INTERNATIONAL CERTIFICATION IN MANAGEMENT OF

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Bruno Campos
Guilherme Soares
Marcos Grossi
Marcos Mourão

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Life cycle simulation and comparation between corrective maintenance and track renew

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ABSTRACT

The renewal of permanent railway tracks is a critical and essential process to maintain the integrity, operational safety and efficiency of railway infrastructure. This final work explores the multitasking and financial analysis aspects of permanent track renewal, covering the life cycle of railway tracks, from renewal to decommissioning. The renovation phase involves strategic planning, meticulous design and efficient allocation of resources, with considerations for labor, materials and permits. Permanent track maintenance is a crucial component, requiring routine inspections, repairs and adherence to safety standards to ensure continued track functionality. Downtime costs and operational impacts are carefully managed to minimize risks to rail services. The decommissioning phase involves environmentally conscious practices, including safe demolition and waste disposal, while monitoring the importance of sustainability in railway infrastructure. In this life cycle, indirect costs, such as project planning, environmental impact mitigation and enforcement of safety regulations, are relevant to the overall economic considerations of permanent road renewal. This final work highlights the importance of a comprehensive Life Cycle Costing (LCC) approach, which involves a systematic assessment of the direct and indirect costs associated with each phase. As the rail industry continues to evolve, the adoption of innovative technologies and sustainable practices becomes an integral part of successful and cost-effective permanent track renewal, ensuring the longevity and reliability of rail systems.

ACKNOWLEDGEMENTS

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We hope to contribute and use the knowledge acquired to improve the railway sector.

LIST OF ABBREVIATIONS

LCC – Life Cycle Costing

NPV - Net Present Value

RAMS - Reliability, Availability, Maintainability and Safety

CWR – Continuous Welded Rail

WACC – Weighted Average Cost of Capital

VPL – Valor Presente Líquido in Portuguese or Net Present Value (NPV)

TIR – Taxa Interna de Retorno in Portuguese or Internal Rate of Return

SUMMARY

FIGURE LISTS

1. Introduction

1.1 Contextualization

VLI is a Brazilian logistics company that operates in the railway sector, being recognized for its large logistics network and commitment to efficiency in cargo transportation. Its role is vital for the movement of various sectors of the economy, standing out as one of the main players in the national logistics scenario.

The Ferrovia Centro-Atlântica (FCA), under the management of VLI, represents a significant part of the railway infrastructure in Brazil. With an extensive network, it connects important regions of the country, playing a strategic role in the transport of goods, contributing to competitiveness and economic development. The concession contract that is nearing its end is a key milestone. This contract outlines VLI's responsibilities, obligations, and rights in relation to the operation and maintenance of the Ferrovia Centro-Atlantica. During the renovation process, crucial issues such as the average age of the locomotives, signalling and level of track maintenance emerge as points of discussion, highlighting the strategic importance of the ongoing negotiations.

Figura 1 - Ferrovia Centro Atlantica, source: ANTT

In this context of contract renewal, it is important to understand how the cost structure works and the representativeness of each sector of the business. This structure is composed of several elements associated with the operation and maintenance of the railway infrastructure. While the specific details may vary, a typical cost structure for a railroad includes:

Permanent Track Maintenance: Costs related to the upkeep and improvement of rails, sleepers, ballast, and other fixed infrastructure to ensure safety and operational efficiency.

Rolling Stock: Expenses associated with the maintenance and refurbishment of locomotives, railcars, and other railway equipment.

Signaling and Communication: Investments in signaling and communication systems to ensure the safety and efficient coordination of trains.

Railway Operation: Costs related to day-to-day operation, including salaries, staff training, fuel, among others.

Logistics and Warehousing: Expenses associated with managing terminals and warehouses along the railway.

Administration and Management: Administrative expenses, including office expenses, administrative staff, information technology, among others.

Compliance and Security: Investments in regulatory compliance, security measures, and training programs.

Finance Costs: Expenses related to financing, interest, and other finance charges.

Other Costs: Any other specific cost related to the operations and maintenance of the railroad.

(Santos, Stiegert, Lopardi, Silva, & Andrigheto, 2020) mentioned that it is possible to observe the distribution of operating costs on 3 main fronts: maintenance, labor, and fuel. An example of the cost structure of a Brazilian freight railroad is shown below:

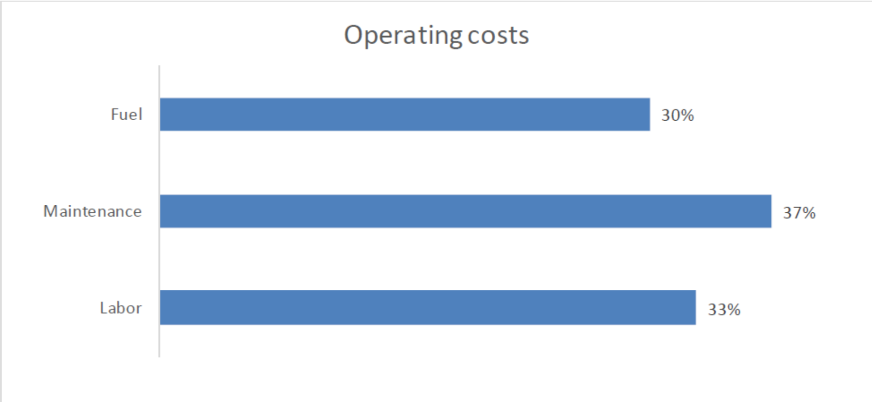

Figura 2 - Operating Costs From Typical Brazilian Freight Operator (Santos, Stiegert, Lopardi, Silva, & Andrigheto, 2020)

Despite being presented separately, it is crucial to understand the direct and dependent relationships that exist between the pillars. Maintenance processes are indispensable to the operation process, as they ensure that assets are in proper condition, from availability to safety. These aspects have a direct impact on the requirements to meet production demands, such as the number of employees, fuel consumption, and the number of assets. The configuration and integration of all these elements are the determining factors of the efficiency of the transportation system and the profitability of the railway business. (INTERNATIONAL TRANSPORT FORUM, 2017).

1.2 Justification for the choice of theme

The choice of the theme "Life Cycle Simulation and Comparison between Corrective Maintenance and Track Renewal on the Central-Atlantic Railway" is justified by its strategic importance in the current context of FCA's railway concession. With the imminent termination of the concession, the renewal and negotiation of contractual terms become crucial for the company's operational efficiency and profitability.

Life cycle analysis offers a comprehensive approach to assessing the implications of different maintenance strategies over 30 years. This not only considers technical aspects, such as the average age of the locomotives and the condition of the track, but also seeks to optimize financial variables, such as CAPEX cash flow, with the aim of increasing profitability and reducing costs in the long run.

In addition, the research aims to understand operational improvements, such as the reduction of failures and transit time of trains. Not only do these factors directly impact operational efficiency, but they also have substantial financial implications, contributing to board-informed decision-making.

Therefore, the proposed analysis aims to provide valuable insights to support FCA's maintenance strategy, aligning with the objectives of increasing profitability, reducing costs and improving operational efficiency in a crucial period of contract renewal.

1.3 Research objectives

- Define the best maintenance method for the expected purposes.

- Set the cheapest maintenance method to the expected maintenance level.

- Increase the company's profitability and reduce cash flow expenses in the medium and long term.

- Improve the transit time of trains on the route.

2 Literature review

(Fonseca, Giffoni, & Gonzaga, 2020) mentions that the productivity of a railroad is influenced by several factors, including operational decisions and the conditions of the railroad line. To ensure the performance of a railway section, it is important to keep the permanent track in good structural condition. The greater the demand for productivity of a railroad, the greater the need to maintain the permanent track in adequate structural conditions. This requires investments in track maintenance, which must be carried out regularly and efficiently to ensure the safety and efficiency of rail transport.

He also points out that the components suffer fatigue in their structures due to the repetition of loads, in addition to the physical wear and tear of their surfaces. The track profile also deviates from its proper position, thus losing the specific geometry. These degradations occur simultaneously, requiring specific maintenance: geometric and structural. The frequency of each of these maintenances is dictated by the rate of degradation of the structures and the administrative assumptions adopted by the railway undertaking. Railways with high performance objectives require higher operating speeds, and in these circumstances, tolerances for deviations and wear of structures tend to be lower, requiring more frequent maintenance.

Maintenance management needs to reconcile demands ranging from the need to keep traffic safe with adequate performance, to financial constraints regarding the volume of activities themselves, since more frequent maintenance is more expensive for the company, which directly impacts the final profit.

