Rail Grinding Technology and Strategy Implementation in a New Brazilian Heavy Haul Railroad

B.M. Borges, C. G. Jorge, R. P. Santos, & T. G. Viana
VLI, Belo Horizonte, Brazil

P. H. P. Lobato
BRFERROVIA, Belo Horizonte, Brazil

ABSTRACT: VLI operates and maintain almost 8,140 km of track (42% are heavy haul) from two railroads, maritime ports and intermodal terminals in the Brazilian territory. This logistic company considers the rail grinding as a very important mechanized process of track maintenance focused to rail life extension through rail wear control and surface defects elimination/mitigation caused by vehicle-track dynamics. Moreover, this maintenance practice, allied to wheel re-profiling and friction management strategies, provides a better distribution of efforts to the wheel-rail interface through contact mechanism improving of the wheel and rail profiles, as well as in the optimization of vehicles movement in curves and tangent tracks. Therefore, a complete understanding of the phenomena that occur during wheel-rail interface and the operability of the features of this heavy maintenance of track machines is very important for this complex mechanical and logistical operation. In order to extent the rail life and reduce the maintenance costs, VLI purchased one modern and efficient rail grinder to work on two VLI's heavy haul railroad routes: Center-East and Center-Southeast.

1 INTRODUCTION

The increasing of the freight transportation and the continuous increment of the axleload in the main corridors of the Central-Atlantic Railroad (FCA), operated by VLI Company, has been bringing significant gains to the rail freight business. However, it had been accelerating rail wear, RCF crack propagation and other surface defects at bordering levels of the mechanical stress supported by the rail, resulting in rail traffic interruptions due to rail replacements and increasing of the track maintenance cost.

Rail grinding is a mechanized process of track maintenance to extents rail service life through wear control during vehicle-track interaction and the elimination / mitigation of cracks and surface defects caused by wheel-rail contact. In addition, this maintenance practice, added to wheel reprofiling, provides an improvement of the stress distribution in the wheel-rail interface by its conformal profiles, as well as in the optimization of the bogie steering on curves and tangents. A complete understanding of the wheel-rail interface phenomena and the operability of the rail grinder system is necessary in this complex mechanic and logistic operations.

In order to extend the rail life and to reduce the track maintenance costs, VLI purchased, in 2012, a modern and efficient rail grinder to operate in the main FCA's Central-East and Central-Southeast routes.

2 RAIL GRINDING

2.1 *Rail Grinding Objectives*

Rail grinding is a rail maintenance process carried out by equipment designed to remove metal from the rail surface using rotating circular grinding wheels coupled to electric motors. The grinding of optimized rail profiles to tight tolerances at preventive maintenance intervals (based on MGT – Million Gross Tons) effectively works to remove cracks and to modify/improve the railhead profile for the purpose of [1]:

- Control the propagation of rail surface defects by Rolling Contact Fatigue (RCF);
- Control the rail corrugation, wear and metal flow;
- Control wheel wear and fatigue (due to optimized rail profiles);
- Control the hunting of the bogies on tangent track;
- Improve the reliability of the rail ultrasonic inspections (rail flaw detection);
- Control the noise in the wheel-rail interface.

2.2 *Rail Grinder*

There are numerous models of grinders, ranging from lighter to heavier models, with 4 to 96 grinding wheels. Generally, according to Sroba [1], small, flexible machines with 8 to 24 grinding stones (sometimes even less) are used on small rail networks or special track work such as detours or intersections. They also work as satellite machines capable of working in small critical stretches, on demand, usually in corrective mode.

High-output machines are already allocated to services that cover long sections of track, usually on a one-pass basis, especially on high-speed or heavy-haul lines. The latter have between 48 and 96 grind stones and can achieve target profiles and specified metal removal in a single pass at high speed.

2.3 *Grinding cycles*

There are two main strategies for grinding rails [2]:

The first strategy, called corrective grinding, is performed to "clean" the rail (of surface defects) and adjust its profile, seeking to conform it to the profile of the wheels, increasing the area of contact between them and, consequently, distributing better / reducing the stresses. This strategy runs at regular intervals of 20 to 80 MGT and is usually associated with multiple passes.

