Group 4 FÁBIO BENEVENUTO DE LIMA

INCREASE BALLAST MAINTENANCE CAPACITY – TRACK RENEWAL AT VITORIA-MINAS RAILWAY

FINAL PROJECT

RAIL TRANSPORTATION MANAGEMENT

Vitoria, march de 2019

SUMMARY

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ABSTRACT

Brazilian railroad transportation has been targeted for public and private investments in the last three decades, as an effort to decrease freight costs and make the national transport system more effective and sustainable. This scenario indicates the necessity for improvement on railway maintenance services performance, to reduce losses on transport capacity caused by possession times. Among all maintenance activities, track renewal is one of the most critical processes due to the magnitude of its duration and the great amount of resources allocated. Thus, this research aims to analyze the track renewal process by identifying critical tasks and resources bottlenecks that must be treated to increase maintenance capacity. This study also presents the cost effectiveness analysis of the proposed solutions for increasing track renewal performance.

1 BRIEF DESCRIPTION

The railroad in Brazil has been experiencing a revitalization process, initiated in 1996 with the privatization of railways, and intensified since 2012, with the launch of the National Logistics and Transport Plan.

Prepared by the Ministry of Transport, this is the consensus model for the maintenance of the new global sustainability model, since it represents a redistribution of the national transport matrix to enable the reduction of operating costs by emissions of pollutants.

Figure 1.1 shows a dimension of the impact that the alteration of the tax matrix can bring in terms of cost and emission of pollutants, comparing the resources needed for each mode (transportation and road) to transport the same load.

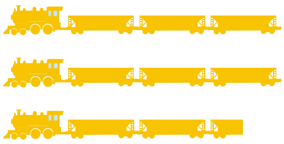
MODAIS	FERRO	RODO
Capacidade de Carga	2,9 Comboios Hopper (86 vagões de 70 t) 	172 Carretas de 35 t Bi-trem Graneleiras 

Figure 1 – Comparative Rail x Road

Source: Brazilian Ministry of Transport

In this context, it was estimated that the increase in the participation of the rail modal would occur not only through the construction of new lines, but also through the reactivation and improvement in the existing network. In the case of EFVM, the third situation occurred, which in the short term reflected in a greater demand for services of permanent way maintenance.

Therefore, the demand for maintenance increased during these years to support the increase of volume, but in contrast our capacity of maintenance remained at the same level, generating a maintenance backlog.

On the other hand, it is also known that the interdiction of a railroad for maintenance can significantly compromise its transport capacity, either by temporary interruption of the circulation in the single lines or by the creation of crossing points of trains in the double lines. Obviously, the lower the number of maintenance and the faster the maintenance, the better the operational performance of the railroad.

Regarding the Vitória-Minas Railroad, this agility in the execution of maintenance is even more necessary, given the volume transported annually and the high demand for maintenance that, besides being generated by the intense traffic, is also influenced by:

- ✓ Geographic location of the EFVM, resulting in a predominantly curved track, where there is a greater wear of rails and where a more stable line is required (greater demand for geometric correction, sleepers and ballast in good conditions);
- ✓ Predominance of iron ore transport, reflecting in greater possibility of ballast contamination by deposition of fines on the railroad;
- ✓ Incidence of a regular rainy period of approximately four months, which may aggravate defects that are not critical in dry climates (lacquered, "rubbery" and others).

Thus, there is a scenario that is very favorable to the analysis of the capacity of maintenance services in EFVM. Considering the scope of permanent way maintenance, one of the services that stand out is the Renewal of the Track, given to:

- ✓ Influence that the ballast condition exerts on the stability of the track and the useful life of the other track components (sleepers, rails and fixings, base);
- ✓ Mobilization of large equipment to carry out activities;
- ✓ Criticality of the process, in terms of the availability of critical equipment (Ballast Cleaning Machine, Unloading Modules and Tamping Machine) and continuous track interdiction time.
- ✓ High demand projection for this service.

However, is it well known that within the process of Track Renewal, the bottleneck is the process of Ballast Cleaning, since for the parallel, predecessor and successor stages they have sufficient resources to accompany the renewal plan.

In view of the above, this paper aims to analyze the Ballast Renewal Process and, based on this evaluation, propose economically viable alternatives to increase the capacity to maintain this type of service and consequently decrease maintenance backlog.

1.1 Formulation Of The Problem

Considering the need to analyze the Ballast Renewal Process and propose alternatives to increase the maintenance capacity, the following questions can be answered:

1. What bottlenecks prevent increased maintenance capacity?
    a. low reliability of the equipment?
    b. low productivity of the equipment?
    c. there are logistical wastes?

2. Will the actions that are proposed, if implemented, also be feasible from an economic-financial point of view?

1.2 Justicications

In a broader scenario, this work is justified by the need to reduce maintenance backlog in order to guarantee the reliability and operational safety of the track, within a strategy that maximizes the life of the permanent track assets and reduces their costs.

In this context, the analysis of the railway renewal process and the determination of strategies that increase its capacity become essential.

It should also be considered that the renewed track recovers its elasticity and draining and geometric capacity, eliminating, among other losses:

- ✓ Consumption of steel sleepers to replace those that suffered excessive deformation and / or breakage due to the hardness of the ballast;
- ✓ Consumption of crushed stone required to recover the ballast geometry, considering the unevenness caused by the effect of the collated ballast on the road subgrade;
- ✓ Consumption of gravel necessary to recover the drainage function of the ballast, preventing signaling failures that occur whenever there is accumulation of water on the railroad bed.

1.3 OBJECTIVES

1.3.1 General Objective

Analyze the Ballast Renewal Process Capacity on the Vitória Minas.

1.3.2 Specific Objective

- Characterize the current process for Ballast Renewal, identifying opportunities for improvement;
- Propose solutions to the operational bottlenecks in the process, verifying the possible gains in terms of reduction of interdiction times, allowing an increase in the maintenance capacity;
- Verify the economic viability of the proposed solutions, in terms of Net Present Value, based on the value of the Stopped Time Train (STT) used as reference.

2 PRELIMINARY REMARKS

2.1 THE VITÓRIA MINAS RAILWAY

In February of 1902, the Federal Government granted by means of decree-law the creation of Vitória-Minas Railway. The dreamed railway connection between the interior of Minas Gerais and the Port of Vitória had its origins in the second half of the nineteenth century (SETTI, 2008).

Thus, with the initial project of linking Vitória (ES) to Diamantina (MG), the first stretch was inaugurated on May 13, 1904, containing 30 kilometers and counting on three stations: Porto Velho, Cariacica and Alfredo Maia. But with the announcement of large ore deposits in Minas Gerais in 1908, the final route of the railroad to the city of Itabira, where the mineral would be exploited, changed (SETTI, 2008).

