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Edilson Fonseca
Lucas Giffoni
Paulo Gonzaga

RAILWAY TRACK SUSTAINABILITY AT MRS LOGÍSTICA THROUGH RENEWAL STRATEGY - A CASE STUDY

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Final Project presented to ITL – Transport and Logistics Institute, CNT - National Transport Confederation, as part of the requirements for completion of the International Certification in Management of Rail and Metro Rail Systems course.

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We hope to contribute to the society and the railroad community with the lessons learned.

ABSTRACT

For the next few years, MRS Logística is studying the beginning of the process of renewing its track assets with focus on the sustainability of its operations. As it is a capital project lasting more than 10 years, it is necessary to apply the main project management concepts to guarantee the success of the project, such as: identification and mitigation of associated risks, adherence to the schedule and the quality of deliveries, reduction of total project costs and engagement and alignment of the stakeholders involved. Considering the complexity of the project, a case study will be presented with the applications of the main concepts related to the maintenance strategy decisions for the permanent way, in order to discuss and compare the main maintenance practices present in the railway market.

Keywords: maintenance; permanent way; track renewal; Project management.

LIST OF ABBREVIATIONS

LCC – Life Cycle Costing

MOW – Maintenance of Way

NPV - Net Present Value

RAMS - Reliability, Availability, Maintainability and Safety

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SUMARY

1. INTRODUCTION

Traditionally, the permanent way of a railroad must guarantee, under stable conditions over time, acceptable support and guide characteristics for the rolling stock traveling through it.

Within the concept of support and guide, the appropriate conditions for traffic will be maintained through a perfect geometry of the surface of the tracks. The maintenance of this geometry will be ensured by the set of items such as rails, sleepers and fastener in the horizontal plane and by the support layers (ballast and sub-ballast) in the horizontal and vertical planes.

The usual procedure of maintaining adequate conditions for rail traffic over time is called maintenance of a permanent way. This maintenance is basically developed through the recovery and/or replacement of the components of the superstructure and the recovery of the geometry, both in planimetry and in altimetry.

Regardless of definitions of maintenance scopes, all of them aim to ensure that the track achieves quality and safety standards at minimal costs. To achieve this combination effectively, an appropriate and objective level of information is used.

The relevance of the theme is due to the importance of deciding on total asset renewal processes within the scope of the current operation of the railway operators. The implementation of these types of interventions must be aligned with strategic objectives and with well-developed planning since they generate impacts and all areas of the railroad.

The objectives of this study are: evaluate and compare models of permanent way maintenance, explore the relationship between the maintenance strategy adopted by MRS Logística and its alignment with long-term strategic objectives, assess the feasibility of applying these models to MRS Logística and assess the implementation risks to reduce impacts and losses

2. RESEARCH METHOD

The case study applied to the topic addressed is classified as a descriptive analysis. Its purpose is to describe, in a detailed way, a solution applied in a given context, providing support for the understanding of the events that will move MRS Logística from one context to another.

The study will allow the questions “how” and “why” to be answered, highlighting the paths, variables and tools used throughout the transition process.

In this context, this monograph will be developed in four steps:

- The first relates to the theoretical foundation of the concepts of permanent way, strategies and maintenance models, involving their concepts, classifications and importance;
- The second, discusses the application of concepts in the context of MRS Logística, the company choosen for the case study;
- The third, concerns the details of the Track Renewal project according to the macro maintenance strategy of MRS Logística, covering aspects of planning, risk management using the HAZOP methodology and aspects of technical and economic feasibility;
- Finally the last step, refers to the conclusions of the work and recommendations;

2.1 ASSUMPTIONS AND RESTRICTIONS

As it is a real and under development project, some strategic data were omitted without charge for the conclusions of the study at the academic level.

3. LITERATURE REVIEW

3.1 PERMANENT TRACK

The permanent way is the set of facilities and equipment that make up the parts of the track where trains run. In summary, for illustration purposes, the items of the permanent way are shown in Figure 1.

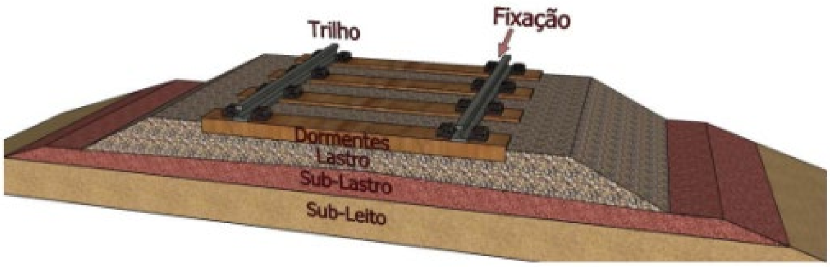


Figure 1 Representation of Permanent Way components
Source: MRS Logística

In this context, the components of permanent way represent a high participation in the annual budgets of current investments and require a high level of availability, which motivates the application of optimization tools and better management of these assets.

In general, the main characteristics of the components of the traditional ballasted track are presented below.

Rail:

- Transmitting and distributing cargo from vehicles passing through sleepers;
- Guide the trains' route;
- Provide an adequate running surface and distribute the acceleration and braking forces;
- Conduct electrical current to the safety circuits of the track
- In Brazil, they are designated by their weight per linear meter. • Ex .: TR - 37, 45, 50, 57 and 68 (Figure 2)

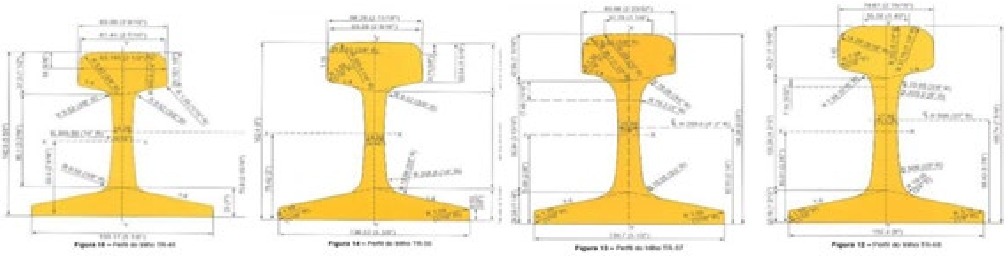


Figure 2 Rail profiles
Source: MRS Logística

Fasteners (Figure 3)

• Keep the rails correctly positioned on the sleepers.

• Prevent the tracks from suffering vertical, lateral and longitudinal displacements caused by the efforts of the vehicle's wheels and by the temperature variation (SELIG; WATERS, 1994)

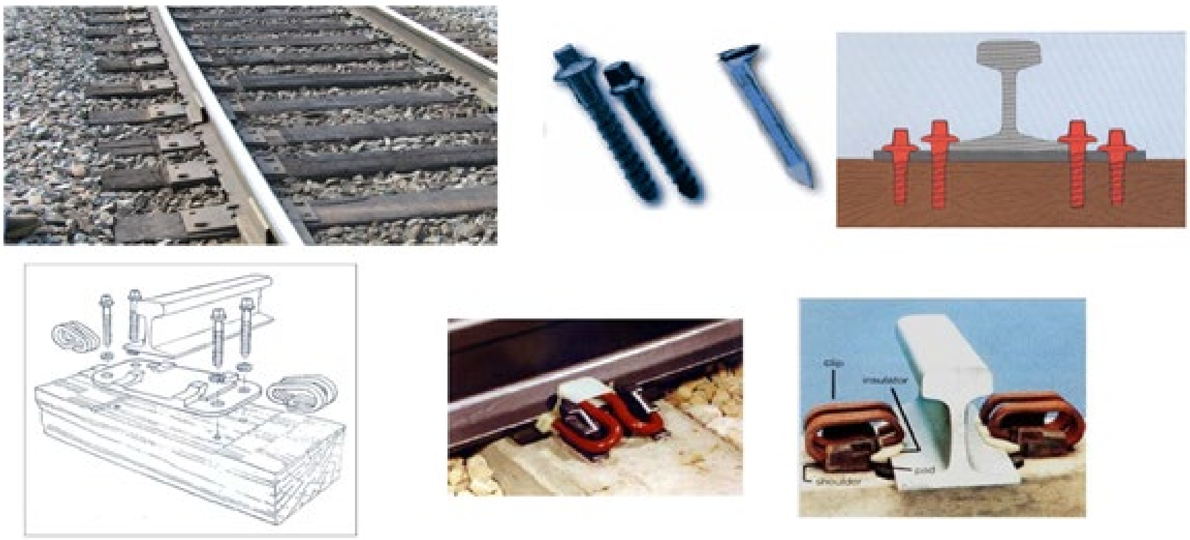


Figure 3 Rail Fasteners Types
Source: MRS Logística

Sleepers (Figure 4 and 5)

- Ensure adequate and safe support of the rails;
- Maintain the gauge and vertical, lateral and longitudinal stability of the track;
- Transmit the loads from the rails as evenly as possible to the ballast;
- Partially dampen vibrations and allow the grid to be anchored with ballast

