Group 1 - Joints Elimination in Heavy Haul Corridors –
A Study on Ferrovia do Aço and Serra do Mar Lines

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March 10, 2019

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1. INTRODUCTION

One of the most expensive components of a railway is the rail. It´s logistics is also very difficult. Because of this a thorough analysis of how this rail will be applied in each condition is necessary. Thus, we usually have 3 options that stand out: short rail application, welded long rail application and continuous welded rail application.

The choice of which model to use impacts directly on several other railway subsystems and has a direct influence on the economic scenario of any railroad. In general all options have advantages and disadvantages, each one being better suited to a different reality of the world's railways.

Table 1 – Rail type application and maintenance characteristics

Rail Type	**Application Cost**	**Safety**	**Preventive Maintenance**	**Other components wear influence**
Short rail	Low	Low	High	High
Long rail	Medium	Medium	Medium	Medium
Continuous rail	High	High	Low	Low

Source: Authors

The MRS Logistica S.A. historically opted for the application of long welded rails. The rails are bought in 24m bars from Japan, these bars arrive to the Port of Sepetiba by ship and are transported by train to the welding yard in Barra do Piraí - RJ. In the yard these bars are joined 10 in 10, forming a welded long rail of 240 m. These rails are loaded into two special rail fleets with a capacity of 45 rails each and are thus taken to the points where the replacement was prospected on the track .

Due to a series of conditions (interval model, number of track maintenance teams, climatic conditions, corrective maintenance, etc.), MRS Logistics does not apply 100% of its rails, new or reemployed, with the use of welds in its joints. Due to this history, a considerable backlog of metal joints has been created all over the track, which directly impacts its maintenance cost, the efficiency of its rail operation and the operational risks of the company.

This project intends to do a quantitative, qualitative and financial analysis of eliminating all joints of the main line of the corridors of the heavy hall the loaded trains run, evaluating the viability of having a continuous rail welded in these particular track.

2. METAL JOINTS

Metal joints are components of the railroad that have the objective of joining two rails through the use of two splints and 4 or 6 screws (depending on model and manufacturer).

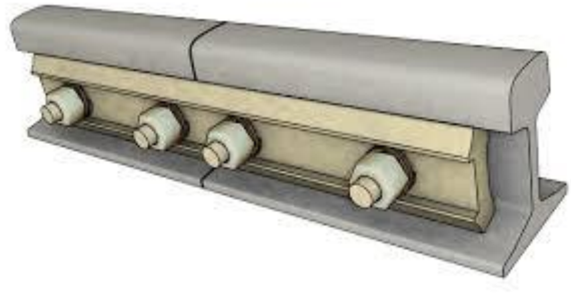

Figure 1 – Metal joint. Source: Authors

The joints can be placed "supported", that is, in this condition the faces of the rails are supported on a sleeper:

Figure 2 – Supported joint. Source: Authors

They can also be placed on a scale, that is, the faces of the rails are suspended between two sleepers:

Figure 3 – Hanging/ in-balance rail Joint. Source: Authors

The joints can be created in a coincident way, so the joints are parallel with those of the opposite rail row, or alternatively, where the joints of the rails of different rows do not lie in the same space of sleepers but rather at a certain distance one from the other:

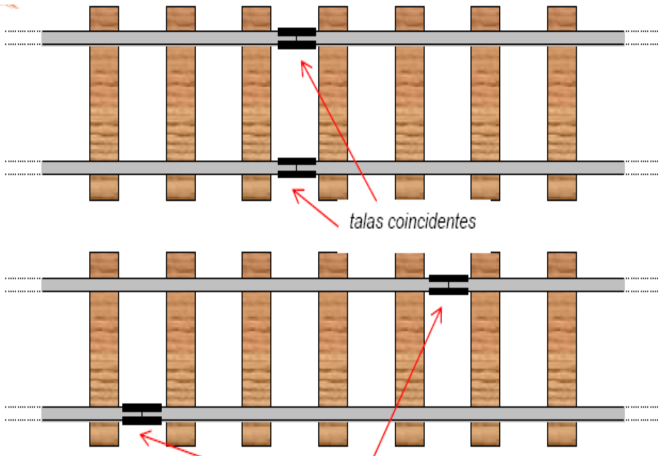

Figure 4 – Coincident and alternate joints. Source: Authors

2.1. Application

The application of joints is the cheapest and quickest way to join the rails, but it inserts a series of instabilities into the system, thus requiring a large volume of maintenance, as well as generating an acceleration in the deterioration of the superstructure and increase of operational risks.

A joint necessarily increases the impact between the wheel and rail at the moment trains are passing on, given its characteristic of discontinuity of the rails. This impact is transferred to the other components of the railway superstructure, causing early anomalies, such as kneading of rails tops, breakage of fastenings, wear of sleepers, loss of geometry and appearance of ballast pockets.

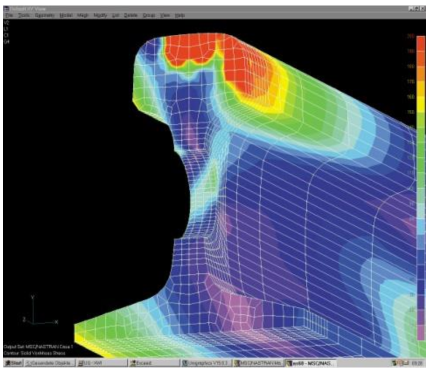

Figure 5 – Accumulation of Rail Tension in the Joint Region. Source: Authors

2.2. Anomalies Caused in the Railway Superstructure Joints

2.2.1. Unconnected joints

This type of anomaly is characterized by the breaking of all the screws of one of the rails that is tied up to the metal joint. These bolts are broken due to several factors:

- ✓ Large thermal variation in relation to the application temperature of the rails:
- ✓ Excess impact between wheel / rail because of the space between the faces of both rails or due to the difference in height between them

✓ Error in making holes.

The major risk involved with this anomaly is the misalignment of the rails vertically or horizontally. The impact of a rail flange with the face of a rail can cause a derailment

Figure 6 – Unconnected joint. Source: Authors

2.2.2. Ballast Pockets Generation and Loss of Levelling

When the wheel / rail impact forces are transferred to the ballast, they cause the friction between the stones what cause them to deform and generate fines, which results in the loss of the drainage characteristics of the ballast at this location. Thus, during the rains, the water is dammed in the ballast, causing great loss of leveling of the track in this specific point.

The main risk of this type of anomaly is the appearance of geometric defects such as twists or torsion, which could cause a derailment by the relief of wheel at the point of the unevenness.

Figure 7 – Ballast Pocket. Source: Authors

2.2.3. Broken Joint

Due to the constant impacts and the characteristic unevenness in these components, there is a natural process of fatigue of the joint and consequently break. This type of anomaly is one of the most dangerous in the railway due to its characteristic of discontinuity, similar to a broken rail. However, the identification is more difficult, since generally the fracture of the joint does not generate occupation of the track circuit, since all the joints are connect by jumpers in the marked sections.

This type of anomaly can culminate in a mismatching of the faces of the joint rails and, consequently, in a derailment.

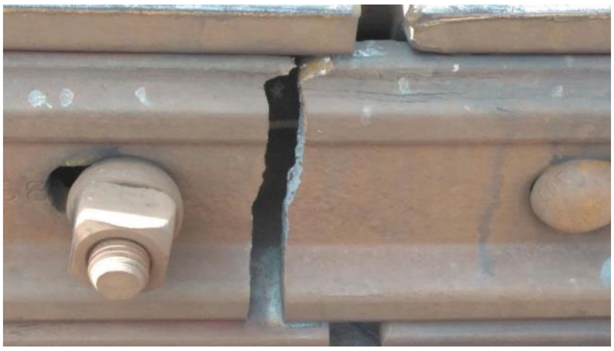

Figure 8 – Broken joint. Source: Authors

2.2.4. Top of Rail Cracks

The excessive effort that the joints have plus the degradation of the other components of the railway superstructure, can cause an accelerated propagation of internal rail cracks, culminating in a top rail crack.

This type of anomaly is also characterized by the discontinuity of the track, and has the aggravating effect of not generating occupancy of the track circuit, because of the joint bonding.