The political questions about the exploration and export of the ore, the installation of a steel industry and the international scenario of the world wars (1914-1919, 1939-1945), made the process of expansion and modernization of Vitória a Minas difficult. The first shipment of ore in the port of Vitória occurred only in 1940 and the rails only arrived in Itabira in 1942 (SETTI, 2008).

The Vitoria-Minas Railway gained momentum after 1942, the year of the creation of Vale, then Companhia Vale do Rio Doce. Located in the Southeast region, EFVM connects with other railways integrating the states of Minas Gerais, Goiás, Espírito Santo, Mato Grosso, Mato Grosso do Sul, Tocantins and the Federal District, as well as having privileged access to the main ports of Espírito Santo, among them Tubarão and Praia Mole.

EFVM has 905 kilometers of track extension and 2,141 kilometers of total track, with 594 kilometers in double track (Figure 2).

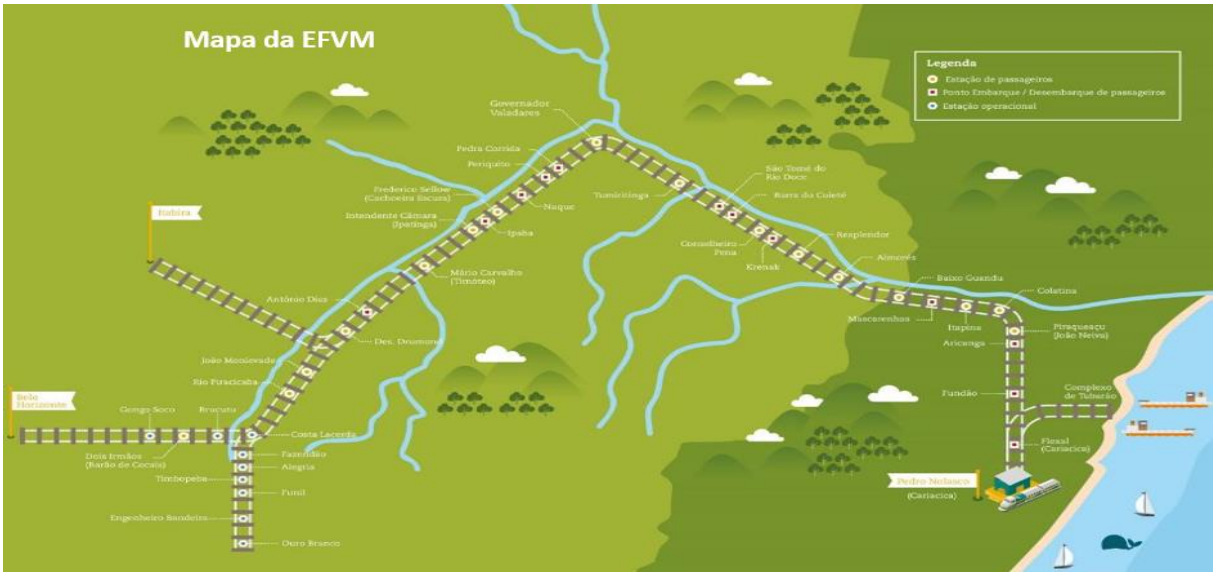


Figure 2 – Schematic Map EFVM

It currently carries about 140 million tons/year, of which 85% is iron ore and 15% correspond to more than 60 different types of products, such as steel, coal, limestone, granite, containers, pig iron, agricultural products, wood, pulp, vehicles and various loads.

The OCC (Operational Control Center), located in its head office in Tubarão (ES), controls all operations of the railroad.

Daily, a passenger train circulates in each direction between Vitória and Belo Horizonte / Itabira, carrying about 1 million people annually.

2.2 CRITICAL REVIEW

This topic presents the current methodology for track renewal planning. From this trend, the productivity of the main work front that make up the track renewal will be analyzed - ballast cleaning.

2.2.1 Current Planning Model for Track Renewal

The model for the renewal of the track considers as the main trigger the cycle of ballast cleaning, that varies between 12 and 14 years, associated with it as a way to take advantage of the interdiction times of the track, the replacement of sleepers. This process consists of 04 main steps, as we can see in the diagram below, figure 3:

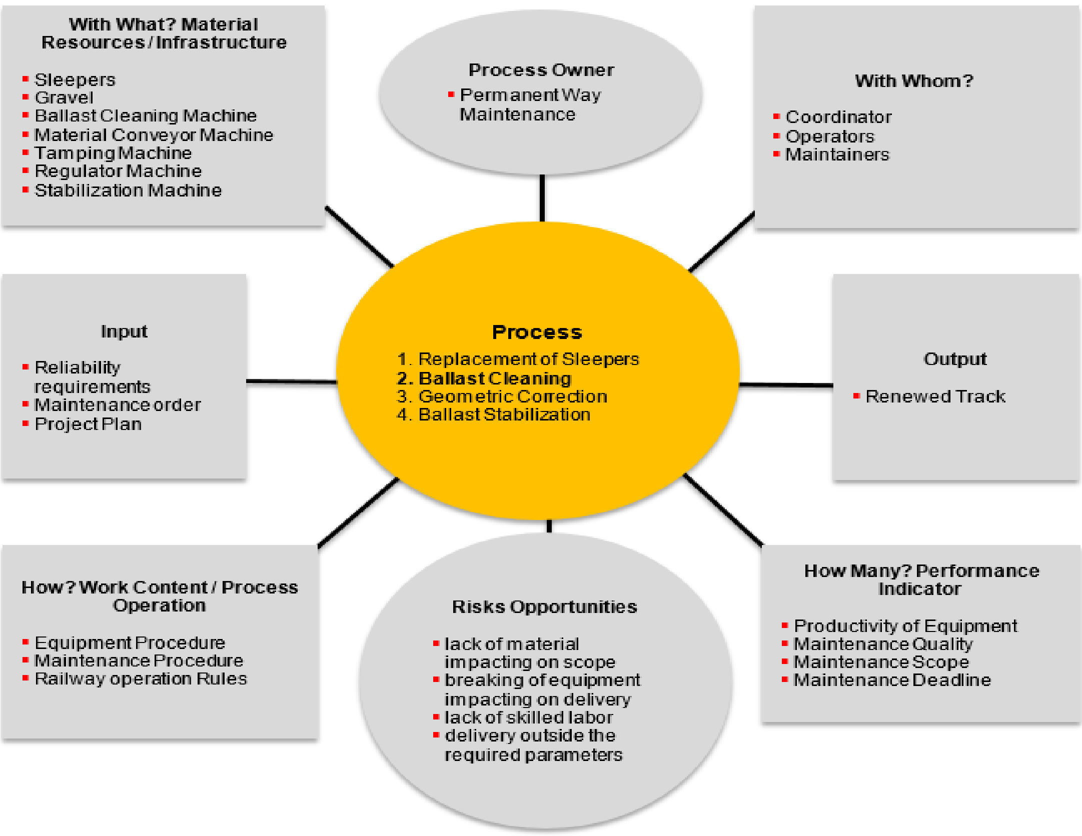


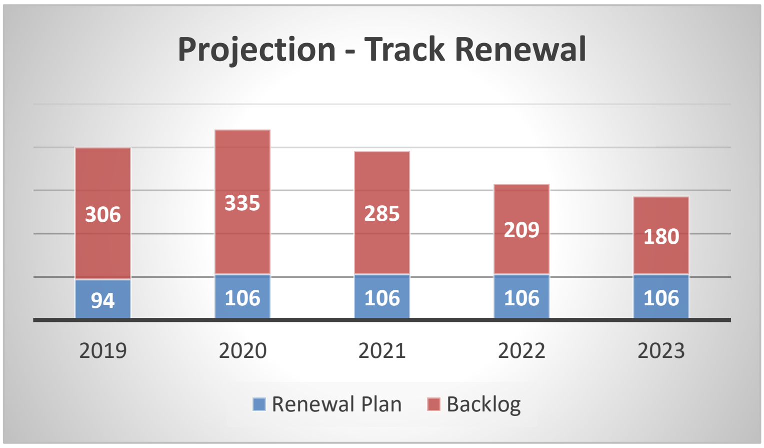
Figure 3 – Turtle Diagram

Thus, the Track Renewal runtime results from a combination of executive sequences, which vary according to:

- Situation of the location (accesses, existence of waste deposit, existence of tunnels, bridges, viaducts, existence of level passages, etc.);
- Rate of rotten / broken sleepers;
- Productivity of service fronts (replacement of sleepers, ballast cleaning and geometric correction).

Based on the above, it is observed that, in the current model, the renewal of the line essentially involves the maintenance of sleepers and ballast, and its execution period is directly influenced by the conditions of the stretch and the productivity of the service fronts that during the interdiction of the line.

According to Maintenance Planning Strategy, the current demand for ballast cleaning follows the graph 1:



Graph 1 – Projection for Track Renewal

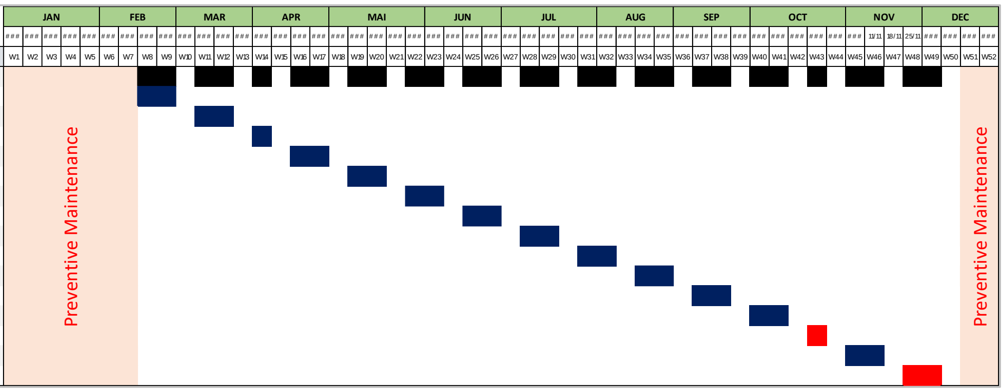
* Fonte PDMF 2019

Table 1 – Annual Capacity Estimate – Track Renewal

Item	Current Model
Non-productive days (Preventive Maintenance + Rain Period)	78 days
Movement of The Ballast Cleaning Machine (Between renewal plans + Traveling for Inversion)	13 days
Process Cycle	21 days
Number of Locations	$\text{Prod. year} = \frac{365-78-13}{21}$ $\text{Prod. year} \cong 13\,\text{locations}$
Capacity	≅ 91 km

Table 2 – Annual Planning – Track Renewal

Equipment	Locations	Extension (m)
DL-1355	*Total DL1355*	*93.671*
DL-1355	Renewal EH 13/14 L1	6893
DL-1355	Renewal EH 55/56 L2	6514
DL-1355	Renewal EH 202/204 L1	1660
DL-1355	Renewal EH 81/82 L2	10278
DL-1355	Renewal EH 67/68 L2	6335
DL-1355	Renewal EH 20/21 L2	6177
DL-1355	Renewal EH 50/51 L2	6219
DL-1355	Renewal EH 36/37 L1	6612
DL-1355	Renewal EH 07/08 L1	6702
DL-1355	Renewal EH 78/79 L1	6997
DL-1355	Renewal EH 26/27 L2	6791
DL-1355	Renewal EH 54/55 L1	7383
DL-1355	Renewal VLi EHF/ECF L2	3950
DL-1355	Renewal EH 63/64 L2	7160
DL-1355	Renewal VLi EHF/ECF L1	4000



Comparing graph 1 and tables 1 and 2, it is clear the difference between the capacity and planning of the current model and the demand of maintenance to do.

2.3 In Scope and Out of Scope

To define the sequence of the work it is necessary to clarify what will be in the scope of the work and what will not be part of the study. As we will see late in the next topic, the Track Renewal basically have 4 steps: ballast cleaning, replacement of sleepers, geometric correction and stabilization of ballast.

2.3.1 In Scope

The main step of Track Renewal:

- Ballast cleaning

2.3.2 Limitations

- Planning of the Locations carried out to avoid conflicts of concession and times due to the proximity between the locations;
- Exclusive use of DL-1355 (RM-900);
- Standard Location with an average length of 6,500m.
- Capacity will be analyzed in terms of critical resource (Ballast Cleaning Machine), considering that any delays in the geometric correction can be compensated by other resources.
- For the current model, the current history of the machine, which indicates low availability due to lack of spare parts, will be disregarded.