2.1 Permanent track

The permanent track is, by concept, the structure necessary to support and transmit railway loads of in order to allow trains to circulate with reliability, safety and availability. For centuries, since the beginning of railways, their basic design has remained very similar, evolving only in its components, in accordance with the advancement of material technologies. Is it possible to split the permanent route into two large subgroups:

a) Infrastructure: comprising the entire set of earthworks and works of art (tunnels and viaducts). It is responsible for providing support to the superstructure and acting on circulation boundary conditions of trains, acting directly to guarantee drainage, preservation of the circulation pattern and transposition of rugged terrain;

b) Superstructure: supported on the infrastructure, the superstructure is responsible for capturing the loads transmitted by the railway wheels, transmit them safely through the structural connections of its composition and unload them in a uniform and dissipated manner onto the railway platform. That is done through correct sizing and adequate overlapping of developed components specifically for each function, from direct contact with the train wheels, through reception, transmission and absorption of these loads.

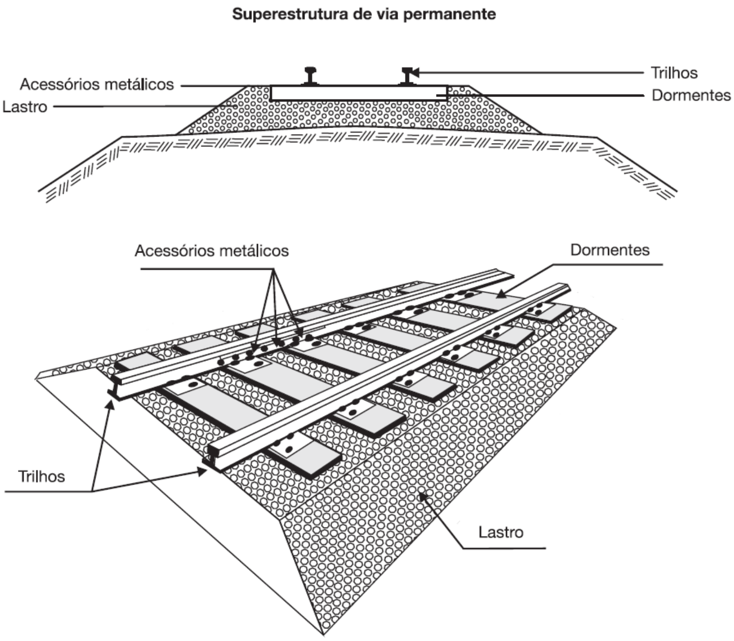

Figura 3 - Via Permanente Aplicada (Steffler, 2013)

2.1 Maintenance of the permanent track

The mission of maintenance is to ensure the availability and reliability of the company's equipment and facilities so that it is possible to serve the final process safely and with care for the environment. Lack of quality in maintenance can cause rework and increase costs (Kardec & Nascif, 2009).

Maintenance is used for several reasons, such as preventing possible breakdowns or breakdowns throughout the production process, ensuring the conditions of use of the equipment, ensuring the greatest efficiency of the equipment, reducing unexpected stops due to breakdowns in the process, reducing maintenance expenses and maintaining excellence in the execution of the work (Neto, 2002).

Isaias (2019) comments that maintenance work can be divided into three categories: geometric maintenance, renovation and remodeling. Geometric maintenance is responsible for recomposing the geometry of the track, that is, replacing the track components in positions that meet the tolerances established by the railroad. This type of maintenance has the shortest useful life among the others and is usually performed in cycles that are repeated within a few years depending on traffic (1 to 5, usually). These services can be performed manually or with the use of large equipment, which increases productivity and quality. Renewals, on the other hand, are structural maintenance that are intended to replace track components when they are at the end of their useful lives. They are called renovations because they replace a large number of items, causing the condition of the road to return to practically the same original design. Usually, components are replaced in large numbers and together during these interventions. Railroads choose to carry out renovations differently since each component has a different estimated useful life, basing this decision on a careful analysis of the cost-benefit ratio of maintaining a certain item. The costs of carrying out this type of maintenance are substantially high, and there is a need for total interruption of the track to carry out the services.

As for remodeling, (Fonseca, Giffoni, & Gonzaga, 2020) details the similarity with the concept of renewal, but it is intended to replace the track components with others that are technologically better or more robust. When the demand for transportation exceeds the limits foreseen in the project, requiring a greater capacity, it is necessary for this section to undergo a remodeling in order to update the capacity of its components. One note is that it is not necessary for all components to be updated, but only the items that are required.

The interval between geometric maintenance may vary, depending on the method used. More conservative methods anticipate interventions to avoid the risk of exceeding tolerances, while more predictive methods schedule maintenance to occur at times closer to tolerance. This definition reflects the management aspects of each company, which are directly linked to values and policies. However, because they interfere with traffic and represent high expenses for companies, it is necessary to seek maintenance arrangements that allow cost savings, respecting safety tolerances.

According to (Rodrigues, 2001), there are three traditional methods of maintenance management: corrective maintenance, cyclical and based on the monitoring of track degradation. Corrective is the repair of defects as they occur. These services are usually not scheduled and are the result of breakage or wear beyond tolerances. Once the problem is detected, traffic is stopped to perform the correction or, when it comes to geometry, a speed restriction measure is applied at that location until proper maintenance can be performed.

According to (Natani & Machado, 2008), corrective maintenance can be classified as planned and unplanned. Planned corrective maintenance is more cost-effective and is based on detective, predictive follow-ups or the decision to wait for failure to occur. On the other hand, unplanned corrective maintenance is more expensive, as the correction is done occasionally and can cause loss of productivity and damage to equipment.

According to Rodrigues (2001), cyclical maintenance is a method in which services are performed in fixed cycles of time throughout the stretch in a scheduled manner. Due to the accumulation of services, a range of resources needs to be concentrated. Normally, this cycle is established by engineering and maintenance technicians depending on the load being transported.

According to (Kardec & Nascif, 2009), preventive maintenance is a strategic plan that involves regular checks of machinery and equipment at predetermined intervals to avoid failures and breakdowns that can harm productivity.

In practice, the dynamics of cyclical maintenance follow the pattern of Figure 2:

• Total Review – RT: concentration of resources for maintenance of all components of the superstructure of a section so that it supports traffic until the next cycle;

• Out of Total Review – FRT: guarantees minimum safety conditions on the stretch until it is submitted to RT.

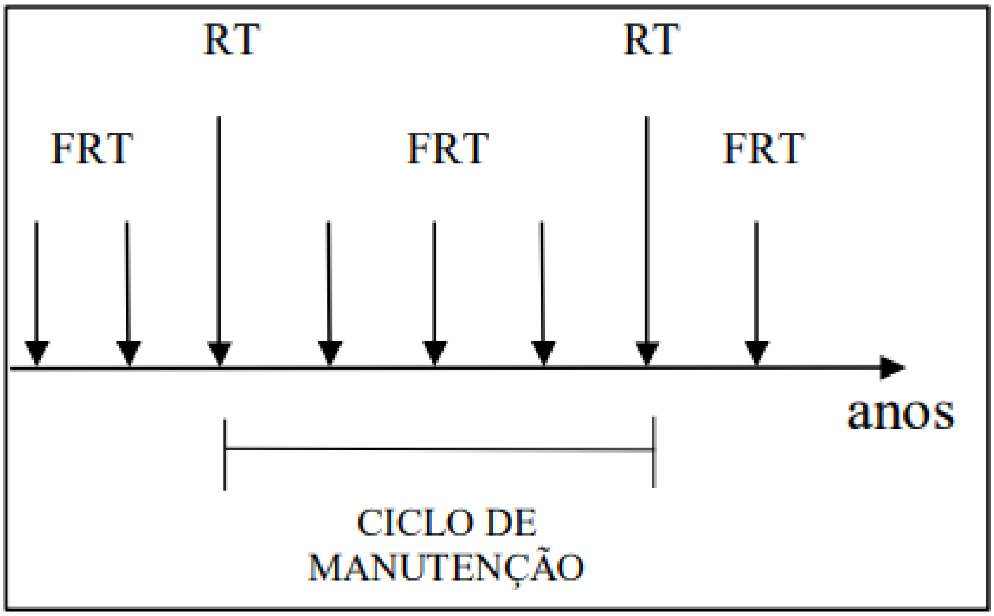

Figura 4 - Cycle Maintenance (Rodrigues, 2001)

Condition-based maintenance involves systematic monitoring of track geometry conditions to determine intervention priority. Maintenance is performed only when necessary. According to (Natani & Machado, 2008), predictive maintenance aims to make necessary adjustments at the ideal time before breakdown occurs. To this end, several activities are carried out to monitor the performance of the machine and equipment and understand the correct moment to intervene in the process to make the necessary corrections.

According to (Takahashi & Osada, 1993), predictive maintenance is a philosophy that aims to avoid early and excessive repairs, as well as unexpected failures that can occur when adopting preventive maintenance. The adoption of this maintenance strategy can lead to more optimized maintenance with better economic advantage.

(Ratton Neto, 1985) suggests that the permanent track maintenance policy is a strategy that seeks to balance the need to keep thetrack in good condition to ensure traffic safety and performance, with the need to keep maintenance costs within reasonable financial limits for the company.