The second strategy, called preventive grinding, is performed at frequent intervals to maintain the profile of the conformal rail and prevent surface defects from appearing. However, the implementation of the preventive strategy becomes a problem when the level of surface degradation of the road is much accentuated and requires multiple passes. In this sense, two new concepts of preventive grinding have emerged:

- Immediate preventive grinding: the first grinding of the rail is corrective, passing soon after to the preventive;

- Gradual preventive grinding: the first (1 to 3) cycles have the function of introducing the ideal profile, the next (1 to 3) cycles have the function of stopping the appearance and growth of cracks, the (1 to 3) cycles Have the function of removing the final cracks and from there, it returns to the normal preventive grinding pattern (Figure 1).

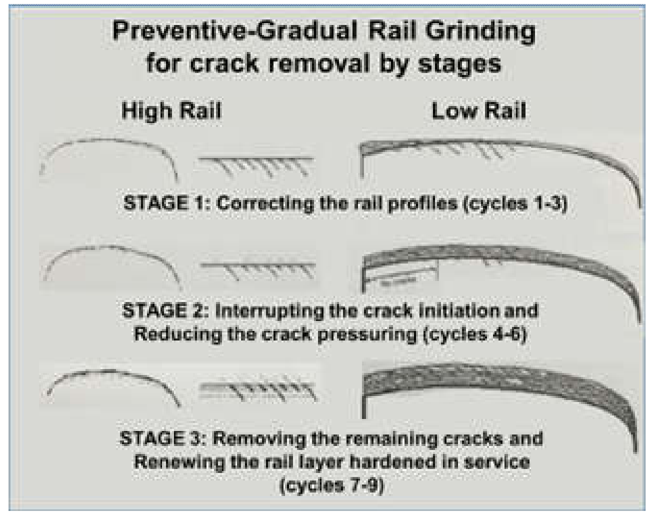

Figure 1. Gradual Preventive Grinding [2].

2.4 *Result from other Brazilian heavy haul railroad*

A study carried out in the MRS, other Brazilian heavy haul railroad, presented in 2005's IHHA Conference the results obtained with the gradual preventive grinding.

In the first year of operation of the equipment there was a reduction of approximately 10% in total fractures and in the first three years the number of rail fractures reduced from 376 fractures to 206 fractures (45% reduction), according to Figure 2.

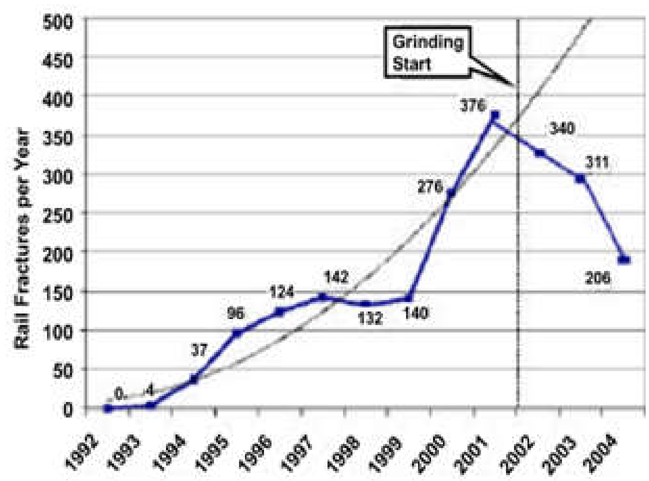

Figure 2. Rail fractures reduction in MRS HH railroad [3].

Improvements in rail profiles reduced the resistance in curves. Consequently, fuel consumption reduced in 3% after the beginning of rail grinding operations in the MRS railroad, as Figure 3.

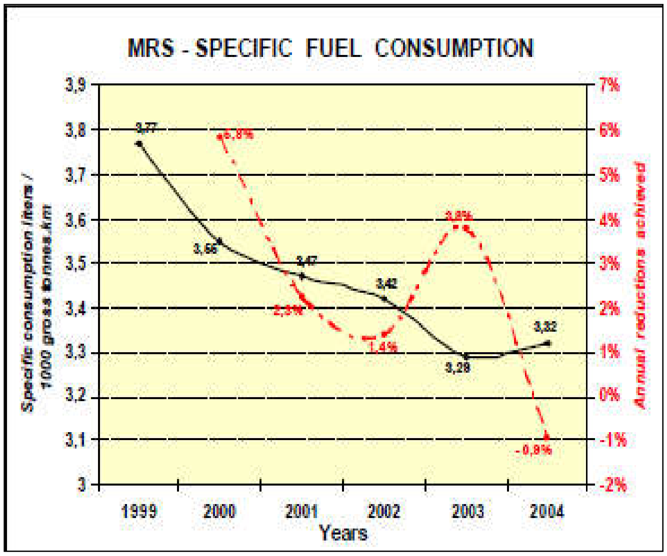

Figure 3. Fuel consumption reduction in MRS railroad [3].