Figure 4 Sleepers types
Source: MRS Logística

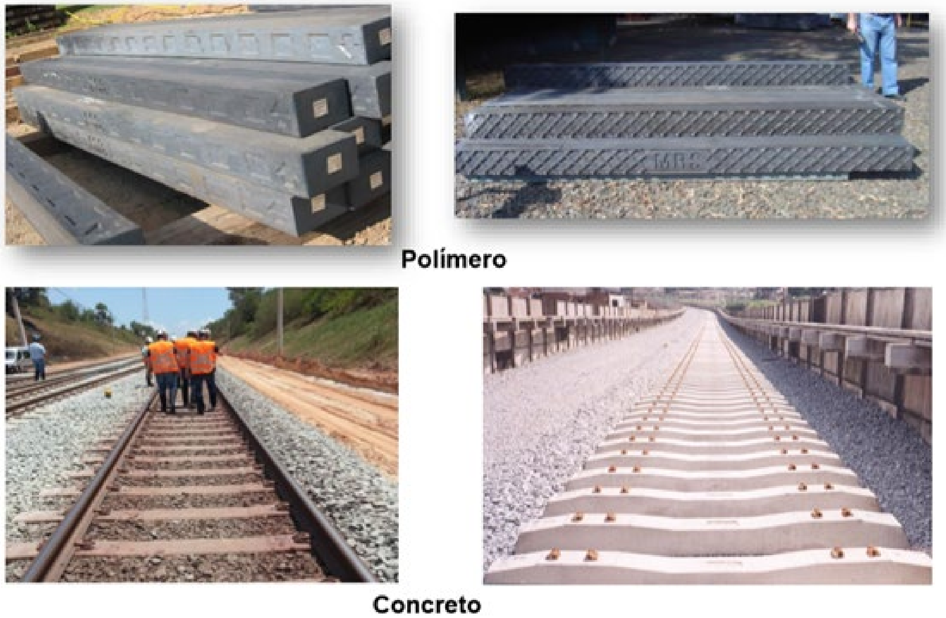


Figure 5 Sleepers types
Source: MRS Logística

Ballast (Figure 6)

- Resilient base capable of absorbing the impacts resulting from vehicle requests
- Transmit efforts homogeneously (Mechanical Resistance)
- Allow leveling
- Absorb vibrations
- Resist lateral movement of the sleeper
- Drainage

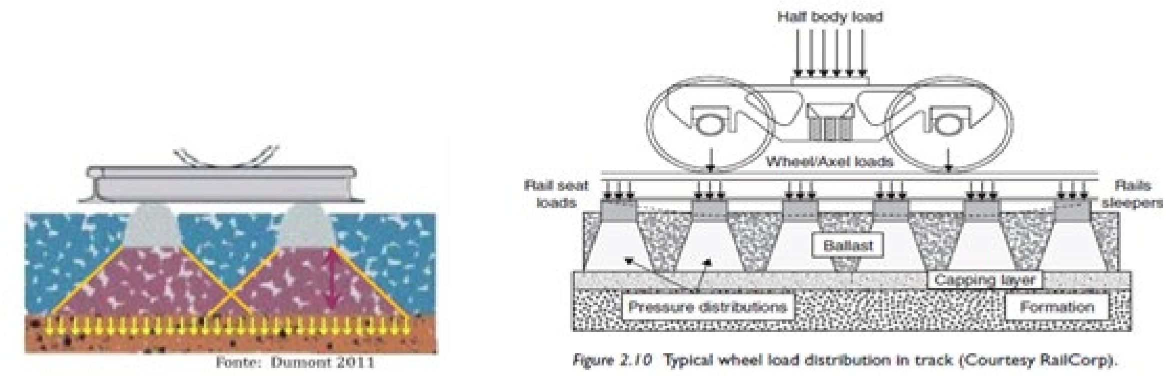


Figure 6 Sleepers types
Source: MRS Logística

Subballast (Figure 7)

• Reduce the loads from the ballast to adapt them to the subgrade resistance;

• Filter and drainage layer - Avoid pumping fines and interpenetrating materials;

• Reduction in the thickness of the ballast layer, which favors savings since the material used in the sub-ballast is less expensive.

Subgrade

• Stability and support for the entire structure;

• Influences the resilience of the structure and contributes to the elastic deflection of the track (SELIG; WATERS, 1994).

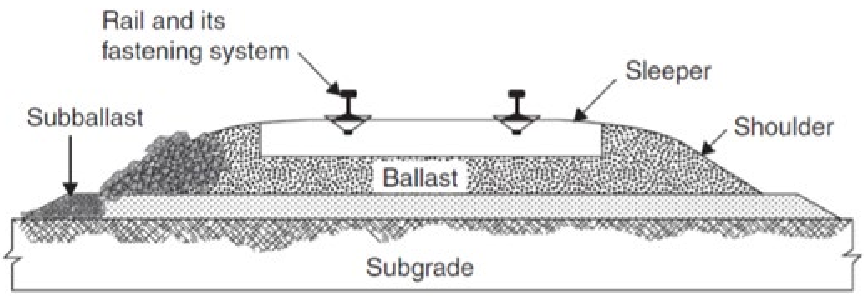


Figure 7- Rail cross section
Source: MRS Logística

3.2 PERMANENT WAY MAINTENANCE MODELS

Currently, the choices between the different maintenance methods are decided by the companies based on strong technical advice and a short to long term financial vision.

The classic maintenance methods widely discussed in railway asset management forums (corrective, preventive and predictive) are no longer analyzed only in terms of simple extension, required quality and / or execution capacity.

With the advent of more robust inspection tools generating a greater amount of information and a better understanding of the useful life of components and the quality of the track in the economic view throughout its life cycle, it was possible to guide the maintenance of the permanent way for decisions with the best cost-benefit ratio for interventions.

The major challenge in the areas of maintenance of permanent assets is to identify the useful lives performed and required for its components, since there is an intrinsic relationship between performance combinations of different layers of superstructure.

In more recent literature, degradation curves based on deviations related to permanent track geometry are presented in a view correlated with the transported volume. It is observed the growing relationship of degradation of the track with the accumulated volume transported in Figure 8.

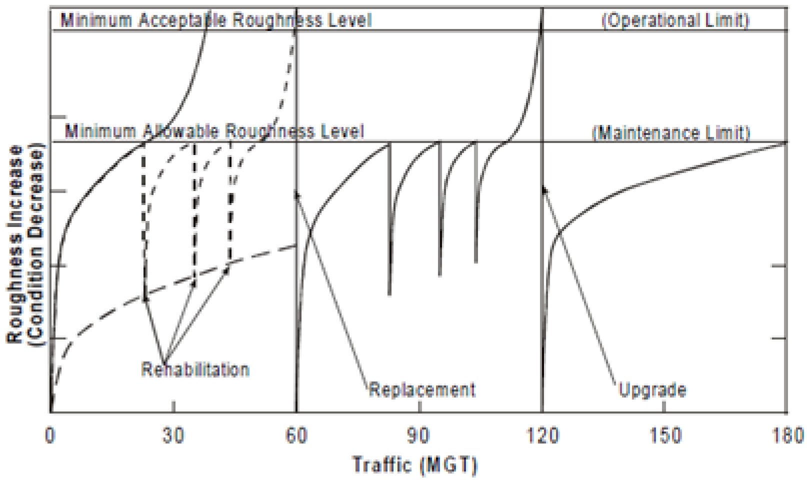


Figure 8 - Hypothetical curve of track geometry degradation
Source: Esveld (1989)

Extrapolating Figure 8, a maintenance limit is applied based on experience and / or regulations where from this limit the deterioration will be progressive. The dotted line shows that a track replacement can be postponed by systematic maintenance. After a while, the effectiveness of this maintenance will become very low (decreasing maintenance interval) and further intervention will be necessary. This intervention must be planned before the condition of the track reaches the operational safety limit, which is configured to guarantee the safety and reliability of rail transport.

Another example of a maintenance decision is shown in the same figure: once the 120 million ton limit has been passed, the track structure is revitalized with, for example, a new layer of superior quality ballast. This results in a lower degradation rate and less maintenance. This improved track quality and the reduced amount of maintenance are variables that must be analyzed from the budget amount to be applied.

The degradation of the track depends on all kinds of factors, such as the initial quality of the construction, the quality of the deeper layers and the loads on the track. Current references suggest using historical data to provide information on actual degradation rates and the effectiveness of maintenance activities under specific conditions. Exogenous factors, such as soil condition and interest rates, will also influence life cycle costs.

The analysis of the reliability curves related to track maintenance costs on high-density railways is also widely observed. In Figure 9, in an article presented at the Cost Optimization Track Maintenance & Renewals Congress of 2012, the impacts on the costs of routine maintenance and maintenance postponement interventions are illustrated in graphs.

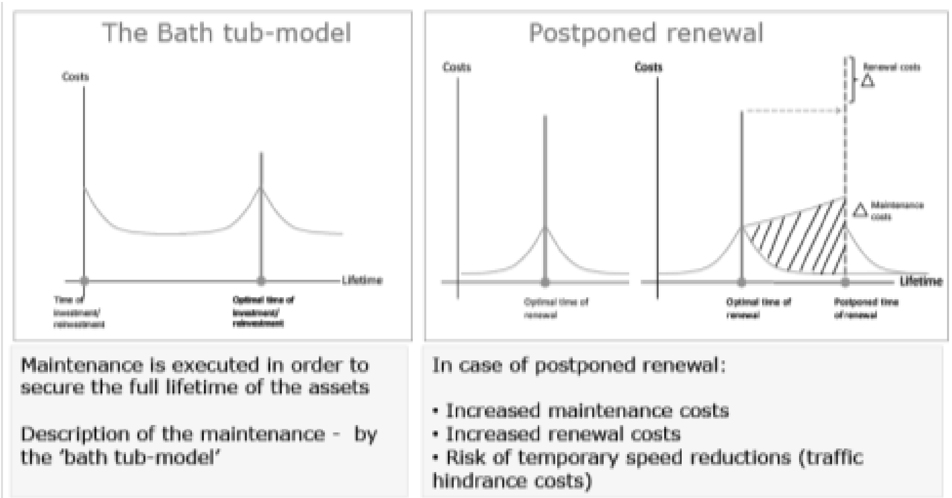


Figure 9 - Costs x assets reliability curves
Source: Boysen (2012)

3.3 ECONOMIC ASPECTS

The decision making process of finding the best option considering the trade-off between performance and costs over the entire life cycle of a product or system.