The main objective of this policy is to determine the optimal time for interventions, so that, in the long run, maintenance expenses are minimized. This is because one of the main ways to save resources is to rationally distribute these processes over the useful life of a stretch (GULER, 2013).

The guidelines that establish a way to manage the timing and technical quality of maintenance make up the maintenance policy, as they represent the degradation management strategy. Figura 5 - LCC: Optimized Track System Strategy shows the behavior of track quality over time and the effect of maintenance on it.

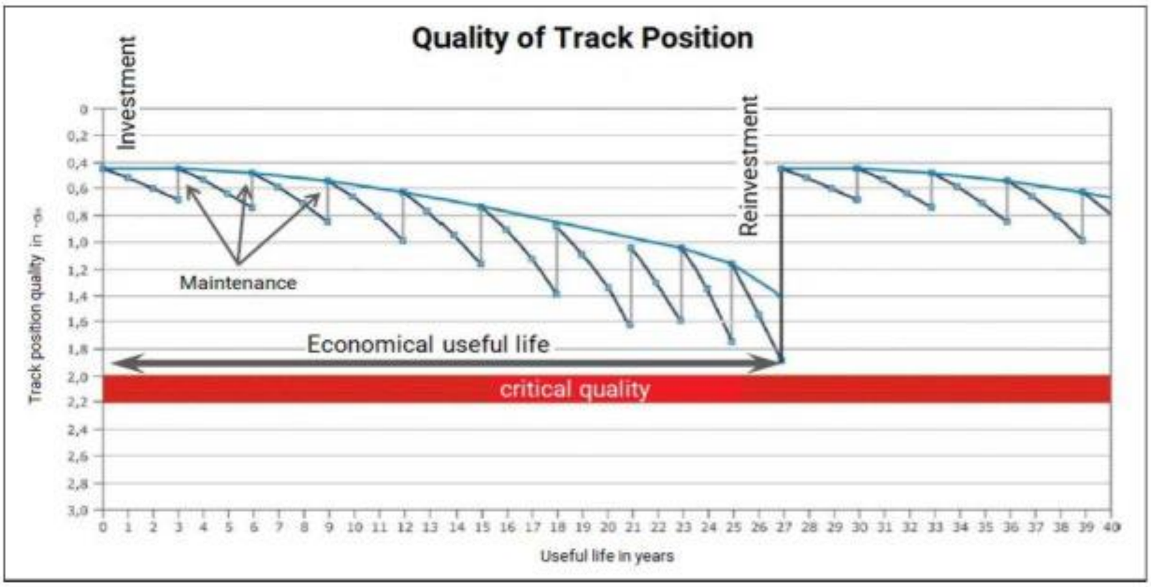

Figura 5 - LCC: Optimized Track System Strategy (Veit, 2016)

To make railways more sustainable and competitive in the logistics market, it is important to analyze the current condition of permanent track maintenance assets with a focus on the best definition of performance. We can define the strategy with the best Life Cycle Cost (LCC) for intervention models, such as geometric maintenance, renovation and remodeling of sections, to ensure the efficiency and quality of maintenance. However, after several maintenances, it may be necessary to recover the section and renew the line to achieve optimal levels of quality and reliability of the lines with the lowest possible maintenance cost (Veit, 2016).

2.2 Life cycle concepts

The management of the maintenance of the railway infrastructure has been undergoing changes in the face of increasing pressures in relation to the requirements of efficiency and effectiveness. Added to this, responsibility for parts of the railway system is often transferred to different actors. To ensure good long-term results, the effects of decisions must be systematically reassessed (Zoeteman, 1999). Putallaz (2003) cites three parameters that influence the performance of railway infrastructure: capacity, lifespan and quality. Infrastructure capacity refers to the measurement of the usage of the branches over a given period of time. Lifetime refers to the average remaining lifespan of your components. Finally, the quality of the infrastructure is determined by the quality of the geometry and components of the track.

Maintenance management is about setting these three parameters at the most appropriate level to maximize efficiency. Capacity can be adjusted through the investment policy, the lifetime of the infrastructure can be adjusted through the renovation policy, and quality can be adjusted through the maintenance policy. However, these three parameters cannot be adjusted independently. An old infrastructure (low lifespan) requires more maintenance to increase quality, while poor geometry (low quality) increases the wear and tear on the infrastructure. Similarly, more engineering works (maintenance and renewal) require more interventions on the roads (less capacity), while more traffic (high capacity) induces more wear and tear on the infrastructure.

According to (Ottoman, Nixon, & Lofgren, 1999), life cycle theory attempts to estimate future maintenance requirements by independently applying life cycle concepts to each system and component. This life cycle analysis provides an estimate of the frequencies required for preventive, corrective, or replacement maintenance. BOYSEN (2012) analyzed reliability curves related to the maintenance costs of high-density railways. Figura 6 - Costs x Assets Reliability shows the impacts on the costs of routine maintenance interventions and their postponement.

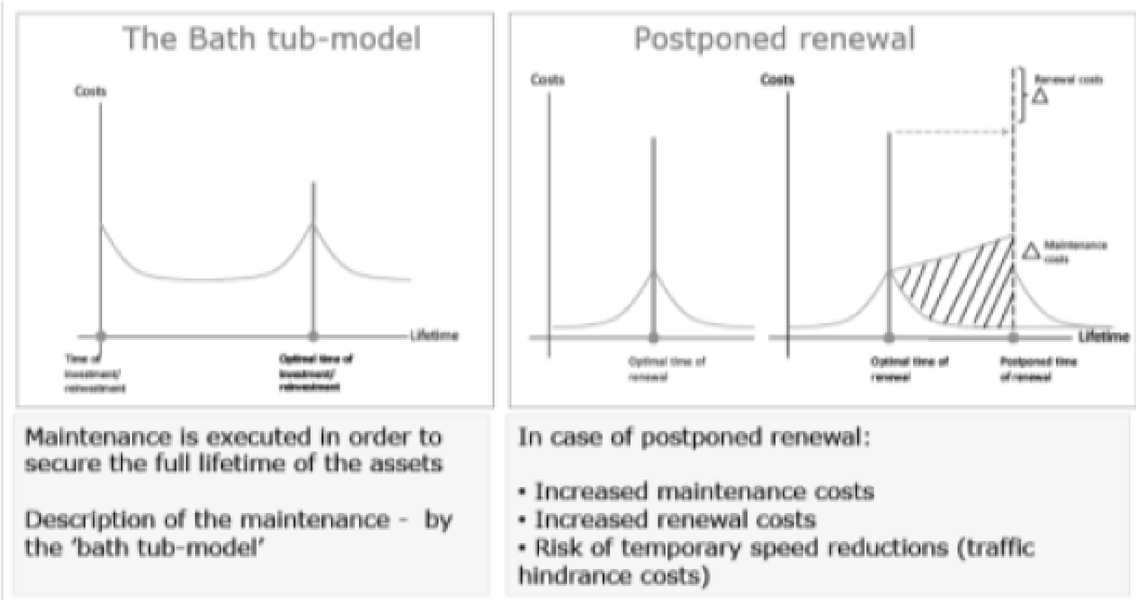

Figura 6 - Costs x Assets Reliability (Boysen, 2012)

Fonseca, Giffoni, & Gonzaga, (2020) mentions that currently, different choices regarding maintenance methods are adopted by companies based on a short- and long-term technical and financial vision. Below are some examples of freight railways in Brazil considered Heavy Haul:

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		

Figura 7 - Examples of Railways Maintenance (Fonseca, Giffoni, & Gonzaga, 2020)

Seraco (2019) comments that considering the Life Cycle Cost (LCC) of the permanent track, that is, the sum of all maintenance costs over the time that the components are installed on the line, it is important to systematically evaluate maintenance services. This is because, by assuming administrative standards with geometric corrections at a higher frequency, the time of use of the materials on the line will be longer, resulting in a high VCC due to the high number of geometric canning. On the other hand, as softer tolerances to geometric deviation are assumed, correction cycles become more spaced out and less numerous. This can anticipate the replacement of components to some extent, and as this process has a significant cost, the Life Cycle Cost (LCC) will be high even in this configuration.

When defining a maintenance policy that will determine the timing and volume of interventions, it is important to seek a balance between these two activities. This is necessary so that, in long-term planning, the Life Cycle Cost (LCC) of the track is as low as possible, even meeting the performance and safety prerogatives recommended by the railroad.