Figure 9 – Vertical Cracks on the Rail – (top rail crack). Source: Authors

2.2.5. Crack in the Holes

The areas around the holes are large effort concentrators, prone to generate micro cracks that will inevitably develop into rail cracks.

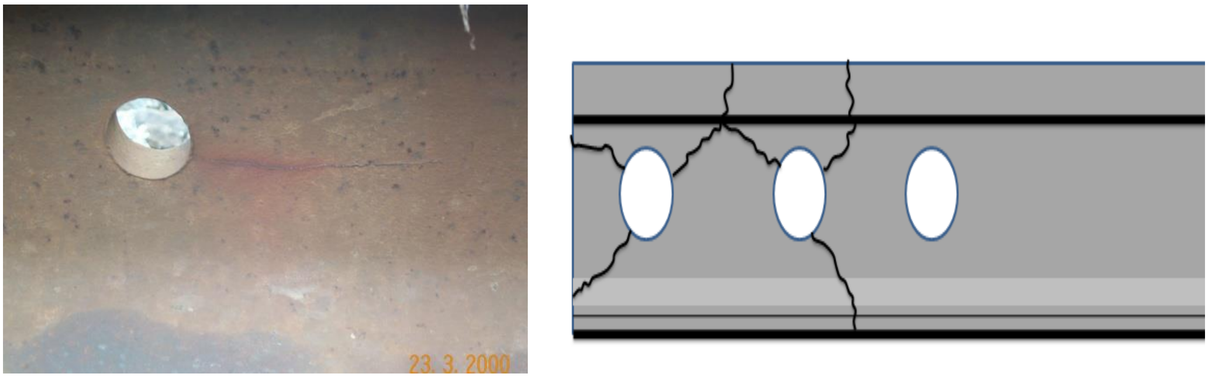

Figure 10 – Crack in the holes. Source: Authors

2.2.6. Rail Misalignment at Gauge Line

The tightening of the bolts on the splints in a joint is fundamental to ensure uniformity in the gauge line of the rails. If the bolts are improperly torqued, it may result in mismatching of the rails on the gauge line. This type of anomaly can cause a derailment if there is an impact of the wheel flange with the face of one of the rails.


Figure 11 – Rail Misalignment at Gauge Line. Source: Authors

2.2.7. Joints Influence on Track Geometry

Based on the paper Continuous Vertical Track Deflection Measurements to Map Subgrade Condition along the Railway Line: Methodology and Case Studies, we analyzed the track deflection on a track with continuous welded rail (CWR) versus jointed rail. The research presents the methodology developed for the use of continuous vertical track deflection measurements from a moving loaded rail car to map the subgrade condition along a railway line, according to the abstract. Using a measurement system installed on the truck, it was possible to evaluate track modulus and stiffness of the track.

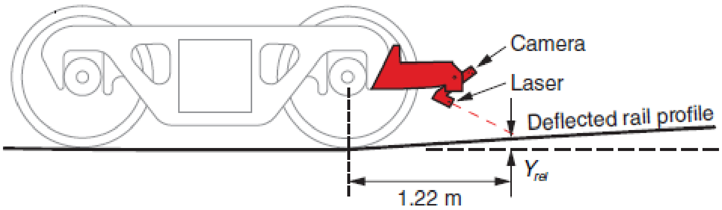

Figure 12 – Measurement System. Source: Continuous Vertical Track Deflection Measurements to Map Subgrade Condition along a Railway Line: Methodology and Case Studies
Alireza Roghani and Michael T. Hendry, Ph.D., P.Eng.2

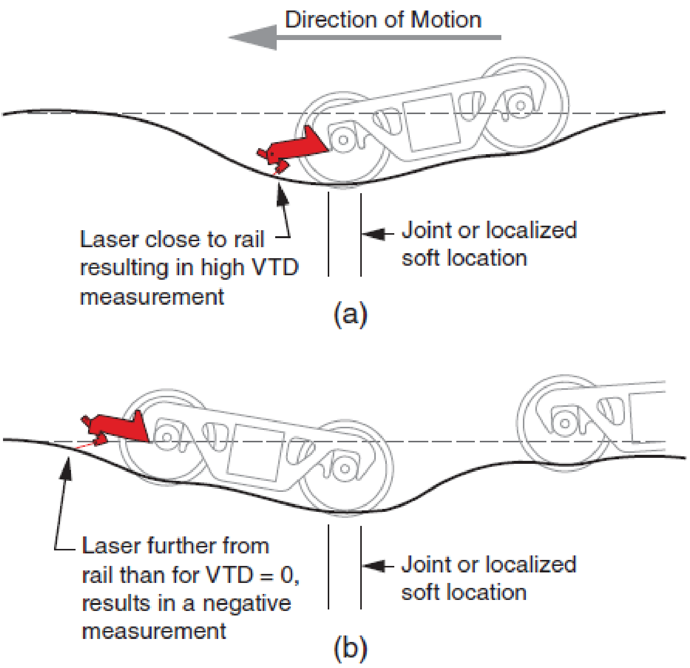

Figure 13– Operation of the measuring system. Source: Continuous Vertical Track Deflection Measurements to Map Subgrade Condition along a Railway Line: Methodology and Case Studies
Alireza Roghani and Michael T. Hendry, Ph.D., P.Eng.2

The following graph shows unprocessed vertical track deflections data recorded on one side of the rail over a 32 km long section of the Canadian National's (CN) Lac la Biche Subdivision. This section of track contains both continuously welded and bolted rail segments. It is possible to identify a clear difference between measurements taken on track with continuous welded rail (CWR) versus jointed rail.

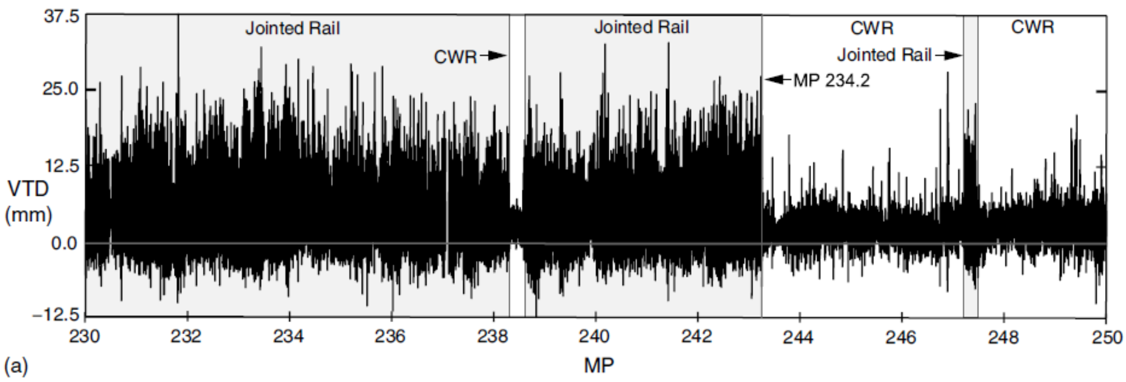

Figure 14– Vertical track deflection graph. Source: Continuous Vertical Track Deflection Measurements to Map Subgrade Condition along a Railway Line: Methodology and Case Studies Alireza Roghani and Michael T. Hendry, Ph.D., P.Eng.2

The next graph shows the variation of the measurements on both sides of the rail over a 200 m subsection of this track. Peaks in the values that occur at a relatively constant 12 m interval on each side of the rail correspond to the space between joints in the track; the negative values measured after the large peaks correspond to the joints. From the configuration of the system, a negative vertical track deflections value implies that the rail is rising above its original position.