The costs include:

1) Initial costs

2) Maintenance costs

3) Operational costs

Performance includes all revenues generated throughout the life cycle of the product or system.

The methods to quantify performance and costs are:

- Life Cycle Costing (LCC)
- Reliability, Availability, Maintainability and Safety (RAMS)

For this work, it was adopted LCC method.

3.3.1 LCC (Life Cycle Costing)

According Esveld (2001), the railway track has a long life span and investments are very costly, so, the decision makers have to consider the long-term cost impacts in the maintenance process.

Figure 10 illustrates the trade-off between initial cost and operating cost (including maintenance costs and downtime costs)

• As initial costs (curve A) increase, operating costs (curve B) decrease

• Total costs (curve c) is the sum of initial costs and operational costs

- Optimal life cycle cost is at the lowest point of curve c

• It is necessary to predict future developments as exactly as possible, the reliability of the trade-off assumption depends on the information supplied

• But: sometimes an increase in initial costs to reduce operating costs is not possible because of limited cost budgets or financial resources

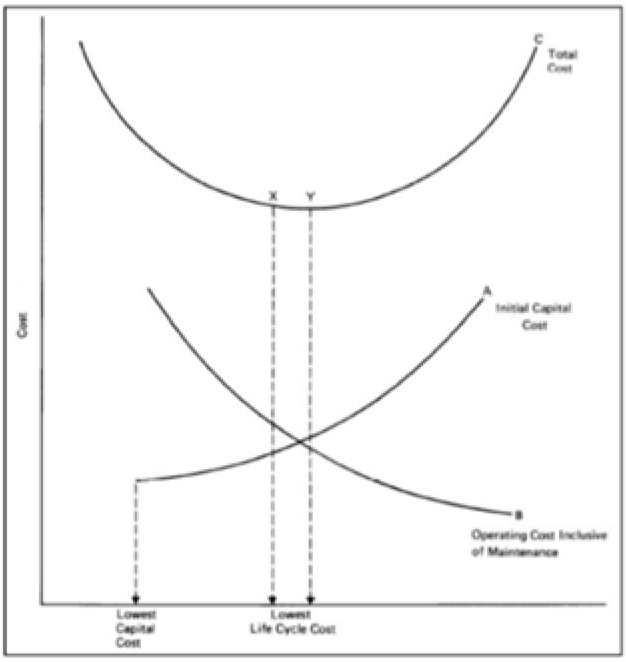


Figure 10 Trade-off between initial cost and operating cost
Source: Taylor, W.B. (1981)

Forecasting method that allows to compare alternatives to find the one that meets all requirements at minimum total costs:

- Mandatory requirements: Ensure that the system is operational; minimum necessary conditions for the system to be acceptable
- Initial costs, maintenance costs and operational costs are calculated using the Net Present Value (NPV) method (= discounting future costs back to their corresponding present value) - Equation below
- Trade-off requirements: Go beyond the minimum requirements; conditions that increase customer satisfaction

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_0$$

C0 = Total initial investment costs
Ct = Net cash flow in period t
r = discount rate
t = time period

When evaluating different alternatives or strategies, the option with the highest net present value is the preferred alternative or strategy.

3.3.2 Sustainability in the Railway System

Quality improvements through initial investments and continuous maintenance increase system sustainability. Short-term savings at the expense of a lower quality reduce system sustainability.

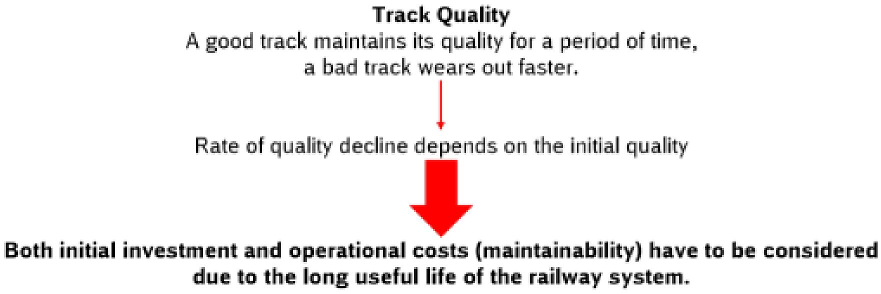


Figure 11- Track quality

Source: Deutsche Bahn AG | Rail Transportation Management | module 4

The Figure 12 illustrates that the track position quality decreases over time. Regular maintenance can correct this decrease to a certain extent.

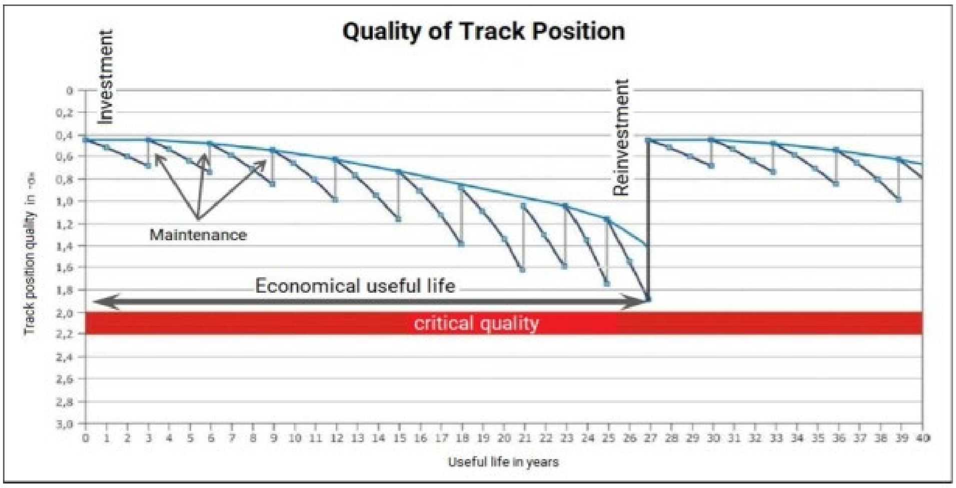


Figure 12 - LCC- optimized track system strategy

Source: Veit, Pete

It is worth mentioning that in order to be more sustainable for MRS Logística and also remain competitive in the logistics market, it is necessary to analyze the current condition of the assets of the maintenance of permanent way with a focus on the best definition of performance, and we can define the strategy with the best Life Cycle Cost (LCC) for intervention models such as current maintenance, recovery and stretch renewal.

After countless maintenance carried out, we can see that the level of degradation of the line does not allow us to reach the level of quality of the previous maintenance, making it necessary after some interventions to recover the section and subsequently renew the line, so that we can reach the quality levels. and reliability of the ideal lines with the lowest maintenance cost x results achieved.

3.4 REFERENCES FOR PERMANENT WAY MAINTENANCE MODELS

The maintenance and updating of the railway superstructure has become a worldwide challenge. An increase in performance is required by government and rail operators, such as more trains per hour, higher production and better punctuality. On the other hand, it comes into conflict with the growing budgetary pressures and operational restrictions, in this context it is necessary to combine activities in maintenance that balance the relationship between reliability and financial viability.

Economic studies on the effectiveness of these maintenance models are widely disseminated. In an American article from 2002, an attempt was made to show the correlation between total maintenance costs with the percentage share of the current budget aimed at renovation interventions (Figure 13).

According to their authors, these results indicate that most of the variation in unit maintenance costs for Class I railroads can be largely explained by the variation in the degree to which they emphasize renovation and emphasize ordinary maintenance in their engineering strategies.

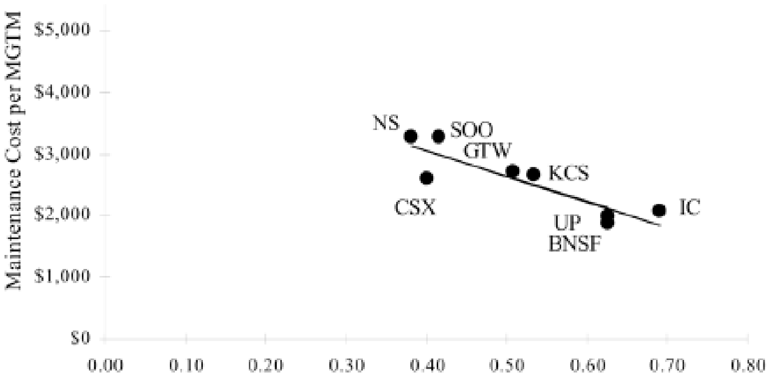


Figure 13 Correlation between total maintenance costs by percentage of maintenance budget for renovation interventions
Source: propriety author

Currently, the choices between the different maintenance methods are decided by the companies based on strong technical advice and a short to long term financial vision. Some current examples on freight railways considered as Heavy Haul:

Table 1 Examples on freight railways

Vale/EFC:	Vale/EFVM:	Union Pacific (EUA):
Main Line removal and renovation - 890 km (in progress since 2010)	Stripping since 1990 (continuous process - 10 to 12 year cycle)	Mechanized Line Renewal Program (2011 to 2015)
Ballast cleaning and replacement	Renewal of the Main Lines: replacement of the matrix of wooden sleepers for steel	Target 1,000 km of renewed lines
Changing the matrix of wooden sleepers for concrete		12 hour intervals
12 to 24 hour intervals		

On passenger railways, systematic permanent track renewals are also consolidated strategies, such as:

Table 2 Examples on passenger railways

Network Rail (United Kingdom):	SNCF - Transalp Renouvellement (France)
Annual renewal of 113 rail miles	Program started in 2013
Replacement of ballast and concrete sleepers	Renovation of approximately 1,000 km of lines in the interior of France
7.5 hour intervals	

4. CONTEXTUALIZATION

4.1 MRS LOGÍSTICA

MRS Logística was created in 1996, when the government transferred the management of the national rail system of the Southeast regional network to the private sector. Its network connects regions producing mineral and agricultural commodities and some of the main industrial parks in the country to the largest ports in the Southeast region, which gives its operation a differentiated economic importance. Approximately 20% of the volume exported in Brazil and one third of all cargo transported by trains in the country pass through the tracks of this company.