The average life of the rails increased from 750 MGT in 2002 to 950 MGT in 2003 (increasing of 27%), as shown in the Figure 04.

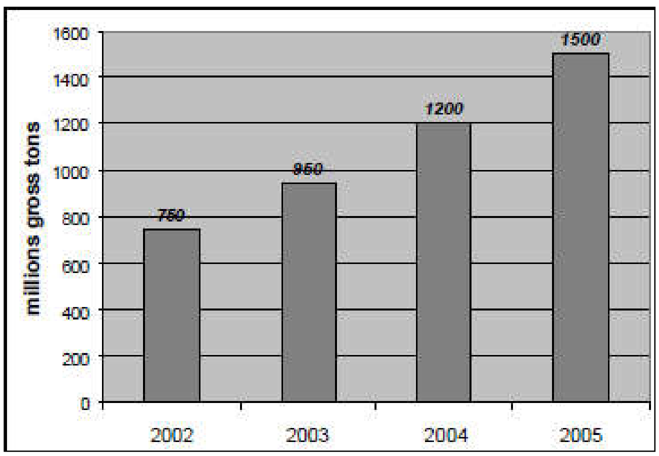

Figure 4. Rail wearing reduction in MRS railway [3].

3 RAIL GRINDING STRATEGY

3.1 *24-stones grinding machine*

The equipment was manufactured in USA and consists of five cars:

- 1 power car with driver's cab;
- 1 standing car with living area and work room;
- 2 grinding cars;
- 1 grinding car with driver's cab.

The grinder purchased by VLI to FCA has a rail profile measurement system, which reads the rail profile and quality, and an automatic alignment system of grinding motors according to the selected pattern.

The main characteristics of the composition are presented at follows:

- Overall length: approx. 66 m
- Dry weight: approx. 167 tonnes
- Wet weight: approx. 212 tonnes
- Capacity of fuel tank: 8,517 liters
- Capacity of water tank: 32,832 liters
- Maximum speed: 80 kph (0% grade)
- Maximum grinding speed: 15 kph
- Minimum curve radius to travel: 60 m
- Minimum curve radius to grind: 80 m
- Track gauge: 1,000 mm (narrow)
- Generator engine: Caterpillar C32 diesel 1350 BHP, 1,007 KW

Figure 5. Power Car [4].

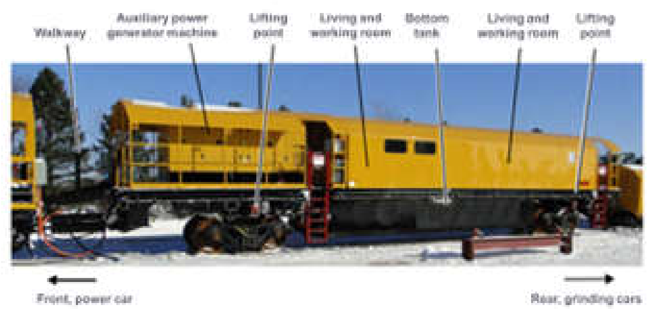

Figure 6. Support Car [4].

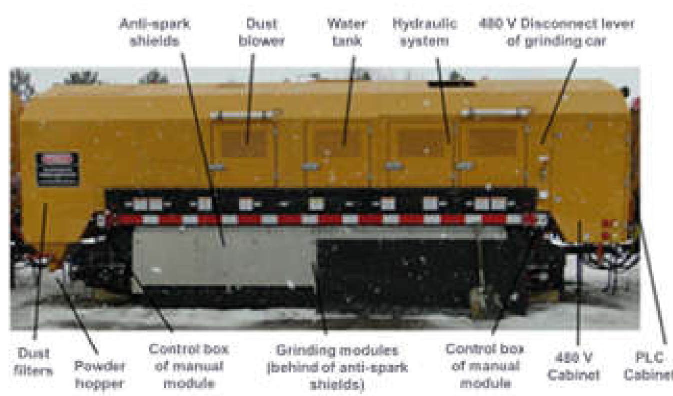

Figure 7. Grinding Car [4].