2.3.3 Out of Scope

- Geometric Correction
- Sleepers Replacement

- Ballast Stabilization
- Track Circuit Renewal

2.4 THEORETICAL BACKGROUND

- Module 01 – Rail Operation: we use some of the learning from this module to analyze the waste in rail dislocations to turn the equipment. between some track renewals, it is necessary to reverse the working direction of the machine.
- Module 02 – Rail Systems: we will not use the learning of this module in the development of the work.
- Module 03 – Rolling Stock and Maintenance: we use part of the learning from this module when we mention how the type of wagon (gondola-type) we use to transport iron ore generates contaminants to the ballast. On the other hand, one of the gains that we have made the track renewals, is the reduction of wear and increase in the useful life of rolling stock (locomotives and wagons).
- Module 04 – Rail Infrastructure and Maintenance: this is the module that most contributed to the development of the work. We use acquired knowledge about mechanized maintenance activities (ballast cleaning and geometric correction), and replacement of sleepers. And as we said for Rolling Stock Module, the reduction of wear and increase in the useful life of permanent way components when we do good maintenance on the track.
- Module 05 – Business Skills – we used the Turtle Diagram to describe the attributes of the Track Renewal Process;
- Module 06 - Management and Leadership: There is a whole management model behind the annual renewal plan, this model is deployed for each renewal plan, each plan being managed as a single project. And we use some knowledge to develop the Risk Analysis and the Project Implementation Plan;
- Module 07 – Economics: we apply the knowledge acquired in this module to elaborate the financial plan, chapter 8, and to realize the economic-financial viability of the proposed solutions, chapter 9.

2.5 THEORETICAL FOUNDATION

2.5.1 Ballast

The ballast is an element of the superstructure located between the sleepers and the bed (sub ballast). It distributes to the railway platform the efforts coming from the loads in the passage of the trains. (DUVAL, WENCESLAU E MAGALHÃES, 2008).

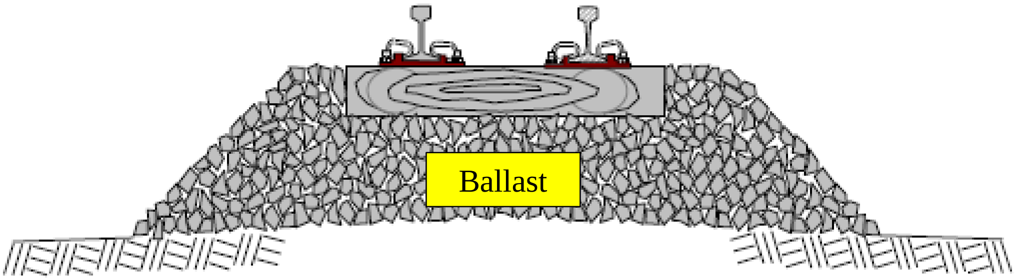


Figure 4 – Ballast
Source: Maintenance Manual for Permanent Way 2009

Its function is to absorb the efforts received from the sleepers and transfer them to the platform, without exceeding the allowable tension of the same. Stabilizes the track vertically, laterally and longitudinally anchoring the sleepers that receive the diverse loads of the rails. Another important function of the ballast is to allow the correct drainage of rainfall (DUVAL, WENCESLAU E MAGALHÃES, 2008).

2.5.1.1 Ballast Characteristics

The railroad ballast consists of crushed stone or slag from steel. As for the granulometry, it is observed that large stones make difficult the leveling work, whereas those of very small dimensions cause the early filling of the ballast occurs, generating loss of its functions of elasticity and draining capacity.

As for the geometric form, the ideal is that the stones have cubic forms and for resistance to rupture (compression) the EFVM establishes a minimum of 800 Kgf / cm^2. Resistance to wear or abrasion is obtained by the Los Angeles abrasion test. In this test, the EFVM establishes as tolerable wear values between 25% and 35%.

2.5.1.2 Ballast Contamination

The transportation of iron ore and coal loaded in open gondola-type wagons leads to the spraying of fines on the line. This material deposits on the ballast and, with the rains, fills the voids, making it difficult to drain the water causing the filling.

With the circulation of trains, in the points where the ballast is impermeable occurs the "lacquered" that is the pumping of the soil bringing to the material ballast of the sub-ballast contributing to the increase of the contamination.

Another important factor is that the multiple loading cycles cause wear and fracturing of the ballast generating more contaminants.

The contaminated ballast, as exemplified in Figure 5, retains rainwater and makes the platform more vulnerable to deformations that generate road instabilities (leveling or alignment).

Figure 5 – Example of Ballast Contamination by

Source: Personal archive

Considering the losses of drainage capacity and maintenance of the geometric characteristics of the track, it is necessary to carry out cyclical maintenance in the ballast, through its renewal, as will be seen below.

2.5.2 Ballast Renewal

The ballast renovation consists of removing the contaminants and worn gravel from the ballast, replacing the gravel that has been discarded and, finally, making the geometric correction, returning to the track the mechanical, geometric and draining design properties.

Its execution is justified by the saving of resources when compared to the complete substitution of the ballast. It should also be noted that a well dimensioned ballast renewal cycle contributes not only to reducing wear on track components (sleepers, rail and accessories), but also from wagon and locomotive wrenches.

The main steps of this process are described below.

2.5.2.1 Ballast Cleaning

Ballast cleaning is one of the most important processes of preventive maintenance of the Permanent Way of a high-load rail per axle, since it renews and restores the main functions of the ballast such as elastic support capacity and drainage. The process of mechanized cleaning of the ballast is done by a machine called Ballast Cleaning.

Railways with a ballast track bed may foul and lose its elasticity after a period of operation. When the degree of fouling on the railway track exceeds 40%, the track requires ballast cleaning. The ballast cleaning machines are used to clean the ballast on the track bed, by excavating the fouled ballast from under the sleepers and cleaning the ballast in an oscillating screening working device to ensure the ballast meet the required quality standard, before returning the cleaned ballast back to the track bed. The residue from the cleaning operations is transported to both sides of the tracks or removed using material conveyor machines.

2.5.2.2 Ballast Cleaning Machine

The purpose of this machine is to clean the ballast by removing the crushed stone and fines with a lower particle size than specified and returning the material that meets the physical design requirements to the track.

Figure 6 – Ballast Cleaning Machine

2.5.2.3 Material Conveyor Machine

The function of these equipment is to store the waste from the drainage and transport it to the nearest boot. When the train modules are fully loaded, the services are stalled and the wagons move to the closest boot for unloading.

Figure 7 – Material Conveyor Machine

2.5.2.4 Ballast Recompositing

After ballast cleaning, the track becomes low due to the loss of approximately 40% of the ballast, both by the discarding in the screening and by what it spread in the exit of the machine.

In a first phase, the ballast regulator uses part of the stripped ballast deposited next to the track and, soon after, enters the ballast, raising the track and doing the first stage of punching. After this first pasture pass, the track is already above the gravel, but needs replenishment. This replacement gravel is brought by a train that generally has 20 hopper type wagons - HNE, totaling an approximate load of 700m³.

2.5.2.5 Geometric Correction

The geometric correction consists in raising the recessed track and repositioning it in the geometric parameters of longitudinal and transverse alignment and leveling.

As soon as the tamping is made, the ballast regulator recomposes the gravel that is out of the ballast, leaving the line ready for another one pass. At this stage, the line is left in restricted traffic conditions, maximum traffic speed of 30 km/h, since traffic for railway stabilization is essential.