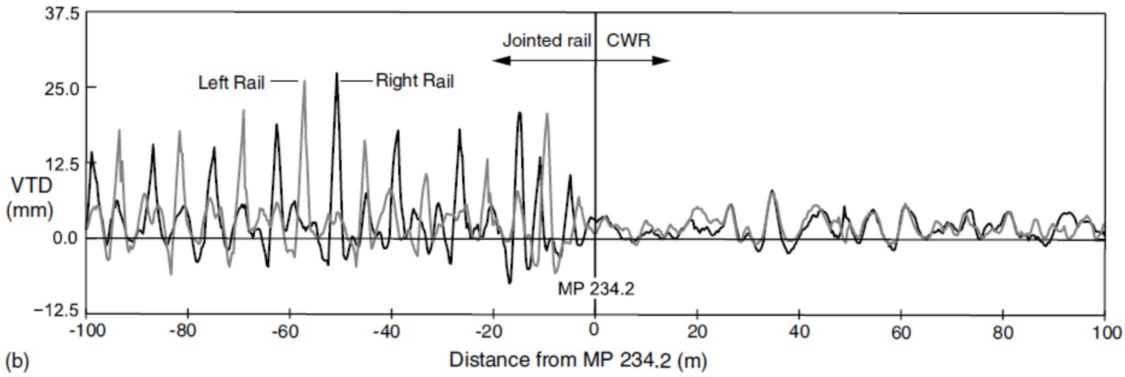

Figure 15 – Vertical track deflection graph (subsection). Source: Continuous Vertical Track Deflection Measurements to Map Subgrade Condition along a Railway Line: Methodology and Case Studies
Alireza Roghani and Michael T. Hendry, Ph.D., P.Eng.2

Examining the Vertical Track Deflection graphs, we observe that in subsections with joints the deflection is considerably larger when compared to the CWR section.

2.2.8. Joints Interference on Bridges and Viaducts

As seen before, impacts between the wheel and the rail caused by metal joints are transferred to the other components of the railway superstructure, thus accelerating the system degradation and consequently shortening the life cycle of the track. However, these impacts are not restricted to the superstructure, and are also transferred to the railway infrastructure (earthworks, bridges, viaducts, landfills).

Bridges and viaducts are the components that suffer most from this overload, with a very short useful life in railroads that work with high axle loads, and reinforcements of greater complexity are required in the short term. In the case of MRS Logistica the loaded cars reaches 32.5 ton / axle.

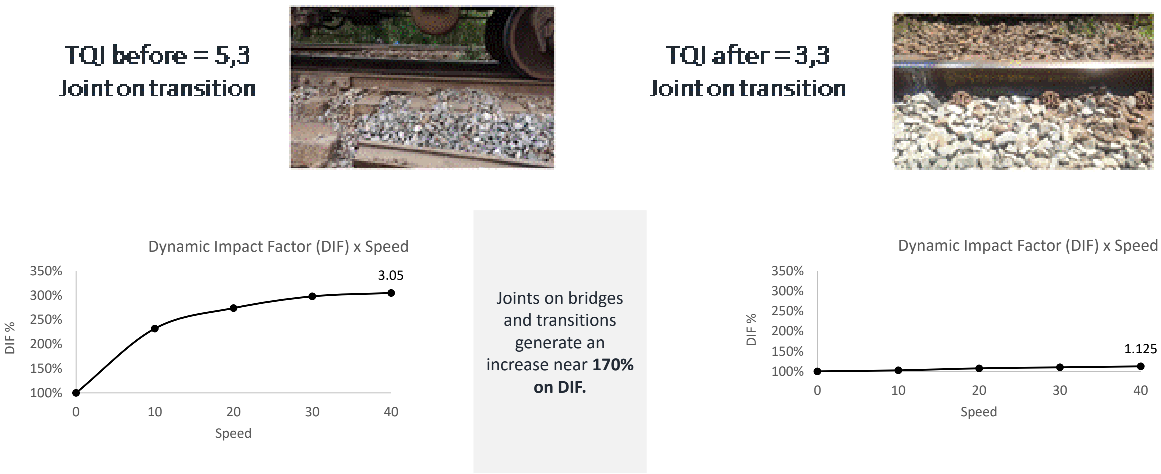

Figure 16 – Running Vehicles Effect on Rail Infrastructure. Source: MRS Logistica S.A.

2.2.9. Preventive and Corrective Maintenance Demand

Due to the efforts that joints add to the railway superstructure system, a great demand for corrective and preventive maintenance is generated in order to guarantee operational safety.

Corrective Actions:
- ✓ Screw replacement instead of broken;
- ✓ Replacement of split splints;
- ✓ Application of rail clamp in disconnected joints;
- ✓ Do the ballast cleaning to eliminate pockets;
- ✓ Rail replacement (in the case of cracks and top rail cracks)

Preventive Actions:
- ✓ Preventive tapping;
- ✓ Replacement of cracked splints;
- ✓ Application of staples;
- ✓ Replacement of guard sleepers;
- ✓ Reapply the screws;
- ✓ Substitution of broken bonds;
- ✓ Visual inspection.

2.2.10. Possible rail Operation Impacts

The problems of the railway superstructure caused by this type of component create great impact to the railway operation, given the excessive number of times that it is necessary to intervene in the permanent way to carry out preventive and corrective maintenance.

In the current work model of MRS Logistica, we have interventions that can only be performed interrupting the railway operation and others that are only performed with the trains running at the restricted speed (speed executed must be sufficient for a stop of the train in the half of the field of driver's view) not exceeding 30 km / h.

In both cases the impacts for operation are relevant since there is an increase in fuel consumption, a high necessity of train drivers because of the increase in transit time, delay in the delivery of customer loads, increase in the number of communications carried out by the traffic controller, etc. Some of these interventions can last up to 6 hours, such as a ballast cleaning.

Interventions with speed restriction:

- ✓ Preventive tapping;
- ✓ Ballast cleaning;
- ✓ Replacement of guard sleepers.

Interventions with interruption of movement:

- ✓ Replacement of broken or cracked splines.
- ✓ Replacement of rails;
- ✓ Application of screws (when necessary the use of the hydraulic tensioner).

3. WAYS OF ELIMINATING RAIL JOINTS

In order to eliminate impact and noise problems, as well as other problems related to the gap between rails or joints by splines and bolts, the rails are currently welded, reducing maintenance costs of the track. The process produces high quality welded rail when properly performed. The weld region has therefore become an important factor to consider in the life cycle cost (LCC) of the rails.

Whether for joining or repairing, a rail must be fit for welding in such a way that every new rail developed must undergo several welding tests, with pre-set limits. The tests include bending, hardness and microstructural analysis tests and the limits differ for different welding techniques. The hardness around the weld should be the same as the base material, however, hardness losses in the boundaries of the heat affected zone cannot be avoided. Independent of the rail class the hardness of the “sphere-like region” amounts to about 300 HB. The process, however, can be adjusted to reduce the extent of this region, allowing the rail to cool faster after welding, for example. If the cooling is too fast, however, there is a risk of forming brittle martensite.

The most common types of welds for rails are the flash butt-welding and the aluminothermic welding (also known as thermite). The first is a semi-automated process being generally applied in yards for joining new rails, although there are mobile equipment being predominantly manual process and is generally applied for field and maintenance welding.

3.1. Aluminothermic Welding (Thermite)

Aluminothermic welding is a process of fusion welding that takes advantage of the oxidation reaction between metallic aluminum and iron oxide, which are converted into alumina and iron metal. The process begins with the alignment of the rails and installation of the mold in the span (about 20 to 25mm). The rails are then preheated to temperatures close to 1000 ° C using blowpipes the reaction is initiated by means of a wick (or other heat source). The heat of the exothermic reaction, which occurs in a crucible, melts the powder mixture (which includes iron alloys and other additives that do not participate in the reaction) leading the bath to high temperatures (about 2500 ° C). The bath is poured into the mold after a few seconds of reaction, filling the gap. The temperature of the bath is sufficient to partially melt the rails generating the weld by solidifying. Finally the mold is removed and the weld is ground. The quality of welding in this case is highly dependent on the skills of the welder and welding conditions, which is often neglected.

According to the Rail Infrastructure & Maintenance`s module of the International Training Program of DB, the steps of the welding process are:

- ✓ Alignment of the rail ends;
- ✓ Installation of half-molds for welding;
- ✓ Quartz sand;
- ✓ Bring the crucible into the welding position;
- ✓ Initiation of the implementation (ignition bar);
- ✓ Inflow of the mass in the molds;
- ✓ Machining of the weld;
- ✓ Rough grinding on the weld;
- ✓ Cleaning of the weld.

Aluminothermic welds may develop defects due to incomplete penetration, lack of fusing of the rails, entrapment of slag, shrinkage or discontinuities. Most of these problems stem from inadequate alignment, preheating or improper mixing.