It is crucial for infrastructure managers to establish a systematic analysis that provides maintenance management in such an efficient way that it takes the maximum utilization of assets. This can be achieved by establishing the geometric maintenance frequency that provides the lowest total maintenance cost for the railway section (Seraco, 2019)

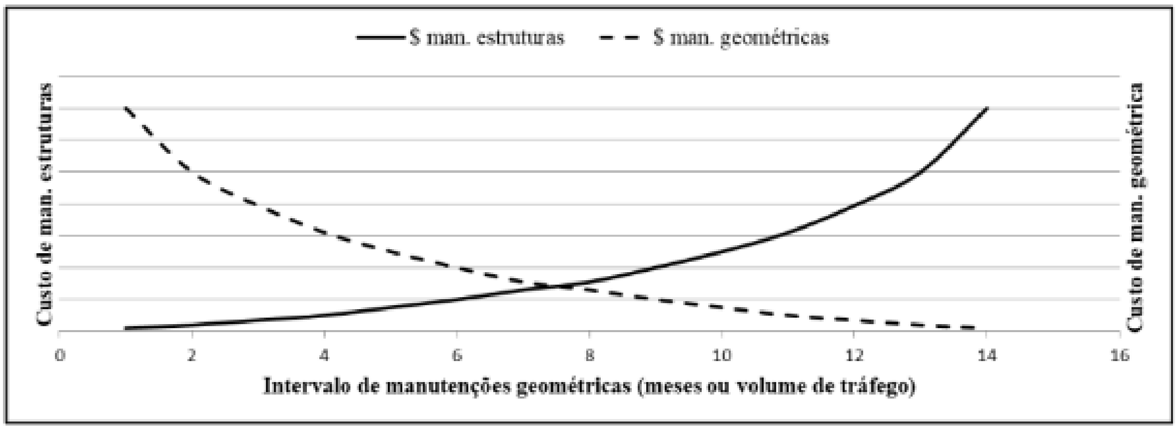

Figura 8 - Theoretical Costs of Structural and Geometrical Maintenance (Seraco, 2019)

According to (Fonseca, Giffoni, & Gonzaga, 2020) there are some methods to assist in the decision-making process about the balance between performance and costs throughout the life cycle of a product, such as: Life Cycle Costing (LCC) and

Reliability, Availability, Maintenance and Security (RAMS). Initial, maintenance, and operational costs are part of the costs. Performance, on the other hand, includes all revenues generated throughout the life cycle of the product or system.

Esveld (1989) points out that railroads have a long useful life and investments are very expensive, so companies must take into account long-term cost impacts in the decision-making process.

Figura 9 - Trade off Between Initial Cost and Operating Costs illustrates the trade-off between initial cost and operational cost. It is noted that as start-up costs increase (curve A), operating costs decrease (curve B). Total costs (curve c) are the sum of startup costs and operational costs. By theory, the ideal life cycle cost is at the lowest point of the c-curve.

Esveld (1989) also points out that it is necessary to project the future as accurately as possible, since the reliability of the trade-off assumption depends on the information provided. Another important note is that an increase in start-up costs to reduce operating costs is not always possible due to limited financial resources.

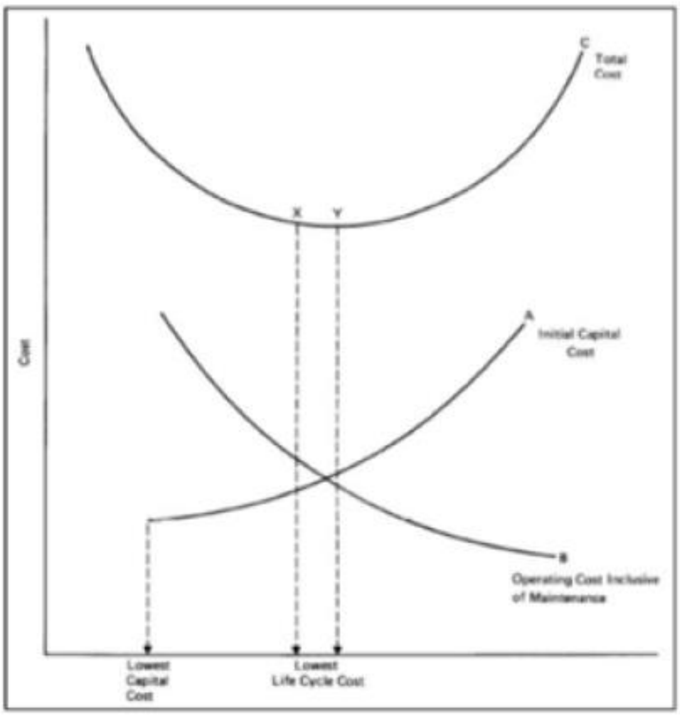

Figura 9 - Trade off Between Initial Cost and Operating Costs (Kardec & Nascif, 2009)

Therefore, it is interesting to use a methodology that allows you to compare alternatives to find the one that meets all the requirements with minimal total costs. Start-up costs, maintenance costs, and operating costs are calculated using the Net Present Value (NPV) method (= discounting future costs back to their corresponding present value). When evaluating different alternatives or strategies, the option with the highest net present value is the preferred alternative or strategy.

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

C0 = Initial cost of investment

Ct = Liquid box flow no period t

r = discount rate

t = time

3 Development

3.1 FCA Structure

The Ferrovia Centro Atlântica (FCA) has a railway network with an extension of 8,000 km of lines (most of them being metric gauge), 800 locomotives and more than 24 thousand wagons mobilized in operations. It was privatized in 1996 and currently passes through more than 250 municipalities, 10 states and the Federal District. Currently, the company VLI operates the railroad concession, in addition to other structures in the sector (VLI, 2024). FCA's current rail concession has a duration of 30 years, ending in 2026.

Due to this extension, FCA transports Brazil's wealth through routes that pass through the North, Northeast, Southeast and Midwest regions, enabling VLI to offer sustainable multimodal logistics solutions to its customers through a highly trained team connecting its ports, railways and terminals. It also has interchange points with the following railroads: Vitória Minas Railroad; MRS Logistics; Transnordestina Logística e Rumo. It also has interconnection with the following ports: Angra dos Reis-RJ; Aracaju-SE; Aratu-BA; and Salvador-BA (VLI, 2024).

To optimize logistics, FCA has some corridors for the transportation of goods, among them: the Center-Southeast, the Center-East, Minas-Bahia, Minas-Rio and Center-North.

This work is focused on one of the great railroad corridors for grain exports in Brazil: the Central Southeast Corridor, with its origin in the state of Goiás and the Federal District, passing through the triangle of Minas Gerais, and ending at the port of Santos (between Campinas and Santos FCA exchanges with other railroads). In this corridor, several types of products are transported, with phosphate, sulfur, bauxite, fuel, corn, soybeans and sugar being given greater prominence.

Figura 10 - FCA Map (VLI, 2024)

The corridor meets the assumptions of trafficked volumes, types of loads, rolling stock and structural conditions very different along its entire length, and it is subdivided into Planalto (Goiânia/Brasília to Uberaba) and Paulista (Uberaba to Santos).

For the growth plan of the Paulista corridor, supported by the projections of the Brazilian harvests, capital investments were made in the construction of two large agricultural terminals located in the cities of Uberaba (MG) and Guará (SP), in addition to investments in the Luís Antônio Mesquita port terminal (TIPLAM).

The railway operation in the Paulista corridor is characterized by export flows higher than imports, and the railway is composed of a single track (vel. Maximum of 60 km/h), crossing yards and a practical axle load capacity of 25 tonnes.

With the end of FCA's current concession approaching, VLI's Planning and Engineering teams have been conducting several studies in the search for more efficient solutions for the possible early renewal of this concession, complying with current regulations and obligations.

This case study, found in (Melo, et al., 2023) conducts a permanent track maintenance LCC study between a base scenario and the proposed scenario. In this work, the main components of the permanent track in both scenarios will be mentioned.

The stretch in question is the route between Uberaba-MG and Paulínia-SP, the main route of the Center-Southeast corridor, with greater volume and denser traffic. In this case, the base scenario refers to the achievement of the technical parameters of the ANTT Obligation Booklet (ANTT, 2023), a document that compiles the concessionaire's obligations during the period of a possible concession renewal (30 years), through maintenance with eucalyptus sleepers and the replacement of the rails in the face of their degradation over time. The second scenario, in turn, refers to the Permanent Track Renovation project, which will be described in detail in the following topics.

3.2 Base case scenario

In this scenario, corrective maintenance of various components is taken into account, without the implementation of the proposed renovation project or any other. This is a maintenance closer to the corrective and preventive maintenance scenario currently carried out on the route in question.

The base case scenario takes into account only the current investment cost line, since it is not a capital project, does not add capacity to the existing network, and is only the maintenance of the already existing assets.

The technical assumptions of the base scenario adopted were based on the achievement of the technical parameters of the ANTT Obligations Booklet (ANTT, 2023). The purpose of the Obligations Book is to define the Annual Monitoring Report (RAA), the Investment Plan, the Minimum Technical Specifications and the Complementary Obligations, which are mandatory to be complied with by the Concessionaire, with a view to ensuring the proper operation of the infrastructure and provision of the rail transport service, the preservation of the assets granted or leased, as well as the reduction and mitigation of social and environmental impacts.

The following are more details regarding the main maintenance items of the base scenario.

3.2.1 Maintenance of sleepers

The technical criterion used in this simulation, made using an algorithm developed in python language, was the criterion of compliance with the ANTT Obligation Booklet (ANTT, 2023), and the sleeper conservation rates allowed in this document are as shown in the table below.