There are 1643 km of main lines in the states of Minas Gerais, Rio de Janeiro and São Paulo, there are more than 18,000 wagons and 800 locomotives, its operational headquarters is located in the city of Juiz de Fora in Minas Gerais, which manages this network as shown in the Figure below.

Figure 14 Map of the situation of the scope of the MRS Logística railway network
Source: MRS (2020)

Currently, the company is among the largest freight railroads in the world, with operations in five ports in the Southeast: Santos, Itaguaí, Southeast, Guaíba and Rio de Janeiro with production almost four times higher than that registered in the 1990s when it was privatized.

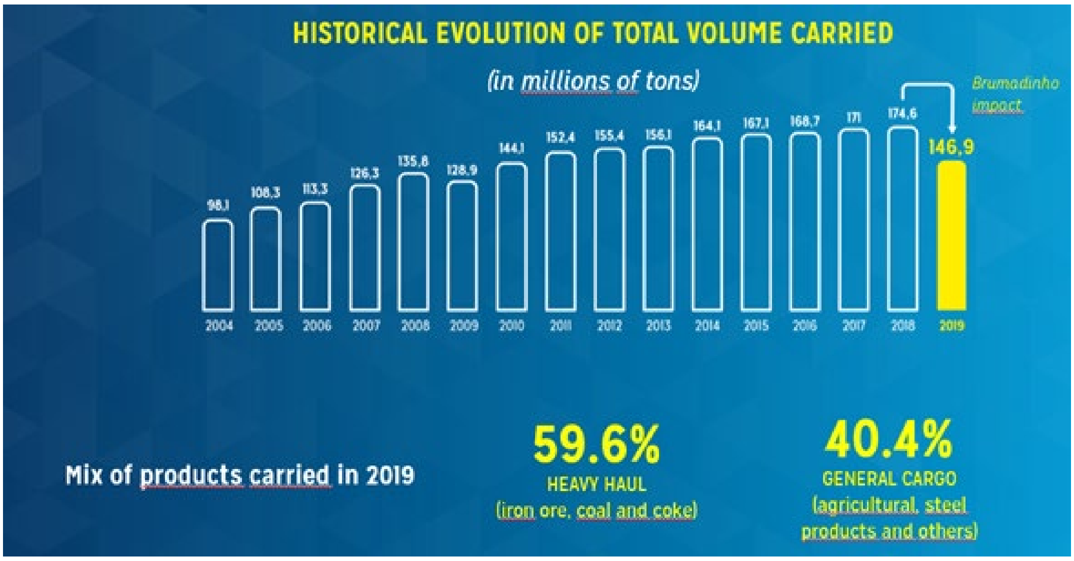


Figure 15 Evolution of total volume carried
Source: MRS (2020)

Today MRS has indicators comparable to those of the most efficient and safe North American and European railways, in terms of energy efficiency, availability and reliability of assets, safety and productivity, and stands out for its intensive use of technology and a culture of innovation.

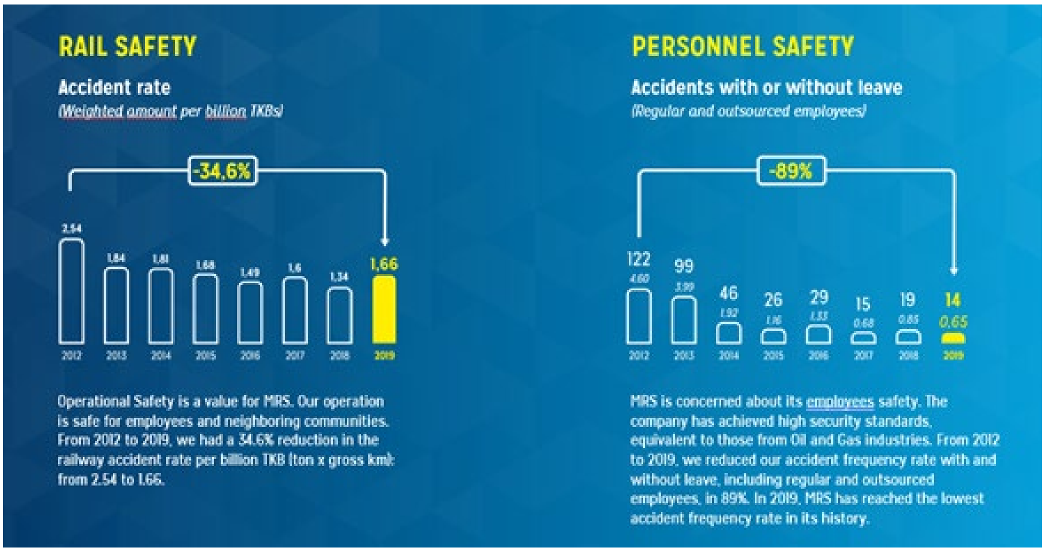


Figure 16 Acident Stats
Source: MRS (2020)

Its mission today is to offer freight transportation focused on the railroad, prioritizing flows that generate scale and long-term relationships, at competitive prices and with predictability, to add increasing value to the business.

4.2 PERMANENT RAILWAY AT MRS LOGÍSTICA

4.2.1 Permanent way division in MRS Logística

The maintenance of a permanent track at MRS Logística is located in the General Management of the Railroad Network and is divided into 5 managements: Ferrovia do Aço, Minas Gerais, Rio de Janeiro, Paraíba Valley and São Paulo, with a total of 18 coordinations and 20 districts.

It is observed the distribution of the maintenance structure of permanent way along the MRS railway network, by the states of Minas Gerais, Rio de Janeiro and São Paulo, as well as the location of their districts with their respective extensions.

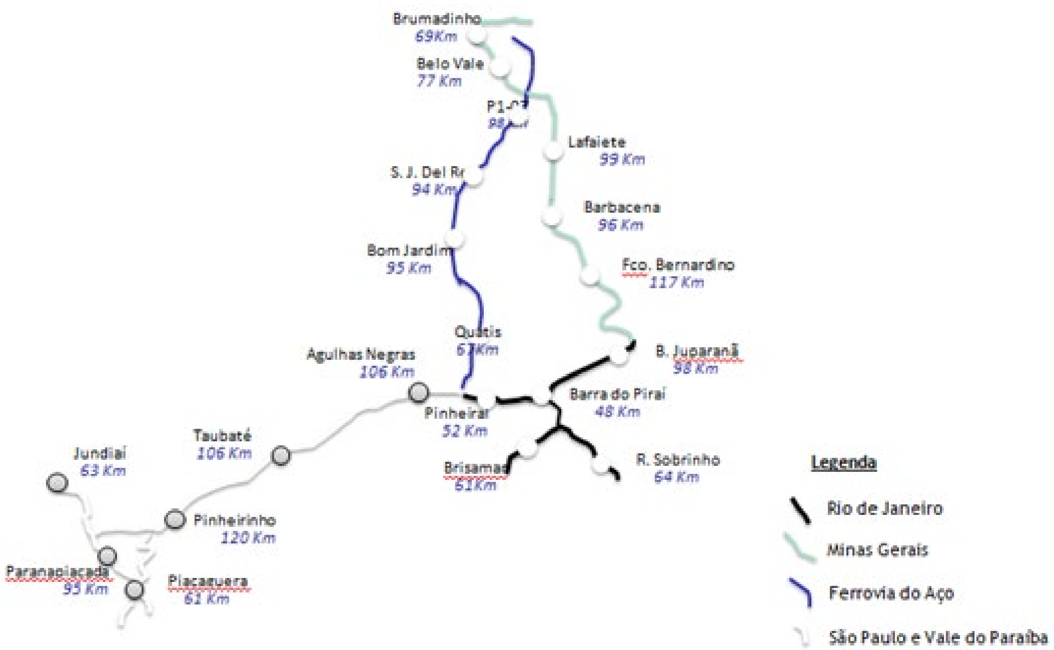


Figure 17 Location of permanent railway coordinations
Source: MRS Logistica

The main responsibilities of the Track Managements are the maintenance of more than 2,000 km of line, including yards, branches, and the operation of MOW (maintenance of way) machines.

For the operation of track equipment, the permanent way has two coordinations, one responsible for the geometric correction equipment, with a fleet of 12 tampers and 8 regulators, and the other responsible for the operation of special equipment, with a fleet of 7 equipment that operate in the maintenance of rails, ballast and sleepers.

Below are examples of equipment from MRS Logística's permanent way fleet.

Figure 18 Tamping Machine
Source: MRS Logistica

Figure 19 Rail Grinder
Source: MRS Logistica

Figure 20 Flash butt machine
Source: MRS Logistica

4.2.2 Permanent Way Diagnosis In MRS Logistica

The investment in railroad inspection equipment is one of the strategies adopted by MRS Logística to enable the inspection of kilometers of lines in a timely and accurate manner. Among these equipments, we highlight the use of control cars, vehicles that, moving on rails, perform automated measurements of the conditions of the railroad.