Ballast track bed get deteriorated after a period of operation or after an overhaul and cleaning exercise, resulting in the straight portions becoming crooked and the curved portions losing their curve. The track may also exhibit vertical and horizontal misalignment. Tamping operations carried out by our tamping machines comprise track lining, lifting and levelling, to restore the track alignment and the straightness and curve of the track to meet the requirements of its original design standard or the maintenance standard. Tamping and packing of the track bed and track shoulder ballast improves the compactness of the track bed ballast under the sleepers, to ensure the accurate alignment of the track for a relatively long period.

2.5.2.6 Tamping Machine

The purpose of this machine is to align and level the track, and at the same time carry out ballast tamping.

Figure 8 – Tamping Machine

2.5.2.7 Ballast Regulator

The main functions of ballast regulator machines are to distribute and profile ballast of the track bed, and to sweep the track. This machine shapes the ballast of the track shoulder to make the cross section of the track bed meet the required standards, and distribute ballast uniformly using the center plough. The machine also removes the ballast left behind on the sleeper and the fasteners after the operation, to ensure that the track meets the required standards and is neat and presentable.

Figure 9 – Ballast Regulator

2.5.2.8 Ballast Stabilization

Once the geometric correction has been completed, the track for circulation with a speed restriction of 30 km/h is released, and a gross weight of 650,000t is fixed on the track for a new verification of the geometry of the section. If there are no significant deformations in the ballast to the point of altering its geometry, it is delivered to the circulation without speed restriction, 60km/h.

3 RESEARCH RESULTS

3.1 PRODUCTIVITY ANALYSIS – TRACK RENEWAL

Figure 10 schematizes the process of track renewal considering only the services of ballast cleaning and geometric correction.

The following average productivities of the service fronts were considered, shown in Figure 11.

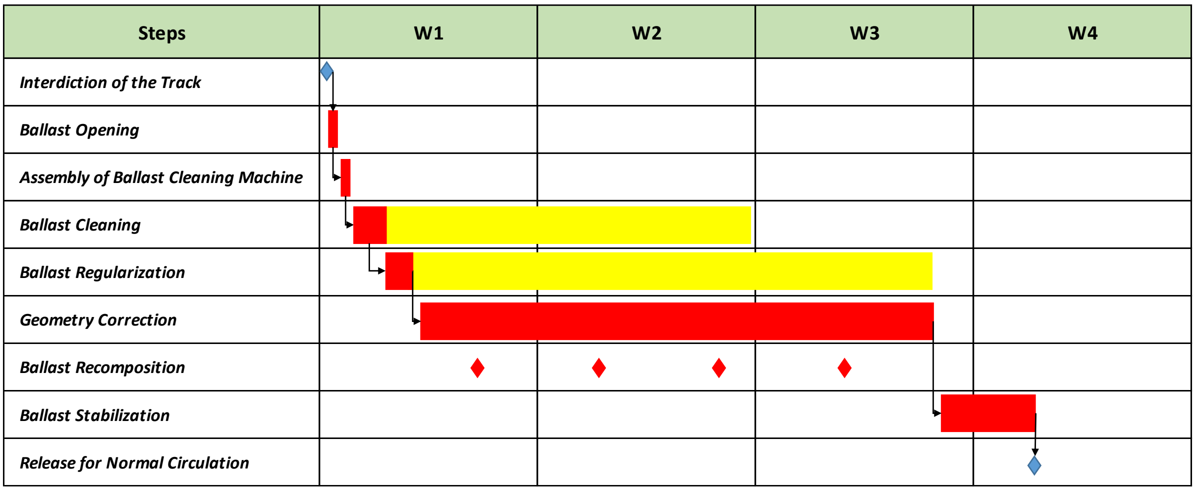


Figure 10 – Schematic planning for Track Renewal without Replacement of Sleepers

For better visualization, a Time x Path graph was elaborated, much used in linear works.

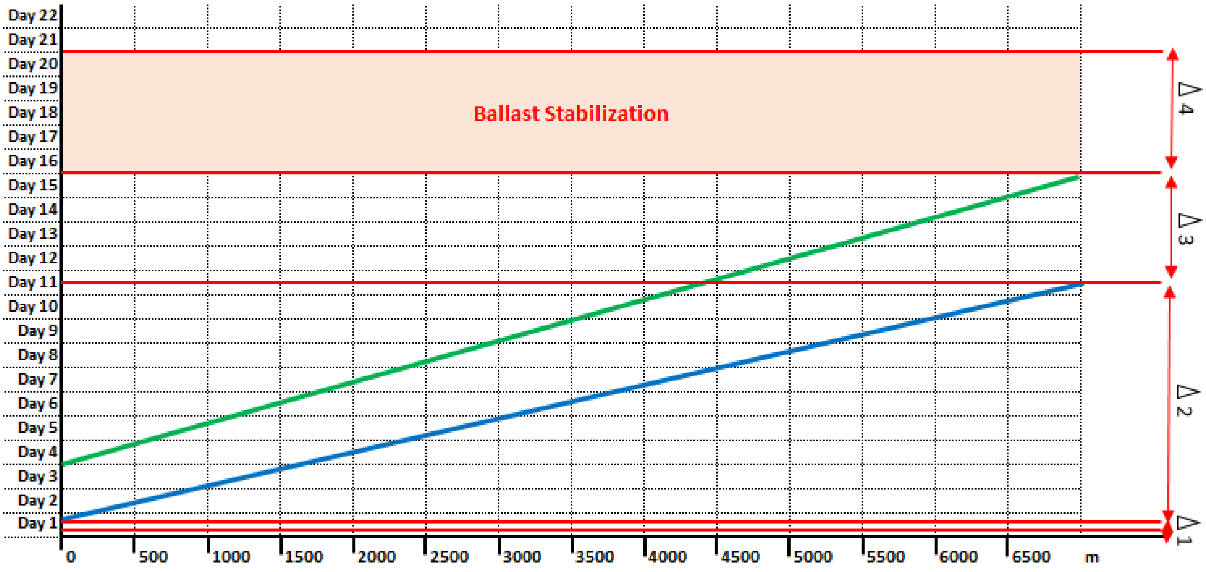


Figure 11 – Time x Path for Track Renewal Services

Based on Figure 11, it can be established:

$$T_{RENEWAL} = \Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$$

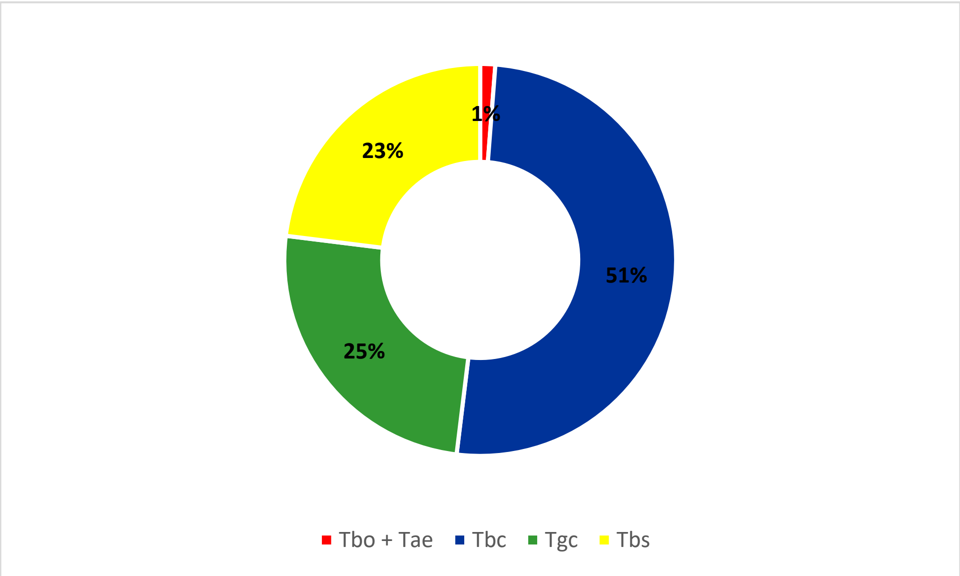
Where:

$$\Delta_1 = \text{Time Opening Ballast} + \text{Time Assembly Equipement} = Tob + Tae$$
$$\Delta_2 = \text{Time Ballast Cleaning} = Tbc$$
$$\Delta_3 = \text{Time Geometric Correction} = Tgc$$
$$\Delta_4 = \text{Time Ballast Stabilization} = Tbs$$

Replacing:

$$T_{RENEWAL} = Tob + Tae + Tbc + Tgc + Tbs$$

Graph 2 shows the time distribution for a standard renewal:



Graph 2 – Time Distribution - Standard Renewal

Analyzing the distribution, for the current productivities, the activities of ballast cleaning account more than 50% of the times.

The time to Geometric Correction also deserves to be highlighted (25%), but since we have 6 sets of SLs, even if they demand 2 per plan, this stage of the process is not currently a bottleneck, and can be studied later.

The time to stabilize the ballast also deserves to be highlighted (23%), since the ballast stabilizer (DGS) is already in the testing phase and should be put into final operation in 2019.

In this way, the productivity of the main service ballast cleaning, will be analyzed.

3.1.1 Productivity – Ballast Cleaning Machine

In the current model, Ballast Cleaning is performed by the equipment DL1355.

Table 3 summarizes the production parameters for fleet equipment, calculated during the year 2018:

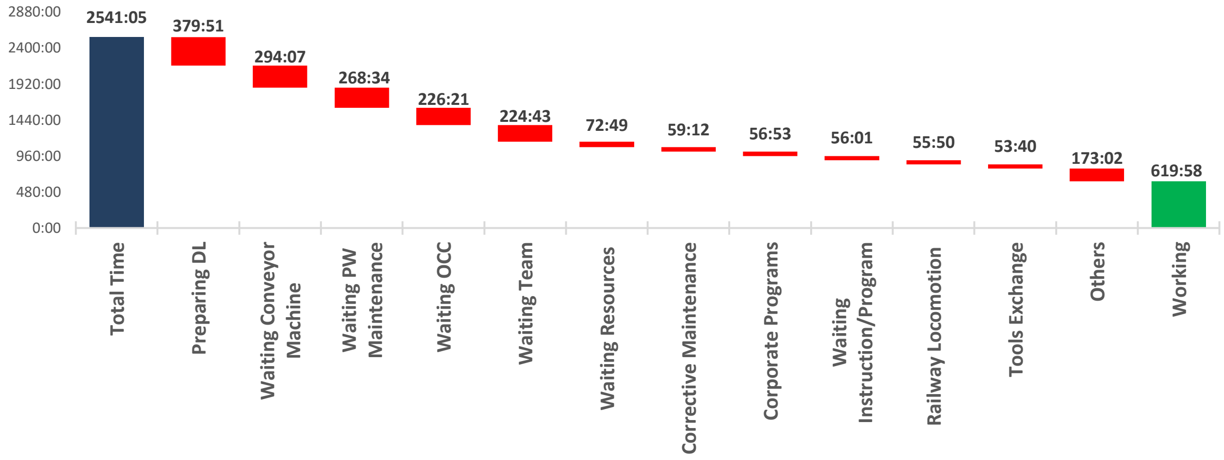
Table 3 – Ballast Cleaning Parameters

DL1355 (RM900)	
Effective Productivity	129 m/h
Effictiveness	24,5%
Effective Productivity	32 m/h

As already mentioned, the productivity of ballast cleaning is a function of several factors, among which it is worth mentioning:

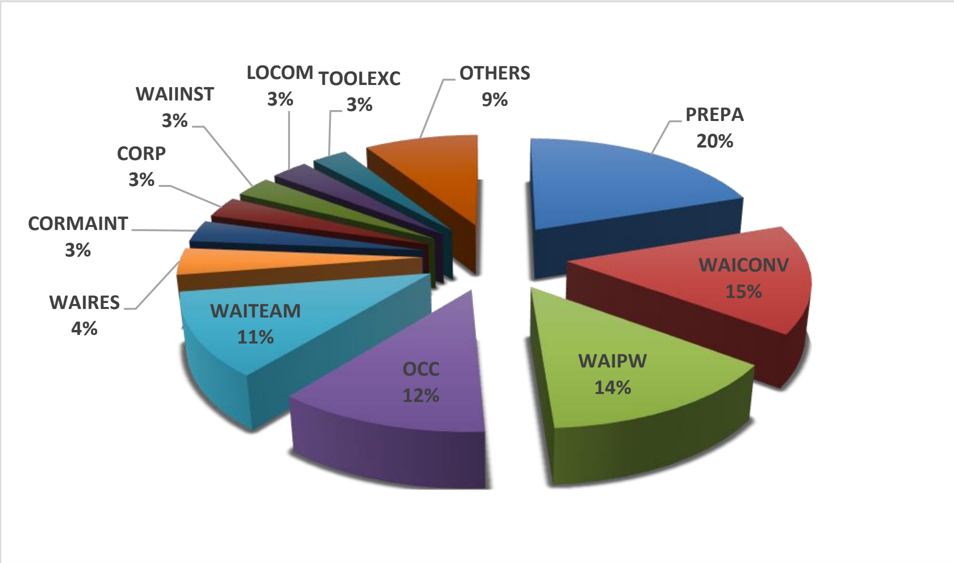
- Waste deposit configuration in and near the location;
- Condition of the ballast to be cleaned;
- Equipment Productivity;
- Condition of the sleepers;

Considering the various points to be treated, it was decided not to discuss aspects related to the track (ballast condition, waste deposit configuration, etc.), restricting the study to the productivity of the ballast cleaning. Graph 3 details the time distribution for the ballast cleaning working.