Grupo de linha	Tipo de trilho	Carga por eixo (tf)	% Dormentes inservíveis admissível			
			Tang	R>=350	250<R<350	R<=250
1,2,3	TR 68	30	20%	20%	15%	10%
	UIC 60 / TR 57	30	10%	10%	5%	3%
Todos	UIC 60 / TR 57	25	12%	12%	7%	4%
Todos	TR 50 / TR 45	25	10%	10%	5%	3%
4,5,6	UIC 60 / TR 57	20	15%	15%	10%	5%
	TR 50 / TR 45	20	15%	15%	10%	5%
7,8,9	TR 50 / TR 45	20	25%	25%	20%	15%
	TR 37	20	25%	25%	20%	15%

Figura 11 - Acceptable Unserviceble Sleepers (ANTT, 2023)

It is important to note that ANTT, through the Obligation Booklet (ANTT, 2023), establishes different Line Groups based on the gross ton transported per day, as shown in the table below.

Grupo de linha	Limites (TBT/dia)
1	T > 120.000
2	120.000 > T > 70.000
3	70.000 > T > 40.000
4	40.000 > T > 25.000
5	25.000 > T > 12.500
6	12.500 > T > 6.000
7	6.000 > T > 3.000
8	3.000 > T > 1.500
9	T < 1.500

Figura 12 - Load Boundaries (ANTT, 2023)

Below is a summary of the annual sleeper quantities required to achieve these parameters. Naturally, these quantities will incur an annual maintenance cost, which will be taken into account during the LCC phase of this work.

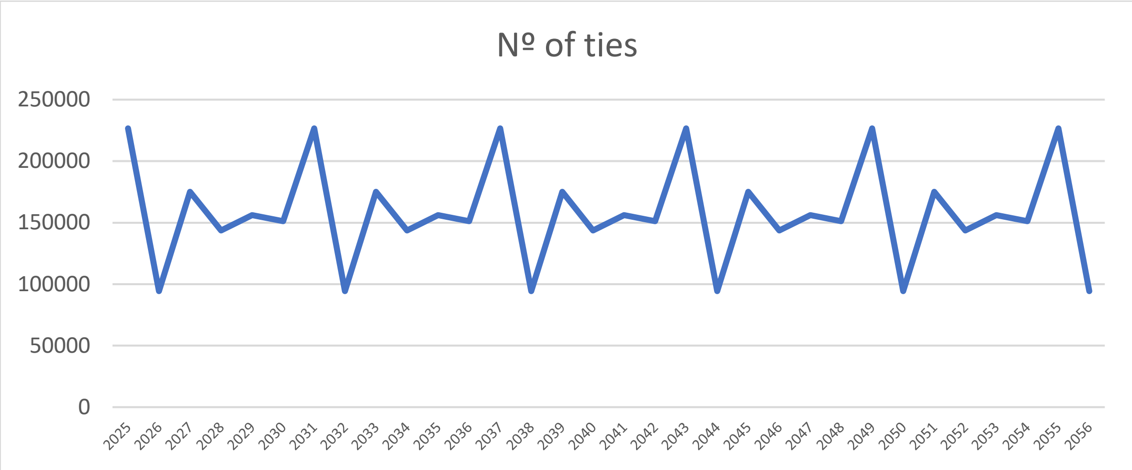

Figura 13 - Number of Ties during the life time (Melo, et al., 2023)

3.2.2 Rail Maintenance

When treating the rail component, a simulation similar to the previous one was performed to achieve the maintenance criterion established in the ANTT Obligation Booklet (ANTT, 2023) summarized in the table below.

Tabela 14: Parâmetros para desgaste horizontal e vertical dos Trilhos – Sem serviços de reperfilamento e esmerilhamento – Grupos 1 a 6

Trilho	Grupos de linha	Desgaste máximo lateral (mm)	Desgaste máximo vertical (mm)
TR 68	1 a 3	11	-
	4 a 6	13	-
	7 a 9	16	14
UIC 60	1 a 3	10	10
	4 a 6	12	10
	7 a 9	15	10
TR 57	1 a 3	10	10
	4 a 6	12	10
	7 a 9	15	10
TR 50	1 a 3	-	-
	4 a 6	10	6
	7 a 9	11	6
TR 45	1 a 3	-	-
	4 a 6	10	6
	7 a 9	11	6
TR 37	1 a 3	-	-
	4 a 6	10	5
	7 a 9	13	5

Figura 14 - Wasting Parameters for Rails (ANTT, 2023)

The quantities originated in the simulation, by rail profile, are as follows.

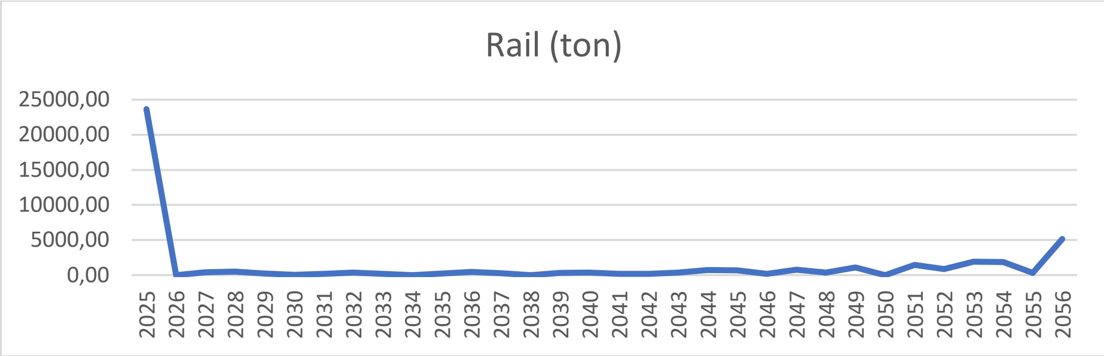

Figura 15 - Rail Tons (Melo, et al., 2023)

3.3 Proposed scenario

The proposed scenario is the total renovation of the permanent track and the replacement of all its superstructure components, the main ones being: sleepers, rails, fixings and railway ballast, within the concept mentioned by Isaias (2019).

To carry out this scenario, complete renovation of the permanent track, we created a maintenance method and called it "new *tie gang*". This method, which will not be explored in depth in this document, is the mechanized replacement of sleepers. For each service front, a sleeper replacement capacity of about 79,200 concrete sleepers per year and a length of 45.3 km of metre-gauge railway line are expected.

In addition to the replacement of all sleepers, the proposed permanent track renovation will replace all lower profile rail than the TR68 (136RE) for the TR68 profile.

You can see in the schematic below the sections that will be renewed, in orange, and the sections that have already been renewed at another time in green. The proposed extension to be renewed is about 351 km of railway line. The stretch is in a simple line with crossing yards in its extension.

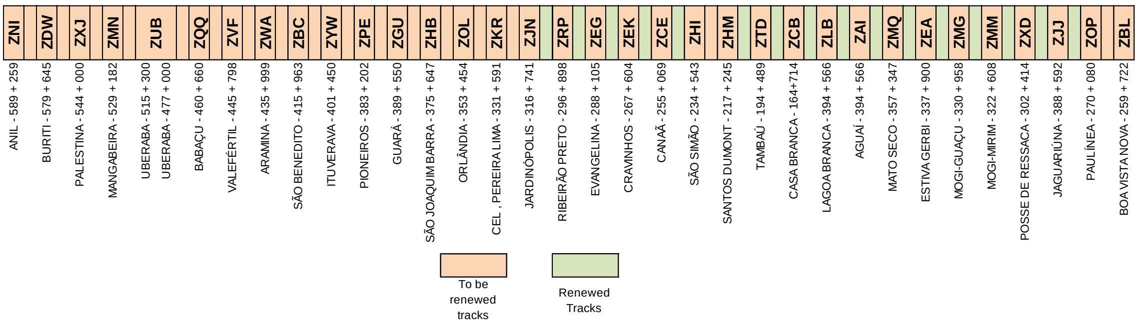

Figura 16 - Schematic of the excerpt (Melo, et al., 2023)

Below is the stipulated amount, in kilometers, of total permanent track renovation over the years and turnouts, respectively.