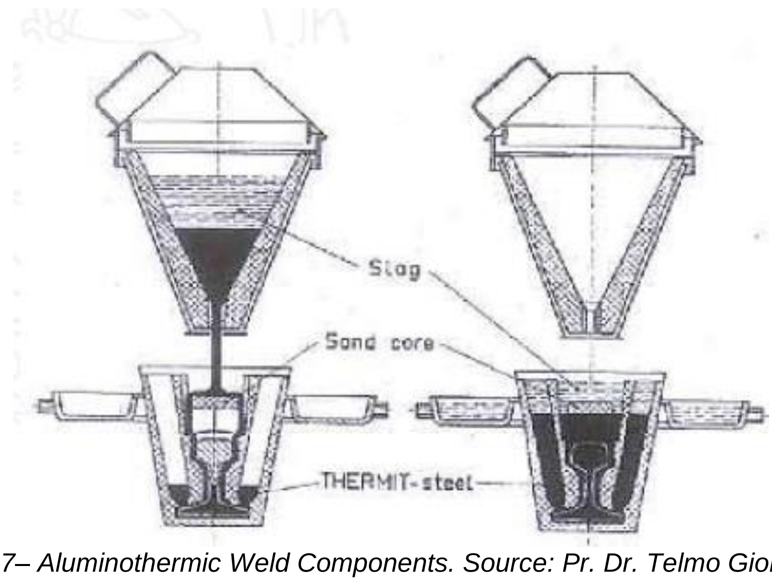

Figure 17– Aluminothermic Weld Components. Source: Pr. Dr. Telmo Giolito Porto

Figure 18 – Aluminothermic Welding. Source: MRS Logística

Advantages:

- ✓ Ease of transport;
- ✓ Disadvantage;
- ✓ Worst quality;
- ✓ Higher cost;
- ✓ Lower productivity.

3.2. Flash Butt Welding

Electric welding, or flash butt welding, is one of the most commonly used forms of welding rails. The process is more robust than aluminothermic welding and produces reliable welds, normally performed on yards, although there are recent options for field use. The process consists in the passage of electric current between two rails (with electric arc closure in the space between the tracks, producing the spark), which heats the region at temperatures close to the fusion when the rails are heated by the application of pressure.

The process begins with the preheating stage where the faces are short-circuited and there is a high current density, heating the assembly. In the scintillation step tension is applied between the rails approaching with determined speed forming electric discharges between the faces of the rails, which are repeated a controlled number of times. These discharges heat and clean the surfaces of the rails until the faces reach melting temperature. The molten metal and oxides are expelled by electromagnetic forces. When the faces are completely melted there is the heating step in which a force is applied by joining the two faces of the rails. The molten metal and remaining oxides are then expelled by the applied force which generates plastic deformation of the ends of the rails. Finally a tool removes the burrs generated by the process. In some situations the preheating step is replaced by non-fusing steps.

It is important that the rails have similar dimensions and that the faces receive an initial cleaning to avoid inclusions inside the weld. The process is considered superior to the aluminothermic solder by eliminating the solidification defects like porosities, inclusions and lack of fusion. However, this must be adjusted for the different rail classes, since the greater the equivalent carbon of the rail, the lower the rate of restriction of the rail after welding in order to avoid martensitic formation. The best way to control the final cooling is to control the heat introduced during welding. Studies have shown that the rate of cooling can be easily controlled with the use of electric pulses before and after welding.

It is possible to join rails together with modern welding machines in a fully automated operation. According to the Rail Infrastructure & Maintenance`s module of the International Training Program of DB, In Europe, flash-butt welding is often used for this. In comparison to the aluminothermic welding process, this welding technology has the advantage that no new material is introduced into the welded joint. In particular when a high quality rail steel is used, the discontinuity in the rail steel can be reduced to a minimum.

In the Welding yard:

Advantage:

- ✓ Higher quality;
- ✓ Lower cost (scale);
- ✓ Increased productivity;

Disadvantage:

- ✓ Difficulty in transportation.

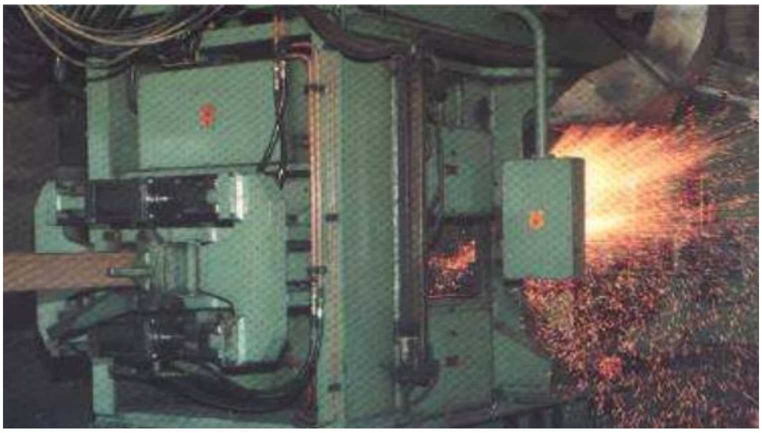

Figure 19 – Machine on welding yard. Source VIDON 2006.

Using Mobile equipment

Advantage:

- ✓ Higher quality;
- ✓ Increased productivity;
- ✓ Logistics.

Disadvantage:

- ✓ Higher cost (equipment purchase).

Figure 20 – Flash butt machine. Source: MRS Logistica

Figure 21 – Flash butt machine in action. Source: MRS Logistica

3.3. Continuous Welded Rail - CWR

Continuous welded rail, according to BRINA (1979), also called CWR, is one in which the gap in the joint is insufficient to allow the expansion, generating consequently internal tensions; in addition, it is characterized by a length such that, in a central part of its length, there is a fixed extension that does not dilate, in a state of maximum internal tension. The rails coming from the steel mills are the rails joined together by electric welds, also called flash-button, or through aluminothermic welds. Currently in the MRS the short rails are bought abroad are taken to the welding yard in Barra do Piraí-RJ, where they are electrically welded through a Schalatter machine, in bars of 240 meters in length. The advantages of using long welded rails are the non-use of joints.

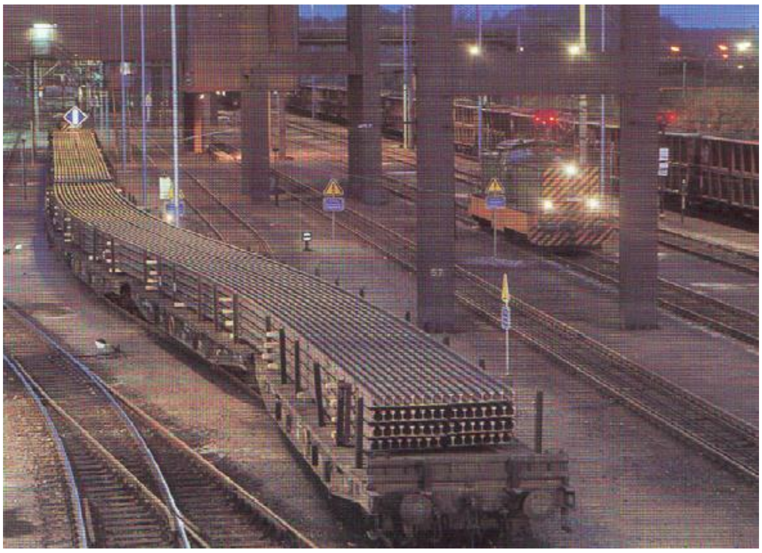

Figure 22 – CWR transport. Source: VIDON 2006.

4. MRS LOGISTICA S.A. CONTEXT

4.1. Rail Network

Integrating the most productive region of the country, the railway network under MRS management has a marked strategic importance for the entire national economy due to its geographical disposition: it establishes a connection between producing regions, major consumption centers and five of the country's largest ports municipalities of Rio de Janeiro, Itaguaí, Sepetiba and Santos). There are 1,643 km of railroad, equivalent to approximately 6% of the national structure and in which about one third of all national production is transported, figures that give the exact notion of the level of productivity of the system.

4.2. Logistics of Iron Ore Transportation

The growth of mining activities and the large volume of its exports make logistics an important element in ensuring fast shipments and customer satisfaction. This became the main product transported by MRS logistics, reaching approximately 75% of the total cargo (by weight) carried by the company.