3.2 *VLI Heavy Haul Railroad Routes*

VLI operates and maintain five railroad routes, and approximately 75% of the volume transported by the company is concentrated in two railroad routes: Central-East and Center-Southeast. For this reason, these were the routes chosen to implement rail grinding first. The main characteristics of these corridors are presented below:

East-Center Railroad Route

- Length: 730 km
- Gauge: 1,000 mm
- Sleeper: Wood
- Maximum ramp: 3.9%
- Minimum radius: 80 m

Center-Southeast Railroad Route

- Length: 1,550 km
- Gauge: 1,000 mm (mostly); mixed
- Sleeper: 17.5% concrete; 82.8% wood
- Maximum ramp: 3.2%
- Minimum radius: 90 m

Figure 8. Rail grinder working routes

3.3 *Grinding cycles*

VLI grinding strategy should include both a corrective and a preventive model. Corrective grinding aims to eliminate the most severe defects such as:

- Rail Corrugation;
- Severe Metal Flow;
- Engine Burn;
- Lateral Wear due to Hunting.

This model should follow the following cycle:

Table 1. Corrective grinding vs MGT [5]

Track line	Zarembski	FCA
Sharp Curves (R < 350 m)	40 - 80	40 - 80
Moderate Curves (350 < R < 750 m)	60 - 120	60 - 120
Tangent Track	80 - 120	80 - 120

The preventive grinding has the function of avoiding that the superficial surface defects evolve to more severe defects and conform the profile for the best wheel-rail contact. Based on a review of several theoretical sources, VLI Track Engineering defined the best preventive grinding cycles for FCA's Premium and Standard rails [5]:

Table 2. Preventive grinding cycles by MGT (Premium rails)

Track line	Zarembski	IHHA	ARTC	AREMA	FCA
Sharp Curves (R < 350m)	15 – 25	15 - 25	15	15 – 25	15 – 25
Moder. Curves (350<R<750m)	30 – 50	30 – 50	30 – 45	n/a	30 - 50
Tangent track	100	100	n/a	100	100

Table 3. Preventive grinding cycles by MGT (Standard rails)

Track line	Zarembski	IHHA	ARTC	AREMA	FCA
Sharp Curves (R < 350m)	8 – 12	n/a	7,5	8 – 12	8 – 12
Moder. Curves (350<R<750m)	16 – 24	n/a	15	16 – 24	16 – 24
Tangent track	40 – 60	45 – 60	n/a	40 – 60	40 – 60

3.4 *Productive capacity*

The expectation is to grind 700 km of track in 2015 - first year of operation - and 1,383 km of track from 2016. This production is enough to carry out approximately bi-annual cycles in all the extension of these two railroad routes.

VLI rails have never been ground in a systematic way, it is expected to act primarily by corrective method in 2015, so the productive capacity considered to 2015 (2 kph) is less than the productive capacity. Considered for 2016 (3 kph), when we will begin a preventive work in order to keep the rails without surface defects and with the best wheel-rail contact.

Table 4. Assumptions of productive capacity.

PRODUCTION	2015	2016
Productivity (kph)	2	3
Total working window (hours)	8	8
Grinding time per day (hours)	2.5	2.5
Working time per week (days)	4	4
Total rail grinding time (days)	187	187
Annual production (km)	936	1,383.7

4 OPERATING STRATEGY

The grinding crew is composed of 4 VLI personnel in the operation and three employees in the maintenance, being:

- 1 Leader of the operation team and responsible for the technical quality of the service;
- 3 Grinding operators, responsible for the conduction and operation of the equipment, firefighting and communication with the Operational Control Center;
- 1 Leader of maintenance team and responsible for the technical quality of maintenance; and
- 2 Track maintainers, responsible for the daily maintenance of the equipment.

Since the equipment works in different locations than the places of residence of operators and maintainers, it was necessary to negotiate with the railroader union a 10 days' work schedule for 4 days off in order to reduce the number of trips for team return and optimize the production of equipment. The team also counts on the support of:

- 1 road vehicle (minivan) for logistical support;
- 1 munck truck with a fuel tank to make the supply and carry the necessary resources and the tailings of the maintenance; and
- 1 water truck, to perform the daily supply of the water tanks of the grinder.

5 MAINTENANCE STRATEGY

The maintenance strategy of the rail grinder has been guided in order to guarantee the available and reliable asset, seeking greater effectiveness in the application of the resources and a better Life Cycle Cost (LCC), being, therefore, an essential element for the installation of the new asset acquired by the maintenance areas.

To guarantee the integration of the grinder to the maintenance routine, maintenance plans were developed and their availability in the automated maintenance system, availability of spare parts for application in a timely manner, according to the planning of the maintenance area. A checklist for routine inspections was also created, ensuring constant monitoring of equipment conditions and preparation for routine operation.