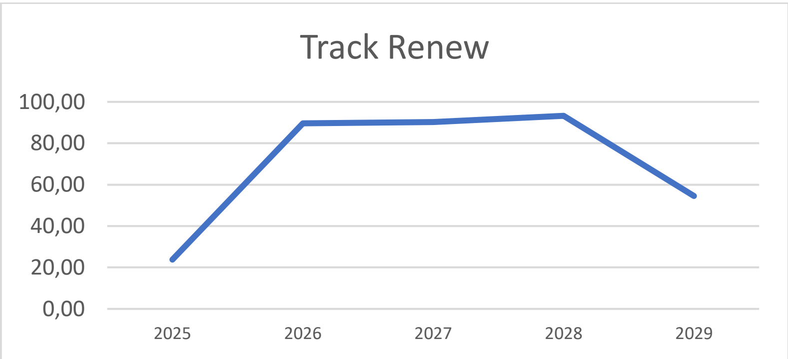

Figura 17 - Track Renew (Melo, et al., 2023)

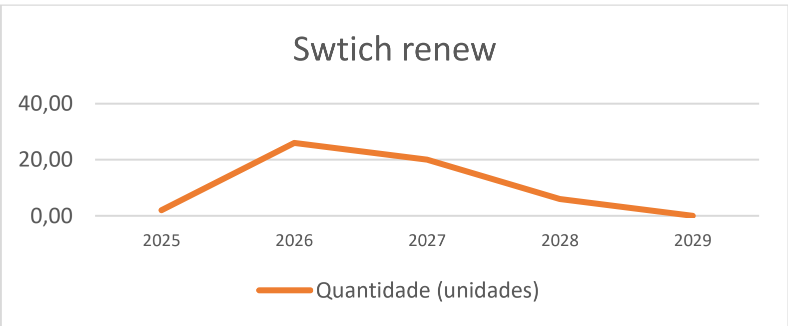

Figura 18 - Switch Renew (Melo, et al., 2023)

In addition to Track and Turnout Renewal, the scope of this improvement project also includes the following items, which will be detailed in the following topic:

• Annual rail grinding to increase the service life of new TR-68 rails;

• Implementation of the Continuous Welded Rail (CWR), to eliminate metal joints, in order to preserve the super and infrastructure components;

• Replacement of end-of-life concrete sleepers with new concrete sleepers;

• Periodic renewal of fixings to preserve the useful life of concrete sleepers;

• Maintenance and execution of infrastructure works to re-establish drainage systems and platform support capacity;

• Acquisition of a set of machines to carry out, maintain and clean contaminated and end-of-life ballast to restore its draining and elastic properties, contributing to the preservation of super and infrastructure components;

• Acquisition of a set of geometric correction machines to perform cyclic geometry maintenance on the stretch and a turnout tamping machine.

3.3.1 Complete Replacement of Sleepers

All sleepers, which are currently made of eucalyptus or concrete already at the end of their useful life, will be replaced, in sequence, during the execution of the complete renovation of the permanent track. The timing of this replacement is identical to that of the renovation shown in Figura 13 - Number of Ties during the life time.

3.3.2 Complete Rail Replacement

All rails, mostly TR50 (100RE), will be replaced by TR68 (136RE), in sequence and after the replacement of the sleepers. The timing of this replacement is identical to that of the renovation shown in Figura 14 - Wasting Parameters for Rails Figura 14 - Wasting Parameters for Rails .

3.3.3 Geometric correction of turnouts

The premise of this scenario is the acquisition of a geometric correction machine for turnouts. These geometric correction cycles will take place on each AMV of the main route every two years. This concept of geometric correction fits into the concept of preventive maintenance exposed by (Kardec & Nascif, 2009).

The CAPEX and OPEX costs of the equipment for this geometric correction will be added in this scenario.

3.3.4 Ballast Maintenance and Cleaning

The route in question has a large maintenance backlog in relation to the railway ballast component, and its entire length can be considered as a ballast maintenance backlog.

To address this backlog, the scope of the project includes a total ballast stripping machine. This service will not necessarily be carried out in the same places as the renovation, since other points, already renovated previously, also need this maintenance. A prioritization study for this service should be conducted.

The CAPEX and OPEX costs of the ballast maintenance equipment, in addition to the geometric correction machines that accompany this service, will be added in this scenario.

After the corrective maintenance of the ballast in this section, the preventive maintenance of this ballast will be carried out. Fitting into the concept of preventive maintenance exposed by (Kardec & Nascif, 2009). But first, the total review mentioned by the authors should be done.

3.3.5 Cyclic maintenance of fasteners

It was taken as a premise in this project that every 7 years, complete maintenance of the set of fixings of the sleepers will be done due to loss of the necessary physical properties, such as clamps and insoles. There is an opportunity here to save future in new LCC studies.

The required quantities of fixtures to be replaced follow below.

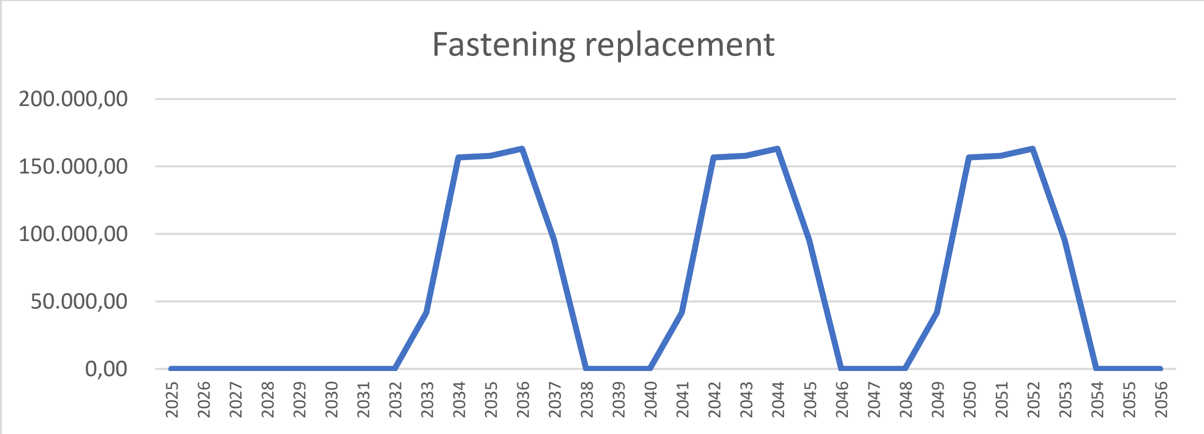

Figura 19 - Fastening Replacement (Melo, et al., 2023)

4. Financial Analysis

After defining the technical assumptions to be used in maintenance over the 30 years under study, a study was carried out to analyze the financial feasibility of the project, using a standard valuation method for capital projects, defined by VLI's Capital Allocation area.

The inputs for the VLI standard valuation are: capital investment, current investment, fixed and variable costs, and revenues and gains. In addition, of course, the costs involved in maintenance in both scenarios are necessary in this study.

It is important to note that in the base scenario, in this case study, we only have costs related to current investment. In the proposed scenario, we have all the inputs mentioned above.

The table below summarizes all the inputs and how they were classified in both scenarios:

	Investimento corrente	**Investimento de Capital**	**Custos fixos e variáveis**	**Receitas**	**Ganhos**
Base Scenario	Maintenance of Sleepers	-	-	-	-

	Rail maintenance	-	-	-	-
	Other maintenance	-	-	-	-
	Maintenance of Sleepers	Track Renewal	Degarrison Operation Team	Alternative revenue from the sale of scrap rails	Reduction of current investment
	Rail maintenance	Switch Points Renewal	Geometric Correction Operation Team	-	Divestment of rolling stock
Proposed Scenario	Fastenings maintenance	Acquisition of Ballast Degarrison	Degarrison Operation Expenses	-	Reduction of fuel consumption
	Other Maintenance	Welded Continuous Rail Deployment	Operating Expenses Geometric Correction	-	-
	-	Acquisition of geometric correction machines	-	-	-

Figura 20 – Scenaries

4.1 Revenues and earnings

The scenario proposed in this case study would imply operational improvements in the section in question due to the total replacement of superstructure components with more robust components, such as replacement of TR50 profile rails at the end of their useful life by new, more robust TR68, as well as replacement of wooden (eucalyptus) or concrete sleepers at the end of their useful life by new monobloc concrete sleepers. with greater bearing capacity.

In addition, the proposed scenario brings improvements in processes that currently occur manually in this section: unguarding and geometric correction of turnouts.

This whole scenario of more robust maintenance incurs operational gains such as: removal of speed restrictions that causes a reduction in transit time, reduction of the wagon cycle , disinvestment in rolling stock, reduction of future current investment, greater energy efficiency and alternative revenue from rails. The VLI Engineering areas, through this study, reached the gains that follow below.

4.1.1 Alternative Recipe

The alternative revenue from the replacement of TR50 and lower profile rails to the TR68 profile during the renovation years.

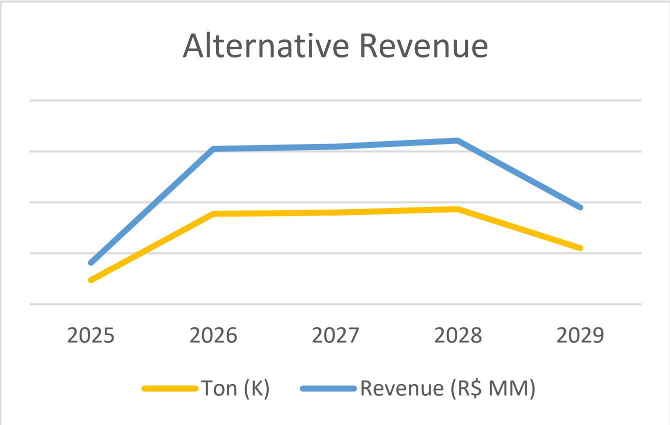

Figura 21 - Alternative Revenue

4.1.2 Transit time and energy efficiency

Due to the removal of restrictions mentioned above, there is a reduction in transit time on the Center-Southeast Paulista route. Below, we have the accumulated reduction during the years of implementation of the proposed scenario.