Pioneer when it comes to railway innovation, MRS also innovated in the acquisition and operation of the Track Star. This equipment, unique in Brazil and South America, is essential for maintaining the international safety levels that the company currently achieves. It works to prevent accidents and, consequently, increases the operational safety that the company offers to its employees, customers and the community.

Star is an acronym that, in Portuguese, means "apply force, test, analyze and release reports". This is precisely the job of the equipment that provides the correct and reliable measurement of gauges, rail profile and track geometry in real time. In this way, it is possible to identify any possible defect imperceptible to the human eye, which parameter may be being exceeded and the need for future interventions. Thus, MRS acts preventively efficiently. During the operation, there is the presence of a road coordinator who analyzes the data and can even restrict or interdict the road if something is outside the standards.

Another benefit of this equipment is the speed with which it can act. It captures all the necessary data at the maximum speed allowed on the stretch, with the minimum of operational intervention. In remote times, this track prospecting service required, for every hundred kilometers, at least 6 months to be ready. Currently, at the end of the inspection carried out by Track Star, the company has all the analysis ready.

Track Star is used throughout the MRS railway network and is requested by other railway companies and even by the Federal Government to carry out inspections

Figure 21 Track Star
Source: MRS Logistica

Very similar to the Track Star, the Ultrasound also maps the path, however, through waves with a frequency higher than those that the human ear can capture. Thus, the equipment is able to identify problems that were previously imperceptible.

The implementation of more of this detection technology, reduced the problems resulting from failures in the rails, providing greater safety and, consequently, offering greater availability of the track. This equipment can also do its job quickly, as it has the ability to reach speeds of up to 40 km / h.

Figure 22 Ultrasound
Source: MRS Logistica

4.3 PERMANENT RAILWAY MAINTENANCE STRATEGY IN MRS LOGISTICA

In MRS Logística's Permanent Way Maintenance Strategy, these degradation curves are represented in summary form by Figure below. Where it is observed that every railway asset will go through a complete life cycle where activities with a higher degree of intervention will be necessary to maintain the levels of reliability and costs at manageable and required levels, with all these phases expected and managed in the track maintenance portfolio since there is great synergy between the operator's activities and operational models.

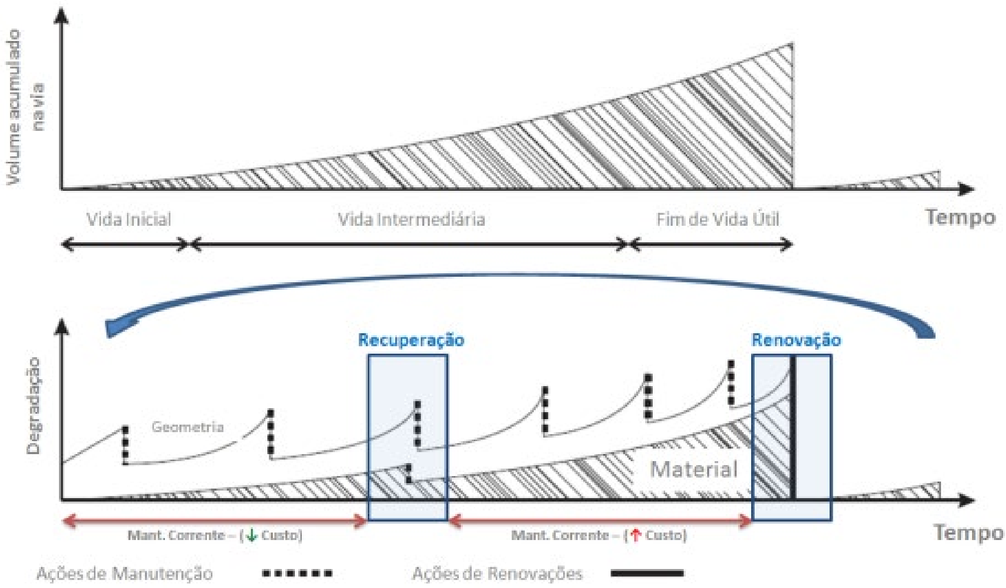


Figure 23 Degradation curve of permanent track assets
Source: Elaborated by the authors

At MRS Logística, a summary flow for analyzing the current stage of the track segment and the type of intervention on the mapped Via Permanente is shown in the next Figure.

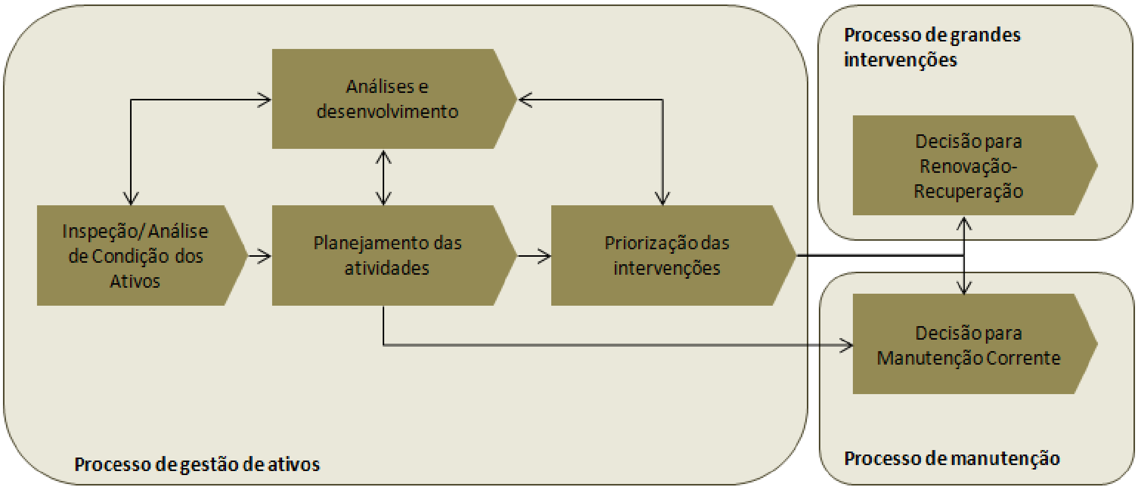


Figure 24 Assets Management
Source: Elaborated by the authors

In the phases of inspection / condition analysis of assets there are numerous criteria analyzed based on objective sources to support the analysis of financial feasibility of asset recovery, in summary, the main items analyzed are listed:

Table 3 - Main items analyzed of assets

Track failure and fracture history;	Iolumes transported: history and projection;
Quality of the sleeper / fixation systems;	Installed geometry;
Evolution of maintenance costs;	Possibility of generating reemployment materials;

In the planning and prioritization phases, the LCC variables (life cycle cost) of the assets involved are analyzed, in principle, in a macro way, are:

Table 4 - Macro way LCC variables

Operations	
resources required for execution and maintenance throughout the useful life;	operating costs: current maintenance, recovery and ad hoc corrective costs;
operational impacts: reliability analysis in the operation (availability);	return on cash flow from interventions;

According to the concepts presented and the maintenance categorization criteria at MRS Logística, the Permanent Way Maintenance Strategy can be summarized in two main pillars as shown in Figure below.

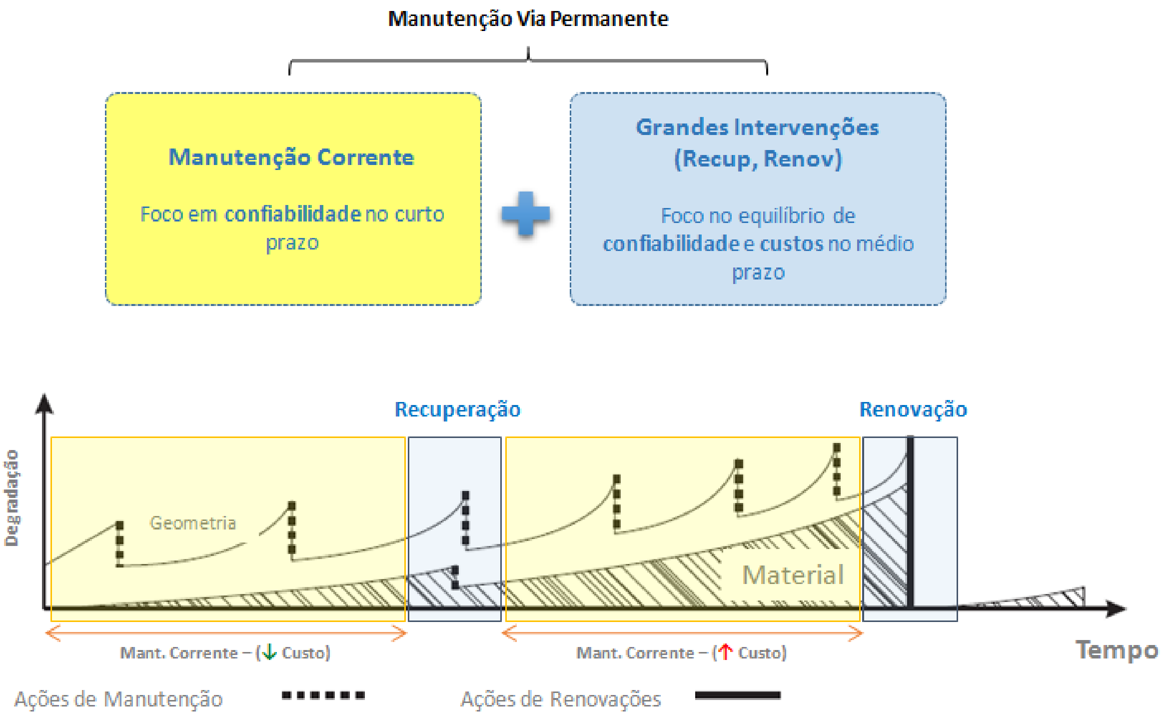


Figure 25 Permanent Way Maintenance Strategy at MRS
Source: Elaborated by the authors

Thus, two groups of interventions are part of the ongoing maintenance of MRS:

- Current maintenance: based on short-term management with a focus on asset reliability and availability;
- Major interventions: activities focused on balancing maintenance and quality costs, being subdivided into two types in the MRS (recovery and renovation).