The logistics system of the extinct MBR is based on three beneficiation units - Vargem Grande, Pico Mine and Mutuca - and in two railway boarding terminals, Andaime and Olhos d'Água. The ore produced at the Pico Mine and Vargem Grande mine (which processes the production of the Tamanduá and Capão do Mato mines) is directed to the Andaime Rail Terminal, from where it the Guaíba Island Maritime Terminal. The production of the Capão Xavier mine, after benefiting at the Mutuca plant, is transported to the Olhos D'Água Railway Terminal. From there, by the MRS Logística Steel Railway, it also goes to Guaíba Island.

The transportation of ore also includes the transportation of boarding points at the Córrego de Feijão terminal, near Brumadinho, Sarzedo terminal and at the Pires terminal, on the banks of BR-040, near Congonhas do Campo, with cargo also coming from of Casa de Pedra, the latter in export scenarios and also meeting the internal demand of CSN.

The trains loaded with Ores originate in the state of Minas Gerais, specifically in six different points of loading:

- ✓ Terminal of Olhos D'água in Belo Horizonte;
- ✓ Terminal of Andaime in Itabirito;
- ✓ Terminal of Córrego do Feijão in Alberto Flores, close to Brumadinho:
- ✓ Terminal of Pires, close to the city of Congonhas;
- ✓ Terminal of Casa de Pedra.
- ✓ Terminal of Sarzedo.

The discharge terminals (for car dumping) are located in the State of Rio de Janeiro, in the ports of Guaíba and Sepetiba. The average distances between the loading and unloading terminals are 550 km to 600 km and include the railway lines called Linha do Centro, Ferrovia do Aço and the Paraopeba Rail.

The vast majority of the ore-loaded trains circulate from the iron quadrilateral region of Minas Gerais to the ports of Rio, through the brokers marked in red on the map below. Due to the high tone transported and high axle load (32.5 tons) transported in this specific stretch, it will be the target of our work.

Figure 23 – MRS Logistica S.A. Loaded Trains Corridors. Source: MRS Logistica S.A.

4.3. Structural and Operational Features of Analyzed Corridors

4.3.1. Ferrovia do Aço

Figure 24 – Ferrovia do Aço Corridor. Source: MRS Logistica S.A.

It is the newest track of the entire MRS network, which was inaugurated only in the late 1980s. It is a simple rail line built with fairly favorable bend radii, generally above 600 m. To ensure this profile, it was necessary to build a high number of bridges and viaducts. In some sections of this corridor, the presence of earthmoving is practically inexpressive, and the train basically runs over bridges or inside tunnels.

The Ferrovia do Aço has a large number of ascending and descending ramps (considering the direction of the freight train), which generates a series of peculiarities in the railway operation, the consumption of diesel and the degradation of the permanent way. For much of this stretch, the train needs the support of locomotives (helper).

Its favorable geometry contributes to the train's speed of travel, which reaches 64km / h for freight trains in some sections and 72km / h for trains formed only by the locomotives of the helper.

4.3.2. Pinheiral

Figure 25 – Pinheiral Rail Section. Source: MRS Logistica S.A.

The section of Pinheiral has approximately 48 km of duplicate line where besides running all the flow of the trains loaded of ore, also runs good part of the flow of trains of general cargo towards the Port of Rio de Janeiro, Port of Sepetiba and some flows to the state of São Paulo.

It is a corridor that has few ramps and that, for the most part, is located in urban perimeter. It is a railway with some chronic drainage problems and has never undergone any cycle of total drainage.

4.3.3. Serra do Mar

Figure 26 – Serra do Mar Rail Section. Source: MRS Logistica S.A.

The section known as Serra do Mar has approximately 55km of duplicate line where the largest train flow of the entire MRS is transported. All the trains loaded and empty of ore, besides all the trains of general cargo with origin / destination to the ports of Rio de Janeiro circulate there.

It is also the company's oldest track, its construction dates back to the second half of the 19th century. Because it is an old project and initially not intended for today's cargo flow, it has an extremely unfavorable geometry, with several curves with radius below 300m, strong caps (ascending from Barra do Piraí to Humberto Antunes and descendant of Humberto Antunes à Paracambi, considering the direction of circulation of the trains loaded with ore). Its platform is extremely narrow and has several structural drainage problems. Despite being a railroad almost 200 years old, it has also never undergone a cycle of total renewing of the ballast.

4.3.4. Brisamar

Figure 27 – Brisamar Rail Section. Source: MRS Logistica S.A.

The section of Brisamar that has 64 km, is the final part of the trip of the loaded ore train. It is in this track where the MRS network accesses several ports of discharge, the main ones being Guaíba (Vale), CPBS (Vale) and Tecar (CSN).
At this point the railroad crosses urban stretches and, in many places, borders the sea. Any maintenance problem at this location can lead to delays in ship loading, which can result in heavy fines for MRS. Another important point is that accidents

in this stretch can have major social and environmental impacts. These facts reinforce the need to have great reliability of the permanent way at this point.

4.4. Operational Impacts Due To Joint Related Failures

In this session, some figures will be presented so the relevance of the problem can be addressed. It is worth stating that in the following analysis, the historic data on joint failures was deemed as a cause of track blockage. Hence, when simulation models were applied, they addressed those events stopping train movements on the track section in which a failure happened.

In advance, it is expected to have major impacts on the corridors made up by single track.

4.4.1. Joint Faults Records

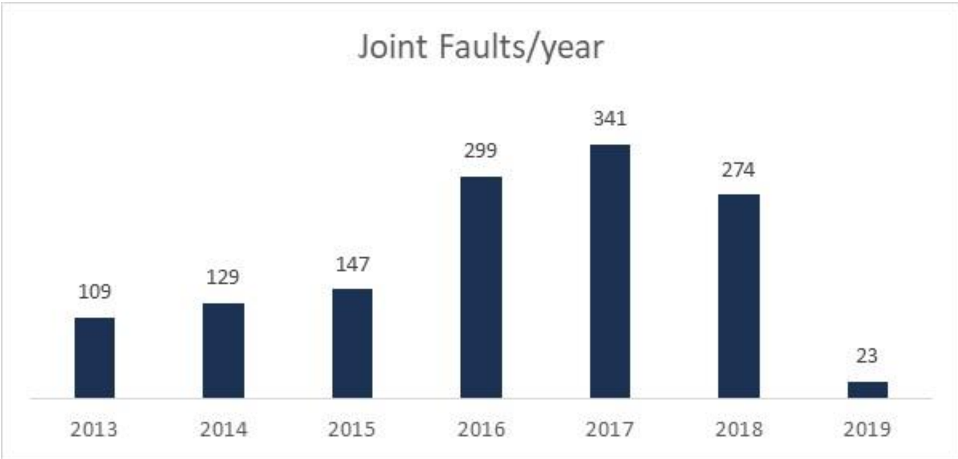

Figure 28 – Joint Faults Count throughout the Entire Rail Network (Figures are higher since 2016 due to a change in sort methodology and a more solid recording). Source: Authors

Figure 29 – Joint Faults Count – Per Track Maintenance Supervision. Source: Authors

As expected, the supervisions of corridors where loaded trains run are the ones with the highest counts. GVP FA, GVP FBA, GVP FBP, GVP FPL and their subdivisions are those to be addressed.

Hence, a first attempt to evaluate these events under the perspective of operational impacts was conducted. A database of maintenance orders for joints was gathered and then, the data was sorted so only those registers with great potential to operational impacts were considered. The roster of those events follows:

- ✓ Joint;
- ✓ Cracked joint;
- ✓ Split Joint;
- ✓ Open Joint;
- ✓ Loose Joint;
- ✓ Worn joint.

With a sorted database, it was stratified into GVP FA (Ferrovia do Aço corridor), GVP FPL, FBP and FBA (these three subdivisions make up the corridor which access the ports in Rio de Janeiro state). With aid from simulation software this database was analyzed for estimating probability distributions of mean time to repair (MTTR) and mean time between failures (MTBF).