Graph 3 – Build up – Ballast Cleaning Time

As can be observed, the working time corresponds to approximately 25% of the equipment's available time. And Graph 4 details the losses of the process:



Graph 4 – Distribution of Losses

Based on this distribution, and assuming that the activities of preparing the equipment for work (PREPA) are activities that do not add value, but are necessary and that we will recommend a more detailed analysis with the operation team of the ballast cleaning machine, the point of analysis for improvement is defined: **Waiting Conveyor Machine (WAICONV).**

Another point that deserves to be highlighted is the losses generated by interference from the services of the permanent way maintenance (WAIPW) – 14%. With the trend of dissociation between ballast renovation and replacement of sleepers, this loss should become negligible.

In the sequence, the current condition of the item mentioned above will be analyzed.

3.1.1.1 Waiting Conveyor Machine

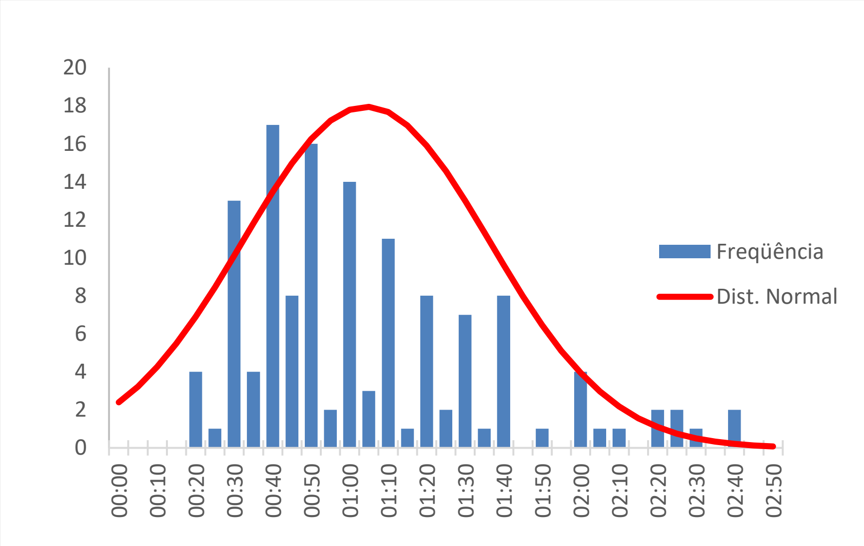
The losses resulting from the stoppage of ballast cleaning to transport the waste to the deposit form the WAICON event.

Its magnitude depends on other factors, from the distance from the front of the service to the waste deposit, the availability of locomotive and equipment for the displacement of the fleet and the condition of the place of unloading.

Given the range of deposits configurations available at EFVM locations, it was decided to analyze the time history that was available in the daily parts of the RM 900 (DL 1355). In this analysis, the important thing was to verify the time of equipment stopped waiting for uncoupling, displacements, discharge in the waste deposit and coupling in the DL-1355. This time is recorded in the AGMDL events.

Table 4 – Summary of values for download time

Events Waiting Conveyor Machine	
Nº of events	135
Average Time	01h05min
Std Deviation	00h30min



Graph 5 – Histogram and normal distribution - discharge times

Once the above times have been verified, the module capacity is analyzed. We have a history of working in 82% of the displacements of the train with 03 conveyors, of the 06 acquired. This availability directly influences the number of trips to the waste deposit and, consequently, the time of execution of the services.

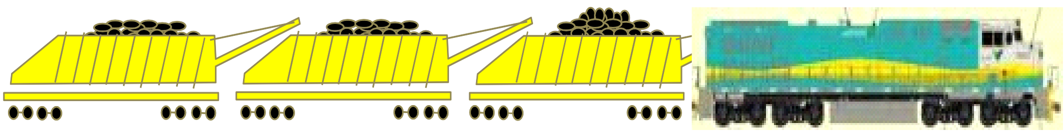


Figure 12 – Schematic with 3 Conveyors Machines

Attention must also be paid to the availability of locomotive equipped (machinists and shunters when necessary) to effect the movement of these conveyors to the waste deposit, as this feature directly interferes with the duration of the trips to discharge waste.

In the face of everything that has been exposed to increase the productivity of the ballast cleaning process, it is worth strengthening the following point:

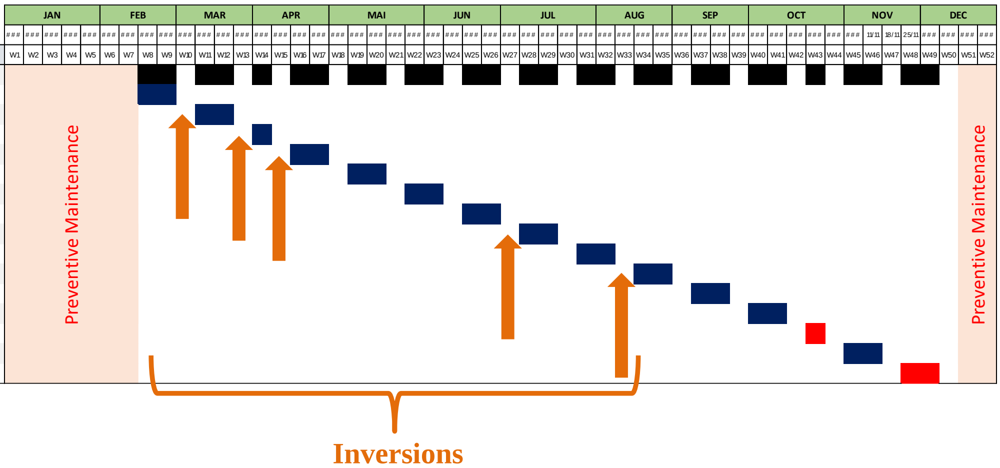
- Dimensioning of the fleet of conveyor machines, reducing or even eliminating waiting times for waste discharge in the deposit.

3.2 Inversion of Ballast Cleaning Machine

A factor that has not yet been explored and not measured, since it occurs between the Renewal Plans and not with the plan in execution, is the need to rotate / reverse the working direction of the ballast cleaning train (ballast cleaning machine + conveyors machines) to enable the cleaning. The need to reverse the working direction of the machine is due to environmental issues for the formation of waste stock that allows the complete collection of the generated material. By 2019, of the 13 planned renewals, at least 05 of them require the inversion of the machine.