Still within the line recovery or renewal phase, it is possible to opt for the total remodeling of components considering the opportunity to carry out the activity at the same time. Practical examples are: remodeling wooden sleepers for steel or concrete sleepers, increasing the rail profile (example: changing the TR-57 to TR-68 profile). Remodeling interventions aim to bring new levels of permanent materials for use in the railways. Generally with more modern materials and long service life.

The table below presents the main concepts for each intervention.

Table 5 Summary of intervention models

	Recovery	**Remodeling**	**Renovation**
Triggers	- High rate of degradation of part of the system components. - Mandatory non-sequential assets	- Asset capacity increase due to the opportunity to maintain Recovery or Renewal	- Assets with undesirable ballast and / or platform condition with considerable reduction in component life
Targets	- Short-term reliability and reduced rework	- LCC-based asset capacity increase	- Reliability and cost reduction in the medium term at project levels
Scopo	- Unserviceable rate of sleepers (0%) - Extensive tampering / line lift (100%) - Removal of all preventive and corrective defects (joints, welds, etc.) - Recovery of drainage assets	- Focus on changing the material matrix to be used (sleeper Wood x steel / concrete, TR-57 x 68 etc.) - Recovery Activities	- Total component exchange (with material generation) - Ballast stripping and platform treatment - when necessary
Operational Impact	- Low. - Differentiated intervals with direct negotiation with the operational planning.	- Low / Medium. - Activities performed at Differentiated Intervals	- Medium / High. - Multiannual analysis of operational impact and multidisciplinary maintenance

5. RESULTS

5.1 DEFINITION OF LONG TERM STRATEGIES

5.1.1. Overview

The long-term maintenance strategy at MRS Logística is carried out through the analysis of the transport conditions of each corridor (loaded or empty train and transport volume), projection of increased load transported in the medium and long term, current condition of maintenance track and the variety of materials available and under development that can be installed, such as sleepers.

After these analyzes of the general conditions of transport and maintenance of the stretch, the best strategy is defined based on the LCC (life cycle cost) for each corridor. When thinking about investment, the most important and crucial part is planning that can support the defined strategy. Developing assertive planning is essential for any company to remain firm and competitive. It is through it that it is possible to analyze the possibilities of the market, which path must be taken for success and which are the necessary steps for the company to be profitable.

The strategy definition for the main MRS corridors is defined below:

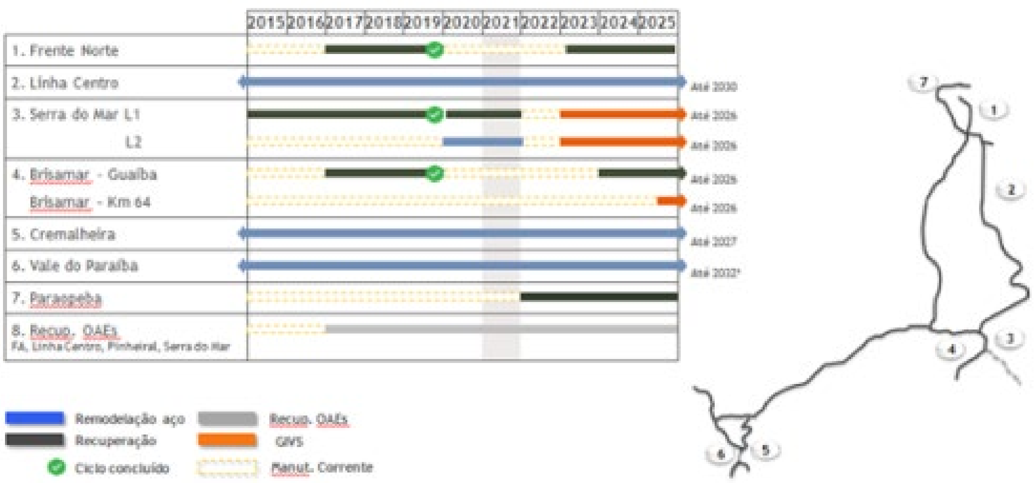


Figure 26 Maintenance strategy by corridor in MRS
Source: Elaborated by the authors

5.3.1 Track Renewal Project

Initially, it is worth reinforcing the main functions of the ballast. According to the main bibliographic references, in general, they are: to support and distribute uniformly to the vertical loads that occur at the dormant / ballast interface to the lower layers of sub-ballast and subgrade; guarantee the stability of the railway grid according to transverse, longitudinal and vertical forces;

provide draining capacity; allow leveling of the rails; and finally dampen vibrations and noise. In addition to the functions mentioned, the ballast also facilitates the conservation, remodeling and renewal of the permanent way.

According to SgaviolliETall (2015), over the lifetime of the ballast, it can occur the filling of its voids, resulting in an increased need for maintenance interventions. The fine contaminants of the ballast have as sources identified in the literature: fracture and abrasion of the ballast particles during the tamping or during the useful life; infiltration of materials from the underlying granular layers or surface materials. However, railways transporting coal or iron ore have high rates of contamination from the surface, as in Australia, for example, where 70 to 95% of fines are due to coal infiltrating the surface and only 5 to 30% come from fracture ballast aggregates (Feldman and Nissen, 2002). A similar situation occurs in the Brazilian railways that transport iron ore and coal, as in the case of MRS Logística.

The consequences for railway superstructure and infrastructure systems are well known for the practice of railway maintenance. The loss of elasticity and capacity during the ballast layer directly affects the reliability of the superstructure layers, such as sleepers and rails, and the lower layers, reducing the subgrade resistance capacity and original earthworks platforms. These effects, combined with the high degradation of geometry, result in excessive maintenance costs and an increase in the probability of failures and greater exposure to the risks of railway accidents.

For effective ballast management, railways have limited alternatives for preventive and corrective ballast treatments. The ballast maintenance practices currently employed are: punctual ballast cleaning (manual or mechanized), socariaw with line lifting, mechanized ballast shoulder cleaning and total mechanized ballast cleaning.

The solutions adopted are closely linked to the maintenance strategies of the operators' Permanent Way assets, aiming to balance the variables of costs, quality and risks. MRS Logística due to its operating characteristic Heavy Haul (high volumes transported with high load per axle) requires robust ballast treatment to maintain the required network availability. The solutions adopted date back to the time of RFFSA, a period prior to the concession. Mechanized and manual models have been adopted since then as a routine maintenance practice of MRS Logística.

The history refers to the use of low productivity ballast cleaners between 1990 to the beginning of the 2000s until their stoppage, due to the obsolescence of the models existing at that time. Starting in 2005, line-lifting strategies (which provide a clean ballast layer under the 100 mm sleeper) and the acquisition of equipment such as shoulder and shoulder vacuum cleaner have since composed solutions for corrective and preventive treatment of ballast at MRS Logística.

Figure 27 Vacuum ballast cleaner machine

Fonte: MRS Logística

With the volume already transported and planned for the long term, and the advent of capacity obtained by the operational improvements in the network, it is possible to complement the high-productivity mechanized total stripping solution on the MRS lines.

Ballast Cleaning Machine (figure 28) is equipment that removes the gravel from the line, makes its sieving, checking which quantity is in accordance with the degranulometry standards and which should be discarded. To meet the proposed schedule according to the expected maintenance cycle and the indicated maintenance windows, high productivity equipment must be used.

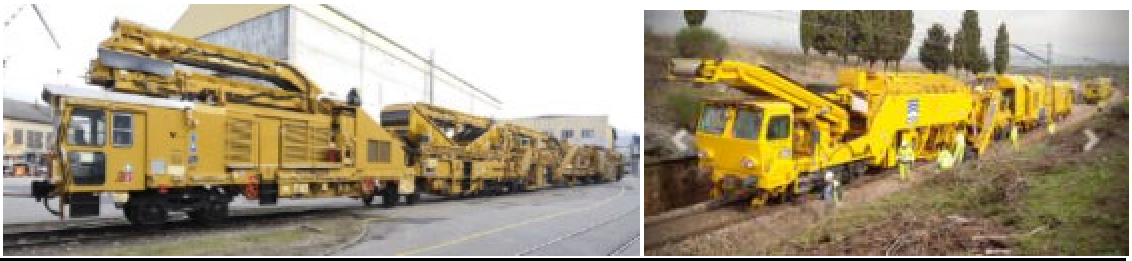


Figure 28 ballast cleaner high production line

Fonte: MRS Logística

The ballast cleaning cycle at MRS considered is between 8 to 12 years for loaded segments. These values converge with the practice of the main railways that adopt this maintenance strategy, according to the references presented in the figures below. Other MRS corridors, due to reduced loading, are serviced with minor interventions, such as cyclic tamping, shoulder ballast cleaning and the line lifting process.