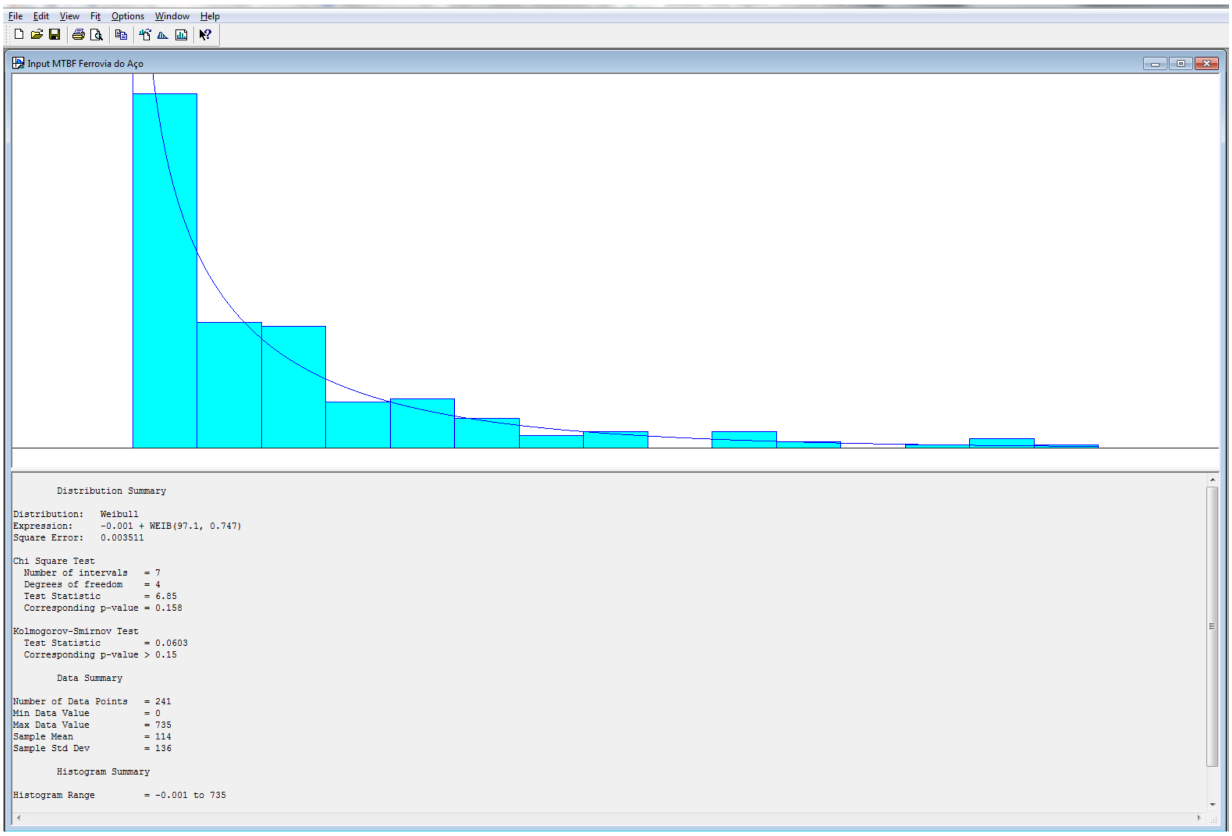

Figure 30 – Estimated Probability Distribution - MTBF for Ferrovia do Aço. Source: Authors

Once these values gathered, two Arena® simulation models were used so the operational impacts could be assessed.