Reduction/Year	2025	2026	2027	2028	2029	2030
Cumulative Reduction of *Transit Time* (h)	-	0,40	1,10	1,40	1,50	1,54

Figura 22 - Transit Time Reduction (Melo, et al., 2023)

Based on the reduction of transit time and other variables, the VLI Operations Engineering area calculated the reduction in fuel consumption, which in turn reduces expenses with this input. Below is a table with the data of this accumulated savings throughout the project. From 2030 onwards, this saving is continuous.

Reduction/Year	2025	2026	2027	2028	2029	2030
Cumulative Reduction of Fuel (R$ MM)	-	2,28	24,18	37,41	37,70	37,94

Figura 23 - Fuel Reduction (Melo, et al., 2023)

4.1.3 Wagon Cycle and Rolling Stock Divestment

Also based on the reduction of transit time from the removal of speed restrictions, it was possible to estimate the accumulated reduction in the wagon cycle of this route, and from there the disinvestment in rolling stock.

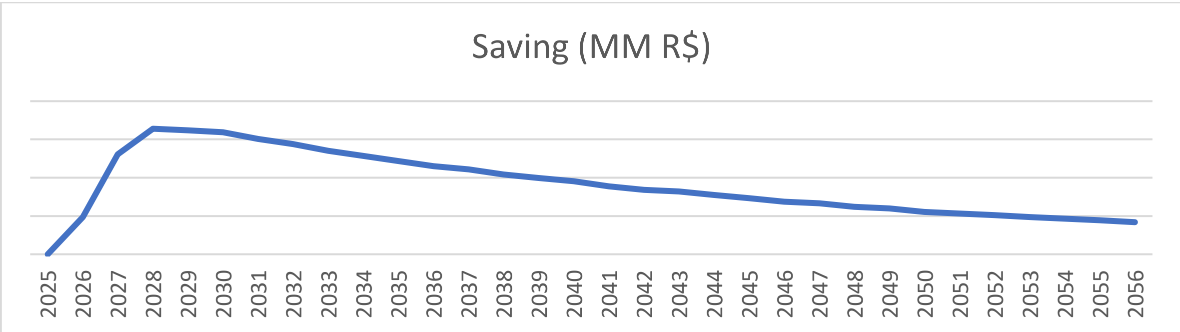

Figura 24 - MM Savings (Melo, et al., 2023)

4.1.4 Reduction in current investment

Since this case study proposes a capital project to renovate the permanent track, it is natural that the future current investment of the proposed scenario will be lower than the future current investment of the base scenario. This incurs future savings with ongoing maintenance investment. In this way, this savings were calculated as current investment from the base scenario subtracted from the current investment of the proposed scenario.

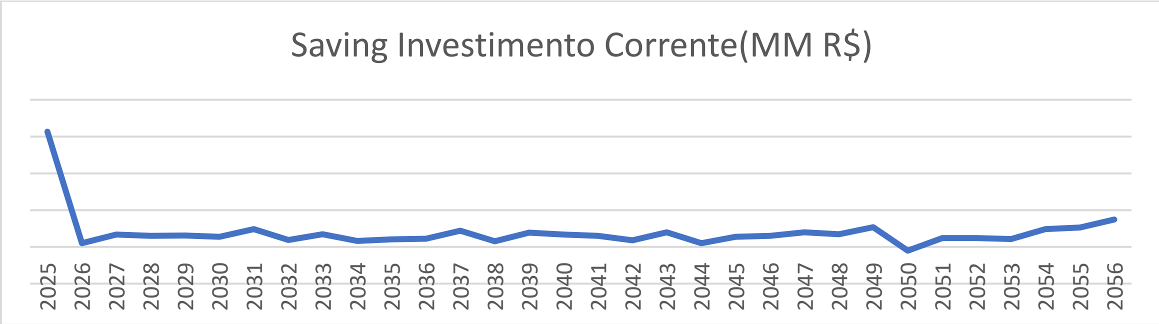

Figura 25 - Saving of Currency Investments (Melo, et al., 2023)

4.2 Cash Flow and Present Value

In order to compare the financial feasibility of the proposed scenario against the base scenario, it is necessary to prepare the cash flow and later this multi-year cash flow result is brought to present value.

In VLI, as mentioned earlier, the standard valuation spreadsheet for capital projects is used, defined by VLI's Capital Allocation area.

The inputs required for the preparation of the future cash flow over the period studied (2025 to 2056) are:

- Revenues: alternative revenue and energy efficiency savings;

- Current investment of the proposed scenario;

- Difference between the current investments of both scenarios

- Capital investment (track renovation and acquisition of large machines)

- Divestment (savings) of rolling stock.

Below, you can see the distribution, over the years, of the project's investments, gains and revenues.

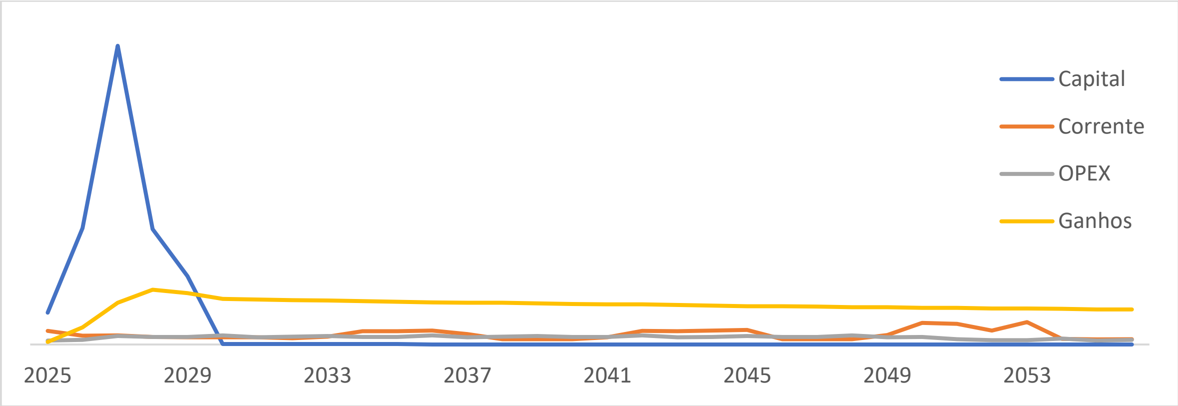

Figura 26 - Overall Savings and Earnings (Melo, et al., 2023)

After the input of these data in the standard valuation spreadsheet, the cash flow below was obtained.

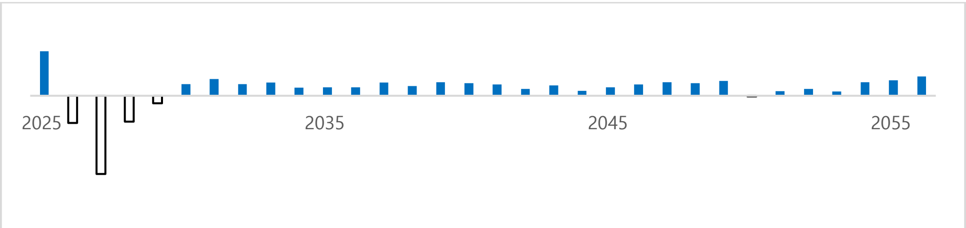

Figura 27 - Cash Flow (Melo, et al., 2023)

It can be noted that during the implementation phase of the project, more precisely between the years 2026 and 2029, the cash flow is negative, and only then from then on the gains added to the savings make the project's cash flow positive.

After the cash flow was prepared, the net present value of this project was calculated based on the WACC rate defined by VLI's Capital Allocation area. For strategic reasons, the rate of return used and the respective net present value found will not be disclosed. In addition, the payback in years and the internal rate of return for both rates were also found, as can be seen.

WACC (%)	[redacted]
VPL (R$ MM)	[redacted]
Payback Descontado (Anos)	**5,71**
TIR (%)	**22,7%**

Figura 28 - Financial Indicators (Melo, et al., 2023)

Above is the internal rate of return of the project stipulated at 22.7% and a discounted payback of just under 6 years. Which makes the project interesting from a financial point of view.

5. Risk Analisys

Risk analysis is a process of assessing and identifying potential risks associated with a particular activity, project, or decision. The goal of risk analysis is to understand the uncertainties and potential negative impacts that may affect the achievement of objectives. It involves a systematic examination of potential risks, their likelihood, and their potential consequences. Here are key components of risk analysis:

Risk identification:

Identify and catalog potential risks that could impact the project or activity. This involves considering internal and external factors that may pose threats or opportunities.