North American Ballast Cleaning Practice - Typical Cycles

	Concrete ties annually 80 MGT		Wooden ties annually 60 MGT	
	Maintenance Frequency (years)			
	Solid subgrade	Weak subgrade	Solid subgrade	Weak subgrade
Under-cutting	12.5	3	20	8
Shoulder-cleaning	3	1.5	3	1

Figure 29 Track ballast cleaning cycle
Fonte: Wenty (2017)

Assuming the service life of ballast is approximately 12 to 18 years; the full ballast section should be undercut and cleaned every 12 years on concrete tie track. This schedule should keep the ballast bed clean and allow the ties to attain their expected life. It is suggested that wood tie track in heavy haul operations be undercut and cleaned every 15 to 18 years. This will help maintain the proper ballast drainage and extend the life of the wood ties. It is likely that with the continued increase of axle loads, more railways will enlist the use of subgrade rehabilitation machines similar to those used in Europe and China.

Figure 30 *Track ballast cleaning cycle*
Fonte: Cantrell (2009)

Considering the length of the corridor loaded in the MRS of approximately 700 km of line (Ferrovia do Aço, Paraopeba, Pinheiral, Serra do Mar e Brisamar) and the aforementioned premises, the interval between ballast cleaning cycles of 8 to 12 years is feasible considering equipment high productivity processes.

With the technical and operational assumptions defined (mentioned in the previous item), a plan for the continuation of the track ballast cleaning activity and switch was carried out along the MRS network.

In the first stage, the ballast cleaning of the switch track of the Pinheiral + Serra do Mar + Brisamar + Ferrovia do Aço railroad south front was established as a target in a maximum period of 12 years. The target of the ballast cleaning of the track activity and switch for the other circulation corridors will be discussed in a second stage (starting from the performance of the first stage).

Table 5 Track ballast cleaning cycle

ITEM	TIPO DO CIRCUITO	CORREDOR	TIPO DE LINHA	EXTENSÃO DE LINHA (KM)			AMV (UND)
				LI	LII	TOTAL	
1		Paraopeba	Singela com pátios de cruzamento	127	36	163	80
2		FA - Frente Norte		61,3	13,3	75	20
3		FA - Frente Sul		293	77	370	60
4		Pinheiral	Duplicada	54	54	108	32
5	Minério Carregado	Serra do Mar		43	43	86	44
6		Brisamar		38	38	76	28
7		Mangaratiba	Singela com pátios de cruzamento	27	4	31	4
8	Minério Vazio	Linha do Centro		367	122	489	120
9	Carga Geral	Rocha Sobrinho		64	1,2	65	6
10		Vale do Paraiba		305	40	345	54
11		Cremalheira		8,1	3,8	12	0
12		Baixada Santista - Margem esquerda		14	2	16	6
13		Baixada Santista - Margem direita	Duplicada	26	26	52	38
Total				**1.427**	**460**	**1.888**	**492**

Legenda

Fase 1

Fase 2

Source: MRS Logística

With the performance target established in the first stage, the work schedule was drawn up with the following performance phases:

- Phase1: Ballast cleaning of the track and switch in the circulation corridors of Pinheiral + Serra do Mar + Brisamar for a maximum period of 4 years (270 km of line + 104 switches);
- Phase2: Ballast cleaning of the track switch in the circulation corridor of the Ferrovia do Aço front south (370 km of line + 60 switches)

The corridors to be renewed are shown in Figure 31.

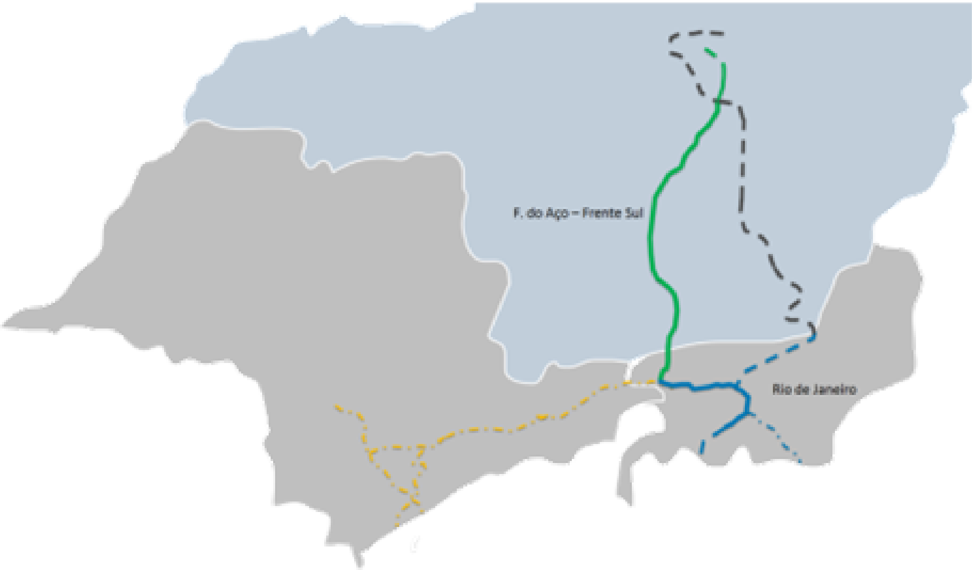


Figure 31 Location map of the corridors to be renewed
Source: MRS Logística

In the opportunity of the full line ballast cleaning processes, the current matrix of predominantly wooden sleepers will be replaced by models that are also fully mechanized for monobloc concrete sleepers (figure 32).

Figure 32 Track Renewal Machine
Source: MRS Logística

There are challenges in the Brazilian market for supplying high density wooden sleepers, justifying the adequacy of the matrix in MRS. However, the adverse situation of the substructure, ballast, sub-ballast and subgrade layers of the Brazilian railway pavement, and the essentially manual maintenance model, pose a challenge for changing the dormant matrix as a challenge that not only involves replacing the material itself, but also rather by a change in railway culture and high initial investments.

In addition, the replacement with concrete sleepers allows a better total cost (LCC), considering the increase in the useful life of the asset, a transition that has already been carried out or is underway in the main heavy haul railroads in the world.

5.2 COST BENEFIT ANALYSIS

The MRS Permanent Track Renewal project has the general objective of ensuring the sustainability of operations in the medium and long terms. This sustainability in a nutshell, is based on the following pillars:

- Availability: reduce the number of maintenance interventions once the components and assets are at the end of their useful life, implying more recurrent maintenance and, consequently, greater demand for intervals;
- Operational safety: reduction of failures due to the increased reliability of renewed assets;
- Maintenance costs: reduce rework in interventions considered palliative coupled with the application of materials with better LCC in the long term.

The main variables were modeled and analyzed in comparative scenarios for the generation of feasibility studies. As an example, figure 33 shows the projected curves of sleepers consumption in the studied corridors. The reduction in the application of sleepers in the long term is the main portion of the financial return of this project.

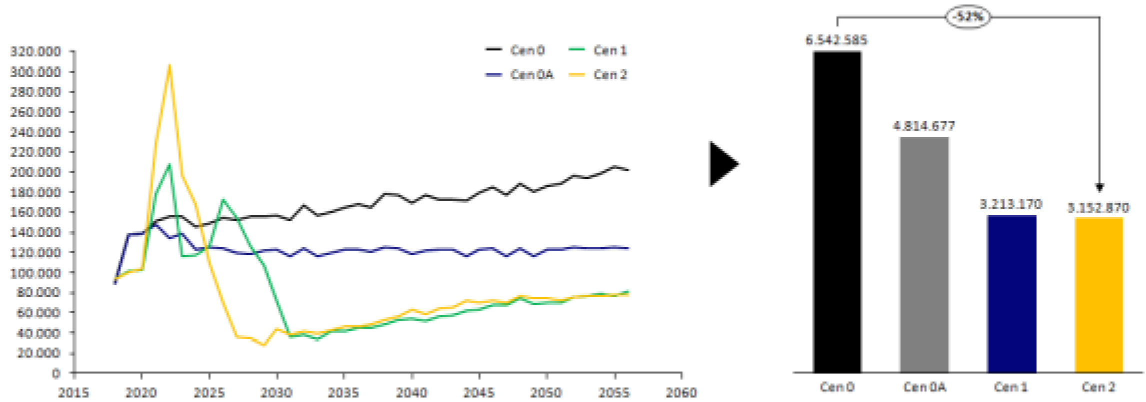


Figure 33 Projected Curve of Sleeper Consumption 2020-2056
Source: MRS Logística

Probabilistic analysis models were used to evaluate the project's financial viability results. In this analysis, all variables have ranges of variations according to the degree of development, example: basic structure projects have more open ranges of price variation when compared to projects at the executive level.

In the evaluated scenarios, with multiple iterations, the result was predominantly positive. For reasons of information restrictions, financial values will be omitted for this study.

5.3 RISK ANALYSIS

A hazard and operability study (HAZOP) is a structured and systematic examination of a complex planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment. The intention of performing a HAZOP is to review the design to pick up design and engineering issues that may otherwise not have been found. The technique is based on breaking the overall complex design of the process into a number of simpler sections called 'nodes' which are then individually reviewed. It is carried out by a suitably experienced multi-disciplinary team (HAZOP) during a series of meetings. The HAZOP technique is qualitative, and aims to stimulate the imagination of participants to identify potential hazards and operability problems. Structure and direction are given to the review process by applying standardised guide-word prompts to the review of each node. The relevant international standard calls for team members to display 'intuition and good judgement' and for the meetings to be held in 'a climate of positive thinking and frank discussion'.