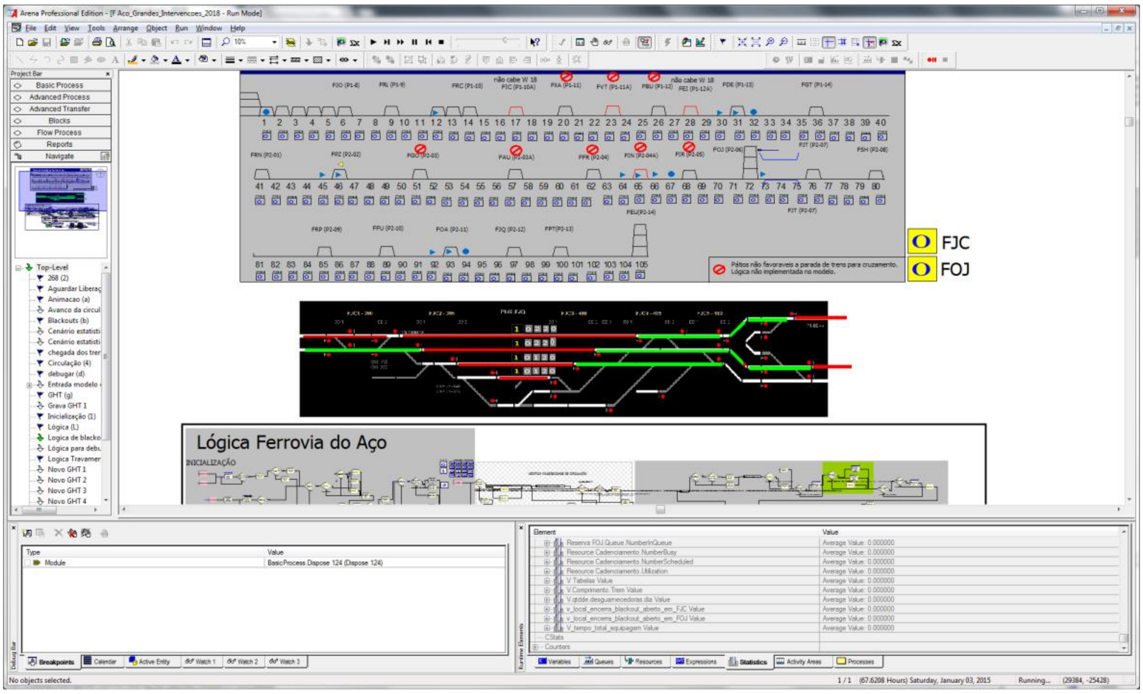

Figure 31 – Ferrovia do Aço Model Screen. Source: Authors

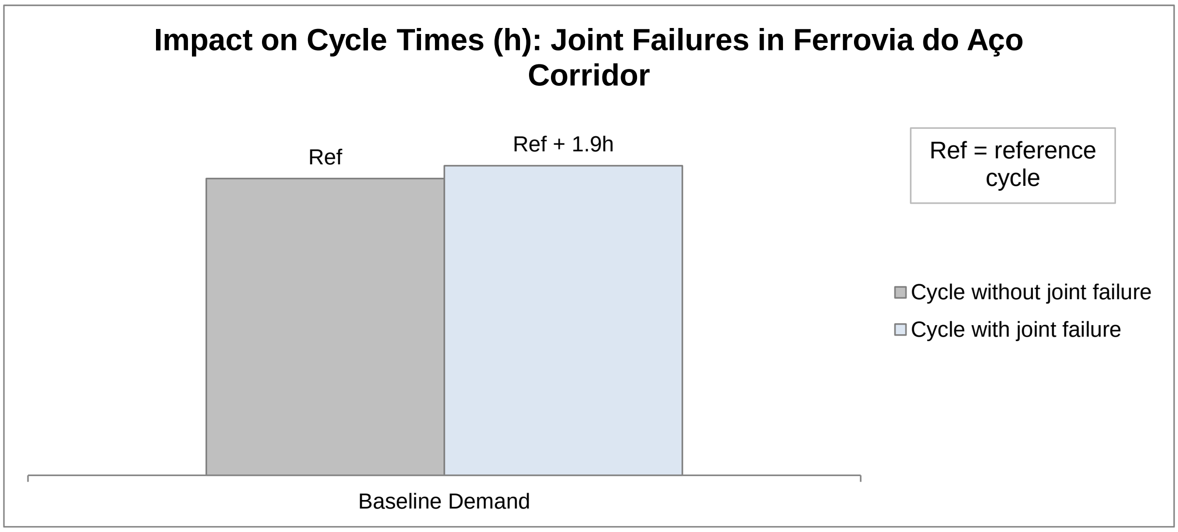

Figure 32 – Operational Impacts in Ferrovia do Aço. Source: Authors

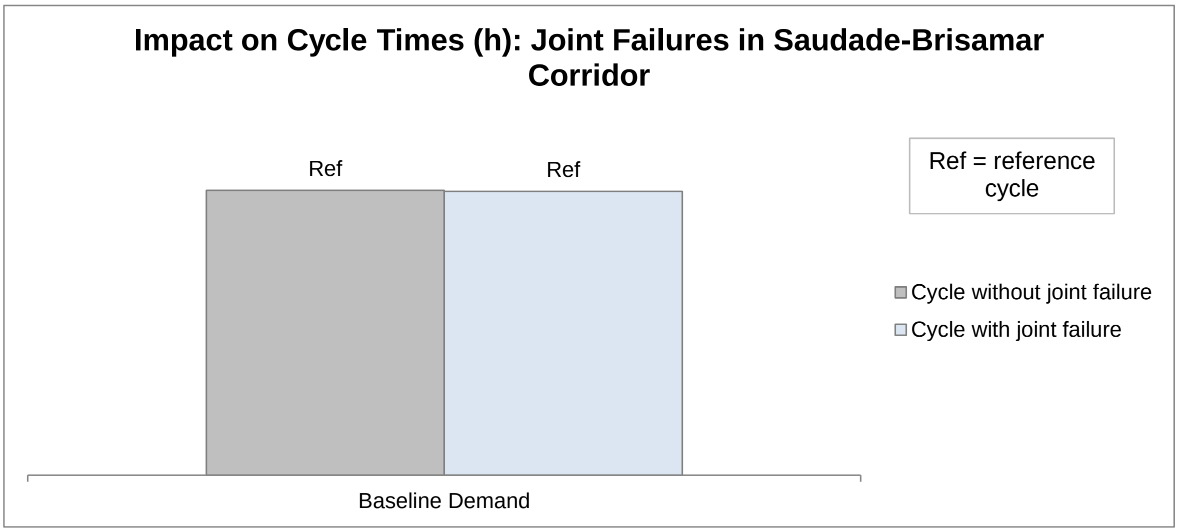

Figure 33 – Operational Impacts in Saudade-Brisamar. Source: Authors

It was expected that in Saudade-Brisamar, the impacts were not be statistically significant, since it is made up by double track, and the mean time of interruption was not high. On the other hand, in Ferrovia do Aço, MTTR was regarded as 7 hours and for a single line network, even featuring sidings, the impact cause the cycle times to increase approximately 2 hours. In terms of capacity it is not a constraint, since the company has train sets to cope with cycle augment. But is reduces profit margin, whereas operational costs increase, leading up to more fuel consumption, work time of train driver (engineer) and other small losses on a daily basis.

Nevertheless, this assumption is for a worst-case scenario, since all joint failures were considered to stop train runs, in this case, on an average of 7 hours. In practice, those events hinder operational by limiting speed limits or are solved during planned maintenances, which was not the situation in simulation. Thus, another approach is to be considered, regarding records of train delays due to joint failures, so a more a realistic scenario can be analyzed.

4.4.2. History of Accidents (Train Delays)

In order to acquire more realistic data, a search on records from 2018 was conducted, so the actual impacts on trains linked to faulty joints were assessed.

Basically, in Ferrovia do Aço, throughout the year, 36.5 hours were computed as train delays regarding joint failures. In comparison, the simulation run appointed an average increase of 2 hours for each train, since all failures were taken as traffic disruptions. Thus, for this corridor, the real impact can be deemed as much lesser.

For Rio de Janeiro area, from Saudade to Brisamar, the simulation run itself had already minor effects and the real records added approximately 14.5 hours of train delays throughout 2018. As for the simulation, it was lesser than Ferrovia do Aço due to track characteristics which were explained previously.

Thus, related to operational impacts, generally failures on joints have slight influence. Nevertheless, sometimes a single accident might have drastic effects on operation, company's image, environment, besides other consequences.

4.4.3. Case: Rail Accident in the City of Volta Redonda-RJ

In November of 2017, a train derailment seriously damaged a viaduct in Volta Redonda. After weeks of investigation, it was found out that a loose joint was the main cause of the accident. Somehow, due to a failure in following track inspection procedures, the joint had no screws holding it.

The event cost millions of Brazilian reais and had severe consequences to operations, maintenance and safety areas.

Figure 34 – Rail Accident in Volta Redonda. Source: MRS Logistica S.A.

5. ACTUAL RESOURCES FOR RAIL JOINT ELIMINATION

There is a daily need for making joints between rails on MRS Logistica tracks due to the constant maintenances. They can be made by welding, aluminothermic or flash butt or even so by metal joints. These maintenances may occur due broken rails, superficial defects, wear, and visually identified cracks or by ultrasound inspection.

When capacity for welding is higher than daily demand for joint making, it happens to have a cycle of reduction on joint counts, normally during summer. Under warm periods, there is the least number of fractures and the highest offer of track possessions for maintenance, due to seasonal behavior of transport demand.

On the other hand, when welding capacity is lower than daily demand for joints, it occurs a cycle of increasing of the latter, often during the winter, due to higher counts of fractures and lesser periods of track possessions.

Generally, welding capacity depends on the availability of teams to be assigned for the task and on the given possession time offered by the OCC. These variables are stipulated in the annual budget and provide strategy guidance throughout the year.

5.1. Budget Analysis of 2019

The budget for maintenance of 2019 was underpinned on the premise of keeping the same record of joints of 2018. Thus, calculation basis forecasted that every rail, be it new, turnout or reapplication should be set by flash butt or aluminothermic welding, but joint backlog would not be welded.

Therefore, what was considered for the corridors addressed herein was:

Table 2 – Estimation of Quantity of Components and Welds for 2019

Component	Quantity	Flash Butt	Aluminothermic
New Rail	10.086 ton	0	1.240 un
Reapplied Rail	1.035 ton	792 un	0
Half Turnout	190 un	0	380 un
Isolated Joint	260 un	0	520 un
Corrective Maintenance	0	757 un	1.720 un
Total		1.549 un	3.860 un

For accomplishing 3.860 aluminothermic welds 17 teams were forecasted. For the 1549 flash butt, two trucks that MRS owns were considered for task execution.

5.2. Track Possession Model

For complying all welding demands, maintenance areas count on a track possession model that is limited by operational requirements, since rail traffic is high in the analyzed corridors.

Therefore, given the difference between single-line and double-line corridors, besides other operational peculiarities, there is a variation on possession models provided by operations planning:

- ✓ ***Ferrovia do Aço*** **–** 4 hours of possession in nearly all the corridor in 2 days a week.

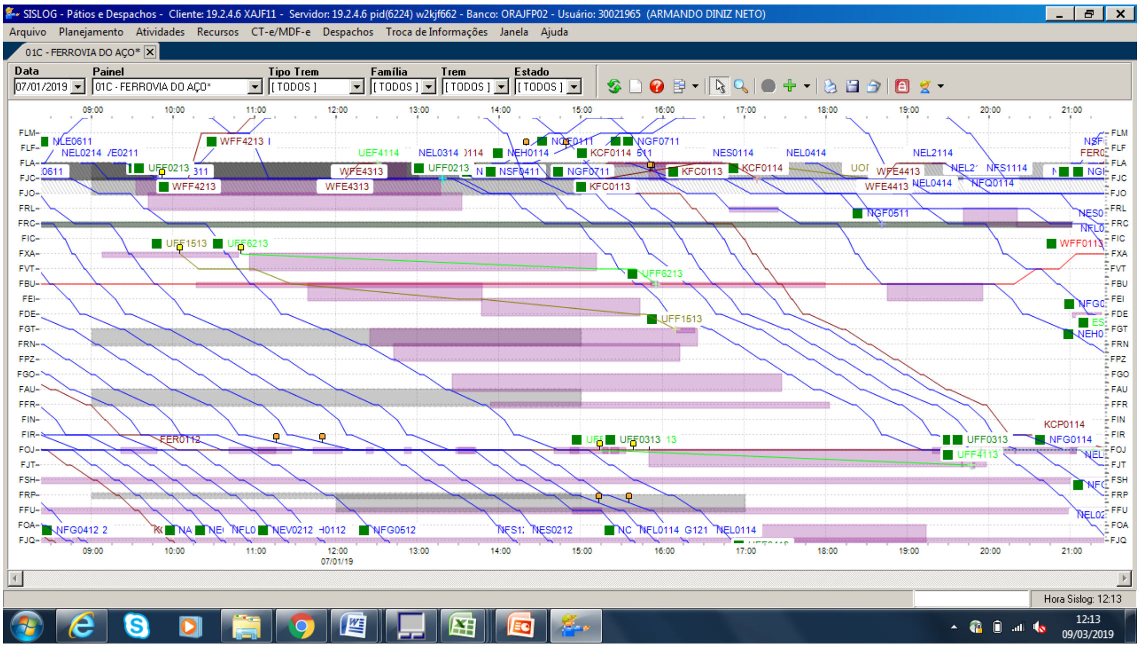

Figure 35 – Time x Distance Plot of Ferrovia do Aço. Source: MRS Logistica S.A

- ✓ ***Pinheiral -*** 6 hours of possession in two block sections 5 days a week.