Risk Assessment:

Assess the likelihood and impact of identified risks. This step involves assigning a probability and severity rating to each risk, helping prioritize them based on their potential impact.

Risk Quantification:

Quantify the potential financial, schedule, or other impacts associated with each identified risk. This step allows for a more thorough understanding of the potential consequences.

Risk Mitigation:

Develop strategies to manage and mitigate identified risks. This may involve implementing preventive measures to reduce the likelihood of a risk occurring or contingency plans to address the consequences if a risk materializes.

Risk Monitoring:

Continuously monitor and reassess risks throughout the duration of the project or activity. New risks may emerge, and the severity or likelihood of existing risks may change, requiring ongoing attention.

Risk Communication:

Effectively communicate identified risks, their potential impacts, and mitigation strategies to stakeholders. Transparent communication is crucial for informed decision-making and managing expectations.

Risk Reporting:

Regularly report on the status of identified risks, including any changes in their likelihood or impact. This allows stakeholders to stay informed and enables timely decision-making.

Risk Response Planning:

Develop response plans for potential risks, specifying actions to be taken if certain risks materialize. This ensures a proactive approach to risk management.

In our work we decided use the HAZOP methodology for the Risk Assessment and Risk identification. According to IEC 61882, Hazard and Operability (HAZOP) "is a structured and systematic technique for examining a defined system, with the objective of: identifying potential hazards in the system or process; identifying potential operability problems with the system and in particular identifying causes of operational disturbances and production deviations likely to lead to nonconforming products."

Based on these questions, all possible scenarios that may represent some risk to the project, as well as their causes, consequences, and treatments, are analyzed. The application of HAZOP for the present study can be evaluated in the table below:

Hazard and Operability (HAZOP) analysis					
Life Cycle Simulation and Comparation Between Corrective Maintenance and Track Renew					
PROCESS	**GUIDE TERMS**	**DEVIATION**	**POSSIBLE CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**
Project Management	More than	Lack of clarity in scopes	Larger budget than originally planned	Delay in project delivery	Perform appoval at the factory-design review Assess the suplier's capacity Schedule of use equipment within the project Hire consultancy for import support Perform benchmarking with railway operator Define/Predict fines for supplier liability delays
	Not Done	Lack of support areas engagement	Delay in Deliveries		
			Reworking scoping		
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	Volalility of railway labor	Delay in project delivery	Hold meetings with the suppliers Bid with trusted suppliers
Order for maintenance	Less Than	Atributtes to execute the prioritize service	Idle teams	Delay in project delivery	Specialists monitoring routine and audits Hold meetings with the teams Backup plans
	Not Done	Delay in execute orders/service	Larger budget than originally planned		
		loss timing and resources	Larger budget than originally planned		
Track Materials	Not Done	Unavailability of materials	Supplier Backruptcy	Delay/Cancelation of part of the project delivery	Define substitute suppliers Request the delivery of materials with planned antecipation Perform a technical visit to the supplier
	More than	Costs above the expected	Exclusive suppliers	Dependence of only a few suppliers on strategic items	Define share of suppliers Develop alternative suppliers
	Later than	Delay in delivered of materials	Failure by the supplier to meet the deadline	Delay in project delivery	Define substitute suppliers Request the delivery of materials with planned antecipation Perform a technical visit to the supplier
	Misordered	Materials delivered out of specifications	Supplier non-compliance with specifications	Delay in project delivery	Define substitute suppliers Request the delivery of materials with planned antecipation 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	Perform alignments and scenario studies with the planning area Define asset and resource buffer to support variations
				Lack of drivers for service trains	
	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
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 thestart of the project	Conduct prior consultations with enviromental agencies
			Lack of manpower for execution and/ or materials		Define medium-term planning with the supply area
Track Machine	Not Done	Equipment not delivered	Supplier bankruptcy	Delay in project delivery	Perform benchmarking with railway operators Asses the suplier's capacity Hire consultancy for import support
	Later than	Delay in delivery of equipment	Problem with the capacity and/or order placement deadline		
	Misordered	Import issues	Wrong or incomplete documentation		

Figura 29 - HAZOP Table

6. Project Planning

Once the feasibility phase was concluded, the next step in VLI´s, and probably in any major railroad operator, would be getting the approval needed from the company´s board and shareholders council. This high-level approval is needed when the project or initiative you are doing need an expressive amount of capital.

A project implementation plan is the bases for any future actions, including capital allocation, procurement planning, execution planning, human resources planning, and in this case even in traffic interruptions that will be needed in case of project approval and execution. So, the operational routine in the route the project is focused will be changed.

Below, we can see the project´s most relevant scope implementation through time:

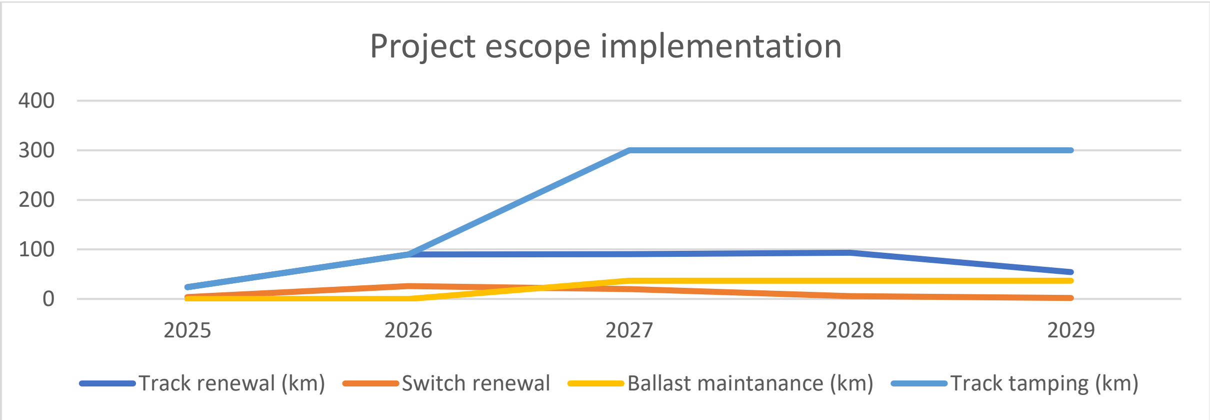

Figura 30 - Escope Implementation (Melo, et al., 2023)

We can observe that even before the acquisition of new tamping machines, this process must be done using the ones VLI already have because is mandatory to track quality and scope execution.

In addition to the scope planning, financial planning is crucial for the success of the project. In the graph below we can see the capital and current investments, OPEX and earnings related to the project implementation. Any delay in the implementation phase could change the expectations shown in the graph.

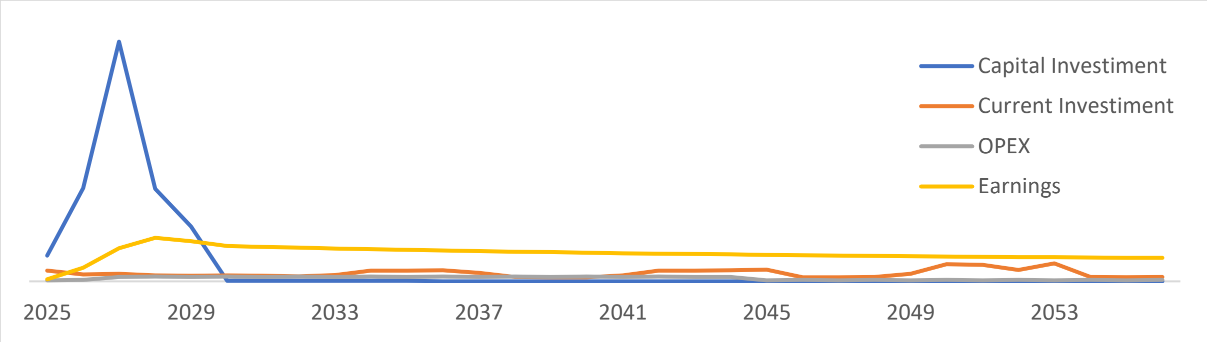

Figura 31 - Cash Flow Over time (Melo, et al., 2023)

7. Conclusions

The proposed scenario proved to be financially feasible and could, if the company chooses to adopt this strategy, since there are others, make the VLI company more efficient during the concession period, both operationally and financially.

Naturally, the need for capital investment accentuated at the beginning of the proposed scenario must be taken into account in order to keep the company's cash flow healthy.

From an operational and risk point of view, after implementing the project and capturing gains in track reliability, there will be a general gain in capacity for the transport system, enabling the elimination of future investments in wagons, i.e., with operational cycles are expected to be reduced (or more efficient), a smaller number of assets (rolling stock) will be needed to transport the demand predicted in the company's business plan.

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8. Attachments