Preventive maintenance intervals were defined based on hour-measuring devices from grinder motors, taking into account the manufacturer's recommendations and experiences experienced by other railroads that have similar assets with maintenance results based on a work strategy already developed. Thus, the maintenance intervals of the LRG26 rail grinder are following the following definitions:

- Daily and weekly checklist (Sensitive Inspection and Lubrication)
- 250; 750; 1,500; 3,000; 4,500 and 9,000 hours of grinding operation

Aiming to find alternatives to reduce equipment failures and, consequently, production losses, we have the tools "Loss Profile" and "Failure Analysis".

The basic assumption for the effectiveness of these tools is the use of the "class of failure", which is a structured form of a fault, which allows recording all maintenance events through standardized hierarchical coding for equipment and components.

The failure class structure was developed through failure mapping, based on the "Affinity Diagram" allowing the grouping of problems in several sets according to natural affinities and relations. In this way, initially the possible asset failures were raised and grouped to the respective items. Failure modes were generated for each class of failure analyzed.

Another definition for the Maintenance Strategy was the criticality of the equipment, seeking greater efficiency in the application of resources and best cost-effective relations and service life that represents the lower LCC of the asset.

6 PROJECT IMPLEMENTATION

Because it is a long, complex project, dependent on a high investment and strategic for the company, it took detailed planning, preparation of several interface areas and careful monitoring of all stages.

The management model adopted for these projects is a mix of PMBOK management tools and the Initial Control methodology used in Vale's asset installation projects [7].

This methodology aims to establish the fundamental assumptions to minimize the impacts caused by the delivery of new equipment to the maintenance and operation of the railway logistics projects, guaranteeing the optimization of their performance and establishing guidelines for the installation and uninstallation of these assets.

6.1 *Planning*

The grinder project began in 2008. In 2009 this idea evolved into the first document of premises and feasibility analysis of the equipment elaborated by Vale's railway operations engineering. However, the price of this equipment in the market only occurred in 2011 when the newly created VLI's Track Engineering Management took over the process.

In 2012, VLI's Track Engineering Management developed the implementation plan and the review of the feasibility analysis of the project in order to guarantee a smooth implementation and a production that adheres to the expectations of the clients and sponsor.

In this same year, the tax benefit of ex-tariff of the equipment was pleaded. The conquest of this ex-tariff allowed us to save R$ 2.4 Million. This amount was used in the construction of a warehouse workshop in Divinopolis-MG (Figure 9) and instrumentation of a workshop in Ibiá-MG, in order to better serve the future maintenance of the equipment.

Figure 9. FCA's track vehicles workshop in Divinopolis-MG

In 2013, the first VLI Rail Grinding Workshop was carried out and the east-central corridor was inspected to identify the feasible grinding sites. These two initiatives were important to generate knowledge and to elaborate the grinding strategy to FCA as soon as the equipment entered in operation.

Parallel to the elaboration of the FCA Rail grinding strategy, the project management plan of the LRG26 grinder was elaborated to guide how the project will be executed, monitored, controlled and closed. This plan has as objectives:

- Determine goals and how to achieve them;
- Eliminate or reduce uncertainty;
- Improve process efficiency;
- Get a better understanding of the objectives;
- Anticipate future problems.

Finally, in 2014, the asset maintenance strategy was elaborated. This document aims to define the strategy for which maintenance should be oriented, in order to guarantee available and reliable assets, seeking greater effectiveness in the application of resources and better LLC.

6.2 *Implantation*

After a long process of technical and commercial approval of the equipment, at the end of 2012, VLI signed the contract with the north-american manufacturer company for the manufacturing of 24-stones grinding machine to FCA and its metric gauge and at the same time began the manufacture of the machine.

Rail grinder manufacturing finished in approximately 1.5 year (Figure 10). During this time, in 2013, there was an intermediate follow-up visit to manufacture the equipment at the manufacturer facility in USA. This visit was important to evaluate the development of the rail grinder manufacturing.

Figure 10. Manufacturing od Rail Grinder' Power Car

In January 2014, a preliminary technical acceptance visit of the equipment was carried out in order to validate the shipment of the equipment to Brazil. In May 2014, the grinder embarked for Brazil through the port of Houston, Texas (Figure 11).

Figure 11. Machine transportation to port of Houston, TX.

