calling grind patterns as a whole, there were some areas where improvement could be made. While focusing on the rail shape, they ran the risk of not reaching the minimum metal removal on the rail head that varies with the initial rail shape. At the time, the rail needed some significant work, which was easier than when it is more subtle. Finally, there is the potential for fatigue when inspecting a large amount of track, along with the potential to rely on a ñfavoriteò set of patterns rather than choosing from the broader spectrum.

5.4 India Rail

India Rail embarked on an aggressive plan to begin a rail grinding program in 2011. Lacking experience in grinding rail, they required a system that could help bring them up to a highly effective level of grinding efficiency and effectiveness immediately. IR posed a unique challenge ï no rail grinding had been implemented for over 15 years and most of the routes were with mixed traffic. This required some ñout-of-the-boxò solutions for the strategy development. The National Research Council Canada Centre for Surface Centre Transportation Technology (NRC-CSTT) was contacted to help develop the overall strategy in consultation with RDSO. NRC-CSTT consultants came to India in 2009 to collect information from the field on rail-track condition, rolling stock condition, geometry information and ongoing maintenance practices. This included over 1000 wheel and rail profiles from different locations. The result was the development of a preventive-gradual grinding program which was to help transition the rail from a corrective condition to a preventive condition. The objective was to immediately gain the benefits of an optimized preventive grinding strategy while gradually catching up to the profile and surface cracks. The advantages of implementing a preventive-gradual strategy instead of a corrective strategy on the NCR & SCR lines were as follows:

- The amount of metal removed from the rail per GMT was reduced by 50%.
- Less metal removed at each track kilometer increases the productivity of the grinder by up to 50%; that is, more kilometers of track could be covered each year.
- The work hardened layer on the rail head would be maintained and the softer steel would not begin to plastically deform after grinding, therefore the engineered rail profile(s) would be maintained for longer tonnage intervals [8].

The rail grinders currently perform the first pass of grinding with a strategically engineered pattern and speed setting, while recording the pre and post ground rail head. The automated grind management system then automatically generates the rest of the grind plan based on post grind rail head measurement and manually input first pass data. Subsequent passes (if needed) are displayed for the RGM operator before the first pass is completed. Although a separate pre-inspection vehicle would eliminate any guessing with the first pass, this current process has proven effective and GQIs have increased consistently as per plan. As the rail conditionð in particular the rail shapeð improves and more single pass grinding is warranted, it may become more beneficial to differentiate on first pass by unique pre-inspection.

5.5 Delhi Metro

While not a heavy haul railway, Delhi Metro wisely recognized the need to adopt an automated rail inspection and grind planning management strategy right from the start to accelerate the effectiveness of their grinder and compensate for lack of experience in rail grinding. Their grinding package included the ability to produce a grind plan automatically and dynamically from the rail grinder itself. In their case, the rail grinder is first run as an inspection vehicle to measure the rail head over a select amount of track, thus creating the grind plan. This plan is then executed by the rail grinder to achieve the desired profile and metal removal.

5.6 Brazil

MRS railway in Brazil embarked on a grinding program in 2002 with immediately favorable results. However, tonnage has continued to climb and track windows have become tighter. They have recently purchased a rail inspection vehicle package to complement additional grinding in order to maximize efficiency and further improve results. This RIV is expected to begin service sometime in the second half of 2012, with the first order of business to map the track, including GPS locations.

6.0 CONCLUSIONS AND RECOMMENDATIONS

In multiple trials, the automated grind pattern selection system has consistently outperformed even the most seasoned manual inspectors in approaching the ideal conformance to a predefined profile template. A predictable depth of cut can be better achieved by considering the shape of the rail before grinding and calculating the amount of shaping that is required beyond just removing a uniform amount from the surface. Speeds can be maximized by reducing the need for a large safety margin or wasted effort by choosing inefficient grind patterns.

However, there are a number of assumptions that must be correct to achieve these results. There continues to be ongoing research and testing on determining the ideal rail template. In fact, it is a target that must be in synch with the wheel profiles. Less than optimal results will be achieved if the rail conforms perfectly to a less than optimal template.

Track conditions such as wide gauge, unstable ties, rail cant deficiencies or elevation problems can lead to unexpected results. While a person experienced in rail grinding may be able to identify these issues and alter the grind plan, they are not currently parameters that are considered in the automatic grind plan generation.

Dynamic conditions are not automatically considered in the current inspection inputs. Should a great deal of rail cant shift take place under a train, the contact patch can shift, leaving an unexpected wear pattern. In addition, if the track structure is corrected after the inspection or grind, the contact area may not match the profile intended with the grind.

The value of quantifying what is done and possessing the ability to go back and look at hard data after the fact and utilize the data for planning purposes cannot be underestimated. This makes the automation valuable in ways that have not yet been fully exploited.

Ultimately, the best path forward is to continue the identification, quantification and development of tolerances of more parameters to automate in the grind planning process. This will better position the automated inspection to consider more of the factors that experienced inspectors consider. Continuation of the learning and fine-tuning of the profiles, along with quantifying the value of achieving a higher GQI in terms of factors such as rail life extension and fuel savings will position the automated inspection to become even more precise in consistently prescribing the most cost-effective solutions for treatment of the rails. In addition, continuing the study of the deterioration of the rail and developing valid prediction models will assist in reducing the need for inspections. While the automation can develop a very good and consistent grind plan, manual experience is still required to achieve paramount results. Until these factors are better understood and incorporated, the best solution at this time is to automate the inspection using an experienced inspector with a working knowledge of all dynamic interactions.

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