- ✓ ***Barra do Piraí e Brisamar –*** 4 hours of possession in two or three block sections, depending on the local, 5 days a week.

5.3. Actual Scenario of Joints Backlog

Actually, in the addressed corridors in this paperwork, there are 1161 metal joints on main lines. These are distributed over the seven permanent way maintenance supervisions:

- ✓ P1-07 – FJC
- ✓ São João Del Rei – FDE
- ✓ Bom Jardim de Minas – FOJ
- ✓ Quatis – FPT
- ✓ Pinheiral – FPL
- ✓ Barra do Piraí – FBP
- ✓ Brisamar - FBA

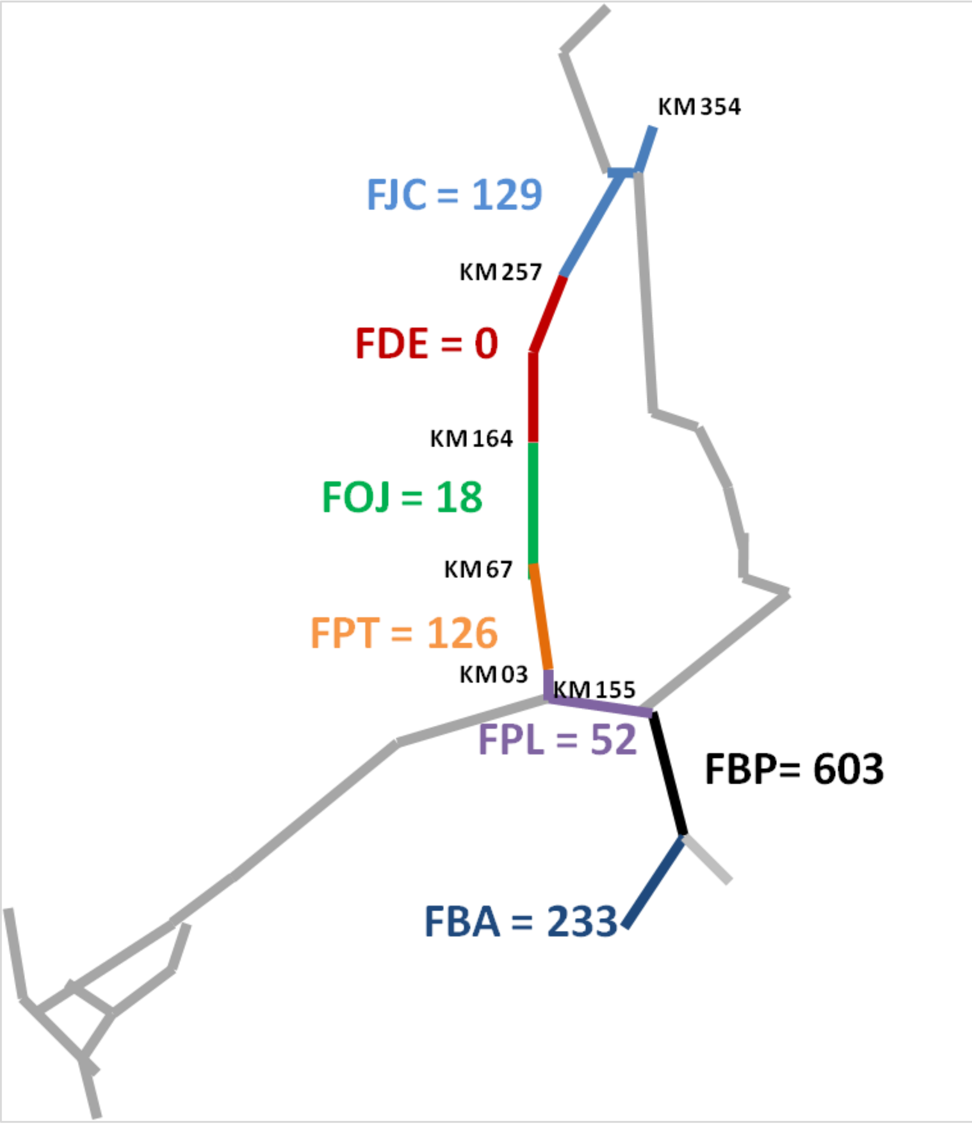

Figure 36 – Spatial Distribution of Metal Joints. Source: Authors

6. COMPARATIVE ANALYSIS

6.1. Joint Backlog Costs

For keeping a joint, maintenance is required, being periodically preventive and, in some cases, corrective. All those interventions generate costs for the company, and in the addressed corridors, the amount for maintaining all those 1161 joints is quite significant, since it is necessary accomplish the following periodic interventions:

- ✓ Bevel tamping e re-tighten of screws monthly;
- ✓ Sleepers replacement every two years on average;
- ✓ Ballast cleaning for pocket elimination every two years on average.

Besides, MRS Logistica has spent approximately R$500,000 on joints and screws purchasing for the studied track during 2018.

All these maintenances cost R$3,000,000 annually. In case of opting for not realizing this cost, it will trigger system performance loss, such track geometry worsening, operation disruptions due to failures, rail accidents and so on.

6.2. Costs for Eliminating All Joints

The existing option for eliminating all these direct costs and some indirect that metal joints generate is the one that transforms long welded rails into continuous welded rails (CWR).

For this, it is necessary to apply short rails (6m-long) and weld their ends. This task can be performed using flash butt or aluminothermic weldings on field.

6.2.1. Flash Butt Weld

The option for this sort of weld demands a high initial investment. Given the fact that the two trucks MRS has this task are already seized by other demands, it would be necessary to purchase a new equipment for eliminating all joints by flash butt welding. Such investment would cost nearly R$10,000,000 and only this cost would be slightly higher than removing joint backlog (all remaining joints) by aluminothermic welding. Hence the option is not worth investing given the opportunity cost.

6.2.2. Aluminothermic Weld

This option represents a low initial investment at almost entirely variable cost. For eliminating 1161 joints it was estimated the application of 1161 pieces of rail TR68 6 m-long, adding up 474 tons, plus execution of 2322 aluminothermic welds.

For this, an investment of nearly R$3,000,000 considering already cost related to use of reapplication rail that, in practice, MRS will not pay out, since the level of its stocks.

7. QUALITATIVE GAINS FROM CWR

Continuous welded rail brings up multiple gains which many times are not easily financially measurable, but those benefits are to be reckoned with. Without impact from wheel-rail contact due to joints, some improvement aspects can be outlined:

- ✓ Durability augment of wheelsets of cars and locomotives;
- ✓ Wear rate reduction on track geometry;
- ✓ Train delays reduction;
- ✓ Derailment risks reduction;
- ✓ Effort on bridges and viaducts decrease.

8. CONCLUSION

In spite of demanding a considerable investment, transforming long welded rails into CWRs on main lines where loaded trains run seems to be a viable alternative.

From the point of view of finance, the payback is reached in a little more than a year, given the estimated large reduction on cyclic maintenances provided by the solution.

The project can be carried out multiannual, reducing gradually the number of joints. The way it might be executed depends on several analysis from the view of economics, strategical planning and other guidance which shall be widely discussed throughout budgeting.

In a qualitative way, there will be also expressive gains, mainly related to rail safety, which is one of the greatest values of MRS strategy. With experience of past events, such Volta Redonda, the company learnt how an accident caused by a joint can be severely harmful and costly.

Other qualitative advantages are relevant for business sustaining, since decreasing track geometry wear rate in a freight transport railway, which does not count on track undercutting cycles, might have direct impact on safety and maintenance cost. In addition, it is worth mentioning the preservation of structures as bridges and viaducts, which constitute a considerable extension of Ferrovia do Aço that might cause a huge financial impact in case of a major accident, and finally a structural collapse.

All these arguments are to be reckoned with in MRS context, given its high tonnage per trains, density of traffic on iron ore corridors, and the cost and reliability opportunities.

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