This equipment arrived in Brazil in June 2014. A team from VLI and the rail grinder manufacturer followed the unloading and assembled the equipment to allow its towed rail displacement. Finally, in August 2014 the equipment arrived at the VLI's Divinopolis workshop (Figure 12).

Figure12. Receiving the Grinder at Divinopolis, MG Brazil.

The training of the operation and maintenance crews was carried out between October and November 2014 and every 4 operators and 3 maintainers were evaluated through theoretical and practical tests and considered fit to start their functions. All pending issues that arose during commissioning were handled by January 2015 when the final technical acceptance of the product was issued.

With the implementation of the project, it is expected to save both the operation, the reduction of train time stopped and the reduction of fuel consumption, as in the maintenance of the track with the increase of the useful life of rail and reduction of rail fractures.

Thus, in light of the results obtained in the MRS presented in item 2.4 of this technical paper, it is expected a reduction of 3% in fuel consumption, 10% reduction in rail fractures and 30% in annual rail wear.

7 RESULTS

Since the effective start of operation of the equipment, there has been a significant increase in the performance of the operators, generating a consequent increase in the productivity of the activity. The graph below shows the production and productivity of the equipment increasing the annual KPH average by more than 44% since the beginning of its actual operation until December 2016.

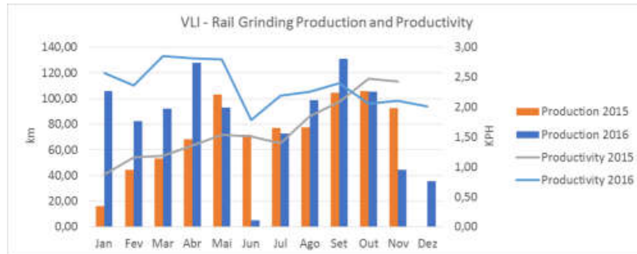

Figure 13. Production and productivity of VLI's Grinder.

Since 2015, VLI has maintained two test sites to evaluate the increase in rail lifespan. The results cannot yet be disclosed, however, preliminary data show that VLI has managed to extract good results with this new maintenance procedure.

8 CONCLUSIONS

The grinding strategy to be applied will allow the FCA the ability to control and manage the harmful effects caused by the RCF and the extension of the useful life of the rails. In preventive grinding, we have a unique chance to apply the correct grinding pattern to each curve or tangent during each cycle.

Many variables (rail metallurgy, machine productivity, grinding intervals, track geometry, etc.) should be considered for a more cost-effective operation of the grinder. As, for the most part, these variables are not constant over time, the grinding program must be flexible and adapt to these changes.

It is an expensive but cost-effective maintenance practice requiring complex logistical operations. It is important to fully understand the phenomenon of deterioration and surface wear of the track.

Everything must be considered, from the selection of the grinding stones to the knowledge of the FCA Rail Operations Regulations. Even the best rails in the world based on railroads with the best infrastructure need to be maintained by Grinding, otherwise the optimal Life Cycle Cost will never be reached.

9 ACKNOWLEDGMENTS

We would like to thank our manager Jean Espindola and our executive manager João Silva Jr. for the opportunity to develop the project and our VLI colleagues for their encouragement and support.

10 REFERENCES

[1]. Sroba, P. Rail Grinding - IHHA Guidelines to Best Practices for Heavy Haul Railway Operation: Wheel and Rail Interface Issues, 1st Edition, Part 6, June 2009

[2]. Zarembski, A. M. The art and science of rail grinding. USA. August 2005.

[3]. Silva, F.C.M. et Al. Preventive-Gradual On-Cycle Grinding: A first for MRS in Brazil. IHHA Conference, Rio de Janeiro-Brazil, June 2005

[4]. LRG26 Rail Grinder User's Manual. Chapter 3. April 2014.

[5]. Viana, T. DT VIA 1186 – Definition of FCA's Rail Grinding Strategy [Definição de estratégia para esmerilhamento de trilhos da FCA]. Belo Horizonte – Brazil, 2013.

[6]. Borges, B. DT VIA 2213/2014 – LRG-26 Rail Grinder Maintenance Strategy [Estratégia de Manutenção Esmerilhadora de Trilho LRG-26]. Belo Horizonte – Brazil, 2014.

[7]. VLI System Management Procedure PGS297 – Installation, capitalization and disposal of assets for projects in railway maintenance. [Procedimento Gerencial de Sistema - PGS297 – Instalação, capitalização e descarte de ativos para projetos na manutenção ferroviária da logística]. Belo Horizonte – Brazil, 2012.