Table 6 HAZOP Guide Terms

Error mode	Description
Not done	The action is not performed or the operator has been unable to perform it
Misordered	An activity or part of an activity is executed in the wrong order
Other than	The wrong activity is performed
Less than	Quantitative: the result of an activity is below the required level
More than	Quantitative: the result of the activity is above the required level
Sooner than	An activity is performed faster than it should have been in the related scheduling
Later than	An activity is performed slower than it should have been in the related scheduling
Part of	Part of the activity has been omitted
Repeated	The same activity is repeated a second time
Opposite	An activity is performed on the opposite way
As well as	An additional activity is performed together with the expected one

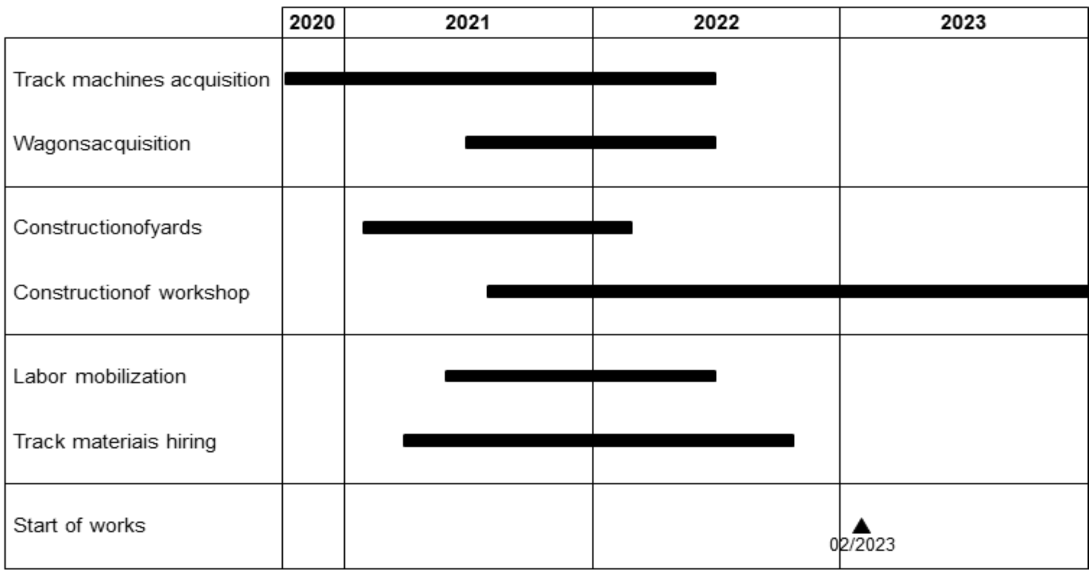
The HAZOP technique was initially developed in the 1960s to analyze major chemical process systems but has since been extended to other areas, including mining operations and other types of process systems and other complex systems such as nuclear power plant operation and software development. It is also used as the basis for reviewing batch processes and operating procedures – see ATTACHMENT 1.

5.4 PROJECT AND IMPLEMENTATION PLAN

As presented in the previous sections, the implementation of the total permanent renovation program at MRS Logística contemplates several fronts to support the execution of the planned interventions.

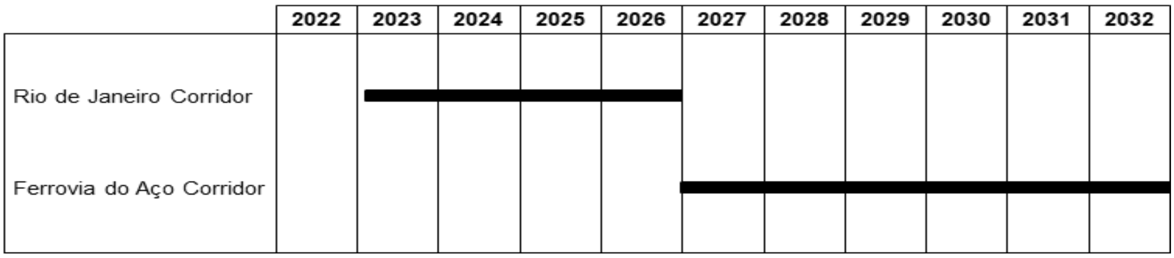
The estimated implementation horizon for these fronts is shown in figure below in a physical schedule format. The information presented for this study is representative, since the investment validations will be carried out according to the evolution of the projects' maturity development.

Table 7 Project Schedule



In the table 6, a physical schedule of progress for renewals by rail corridor of MRS Logística is presented for the first cycle of interventions. For this first cycle of heavy interventions, 10 years are expected.

Table 8 Interventions Schedule



5.5 FINANCIAL PLAN

The project's investment plan is broad based on the various fronts that are necessary for its implementation.

In the portion of associated investments, the main planned packages are didactically grouped at Table 9:

Table 8 – Type of costs

TYPE OF COSTS	DESCRIPTION
Investments in Assets	purchase of track equipment purchase of service wagons expansion of support yards renovation and expansion of track equipment maintenance stations
Direct and Indirect Costs	Labor to carry out interventions Operation resources (locomotives and equipment) Support and support services for material logistics Track materials Etc.

Due to all the variables presented, when analyzed in the long term, a scenario of unitary maintenance costs lower than those of the present scenarios and projected in an as is condition is signaled. For reasons of information restrictions, financial values will be omitted for this study.

6. CONCLUSION

This work aimed to evaluate a case study of the MRS Logística Permanent Way Renovation.

According to the data presented, the maintenance strategy adopted is in line with the best practices of Heavy Haul railroads worldwide and bibliographic references. The activities that aim to renew the components will guarantee reduced future costs with greater reliability of the assets, consequently guaranteeing a safer operation for a longer time.

Through the analyzes and data collected, it is observed that a sustainable maintenance model in the current molds is not feasible due to frequent corrective maintenance, according to the permanent degradation studies presented.

The implementation of these types of interventions must be in line with strategic objectives and with well-developed planning since they generate impacts and all areas of the railway.

As it is a complex project with a high associated investment, it used the risk assessment technique called HAZOP. This methodology, has the intention to perform the review the design and engineering issues that may otherwise not have been found.

With the addressing of the mapped risks, and the information regarding the management and planning of the project, based on the LCC of the evaluated models, it is recommended to continue the project by performing the steps of physical and financial schedules for subsequent implementation.

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ATTACHMENT 1 – HAZOP ANALYSIS

Process	Guide terms	Deviation	Causes	Consequences	Safeguards
Track machines (MOW) Acquisition	Not Done	Equipment not delivered	Supplier bankruptcy	Delay in project delivery	- Perform approvals at the factory - design review; - Assess the supplier's capacity; - Schedule of use of equipment within the project; - Hire consultancy for import support - Perform benchmarking with railway operators - Define / predict fines for supplier liability delays
	Later Than	Delay in delivery of equipment	Problems with the capacity and / or order placement deadline		
	Misordered	Import issues	Wrong / incomplete documentation		
	Misordered	Assembly / construction error	Specification failure and / or specification non-compliance		
Project Management	More than	Lack of clarity in scopes	Lack of knowledge of the project	Larger budget than originally planned	- Hire a team with experience in similar projects - Perform benchmarking
	Not done	Lack of support area engagement	Initiative not aligned with the company's strategic objectives	Delay in deliveries Reworking scoping	- Ensure alignment with senior management
			Inefficient communication		- Define and plan change management
Support Structures	Not Done	Support yards have not been built	Yard project not delivered	Delay in project delivery	- Perform planning in advance of the project stages
	Later than	Delay in delivery of support yards	Delays in environmental licenses	Lack of structures to receive the equipment Delay in the start of the project	- Conduct prior consultations with environmental agencies
			Lack of manpower for execution and / or materials		- Define medium-term planning with the Supply Area
Wagons Acquisition	Not Done	Wagons of other support equipment not delivered	Supplier bankruptcy	Delay in project delivery	- Ensure hiring of companies with positive financial health
	Later than	Wagons of other support equipment delivered late	Failure by the supplier to meet the deadline	Delay in project delivery	- Predict fines and penalties on schedule items
	Misordered	Assembly / construction error	Supplier non-compliance with specification	Delay in project delivery	- Ensure hiring of companies with expertise
Track Materials	Not Done	Unavailability of materials	Supplier bankruptcy	Delay / Cancellation of part of the project delivery	- Define substitute suppliers; - Request the delivery of materials with planned anticipation; - Perform a technical visit to the supplier
	More than	Costs above expected	Exclusive suppliers	Dependence of only a few suppliers on strategic items	- Define share of suppliers - Develop alternative suppliers
	Later than	Delay in delivery of materials	Failure by the supplier to meet the deadline	Delay in project delivery	- Define substitute suppliers; - Request the delivery of materials with planned anticipation; - Perform a technical visit to the supplier
	Misordered	Materials delivered out of specification	Supplier non-compliance with specification	Delay in project delivery	- Define substitute suppliers; - Request the delivery of materials with planned anticipation; - Perform a technical visit to the supplier
Work Windows	More than	Higher volume to be transported than budgeted	Increased demand for rail transport	Increase in assets to realize volume Lack of drivers for service trains	- Perform alignments and scenario studies with the Planning area - Define asset and resource buffer to support variations
	Not Done	Reduction of work intervals for the project	Increased demand for rail transport	Postponement of project delivery	- Transport demand assessment for the coming years to scale capacity of work breaks without impact on production
Labor	Not Done	Delay in mobilizing labor	Difficulty finding qualified labor	Delay in project delivery	- Define Development Plan with the HR Area; - Bid with trusted suppliers
	Less than	High labor turnover	Volatility of railway labor	Delay in project delivery	- Hold meetings with the supplier periodically; - Bid with trusted suppliers