Table 5 – Annual Planning – Track Renewal + Cleaning Machine Inversion

Equipment	Locations	Extension (m)
DL-1355	*Total DL1355*	*93.671*
DL-1355	*Renewal EH 13/14 L1*	*6893*
DL-1355	*Renewal EH 55/56 L2*	*6514*
DL-1355	*Renewal EH 202/204 L1*	*1660*
DL-1355	*Renewal EH 81/82 L2*	*10278*
DL-1355	*Renewal EH 67/68 L2*	*6335*
DL-1355	*Renewal EH 20/21 L2*	*6177*
DL-1355	*Renewal EH 50/51 L2*	*6219*
DL-1355	*Renewal EH 36/37 L1*	*6612*
DL-1355	*Renewal EH 07/08 L1*	*6702*
DL-1355	*Renewal EH 78/79 L1*	*6997*
DL-1355	*Renewal EH 26/27 L2*	*6791*
DL-1355	*Renewal EH 54/55 L1*	*7383*
DL-1355	*Renewal VLi EHF/ECF L2*	*3950*
DL-1355	*Renewal EH 63/64 L2*	*7160*
DL-1355	*Renewal VLi EHF/ECF L1*	*4000*



This inversion occurs by traveling with the ballast cleaning train near to the begining of railway and doing the shunter movement. This place, RH03, is the only one place on the railroad that allows shunt movement inversion, Figure 13.

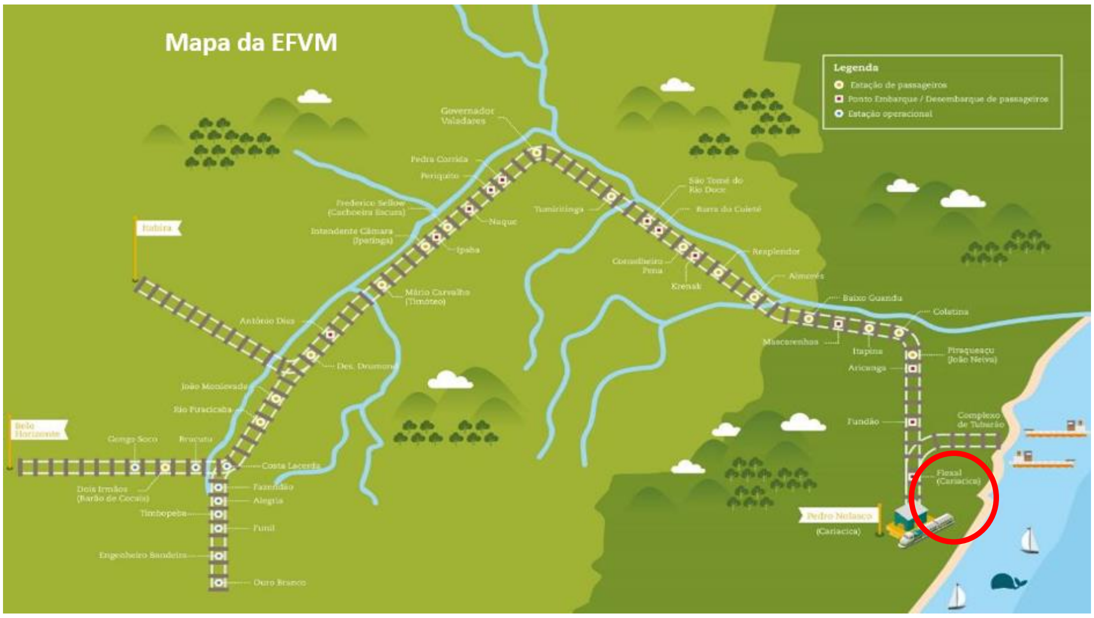


Figure 13 – Schematic Map EFVM – Inversion Place RH03

So, this traveling to the train's inversion is a great waste of time, especially since the renewal plan is at the opposite end of the inversion place, waste of labor and diesel also.

In the face of everything that has been exposed about this waste of time, it is worth strengthening the following point: To reduce or eliminate this traveling time.

4 HYPOTHESIS

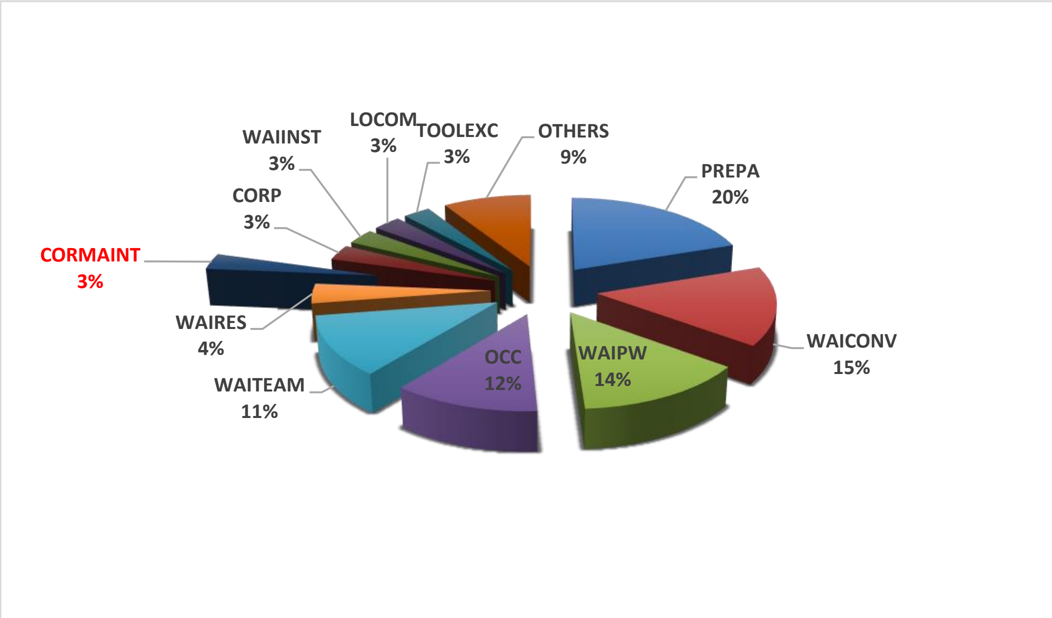
Once the problem was formulated, the justifications for the importance of addressing and presenting the actual results of the process, it is time to respond to the key issues of the problem:

What bottlenecks prevent increased maintenance capacity?

a. low reliability of the equipment?
b. low productivity of the equipment?
c. there are logistical wastes?

4.1 Hypothesis 01 – Low Reliability of the Equipment

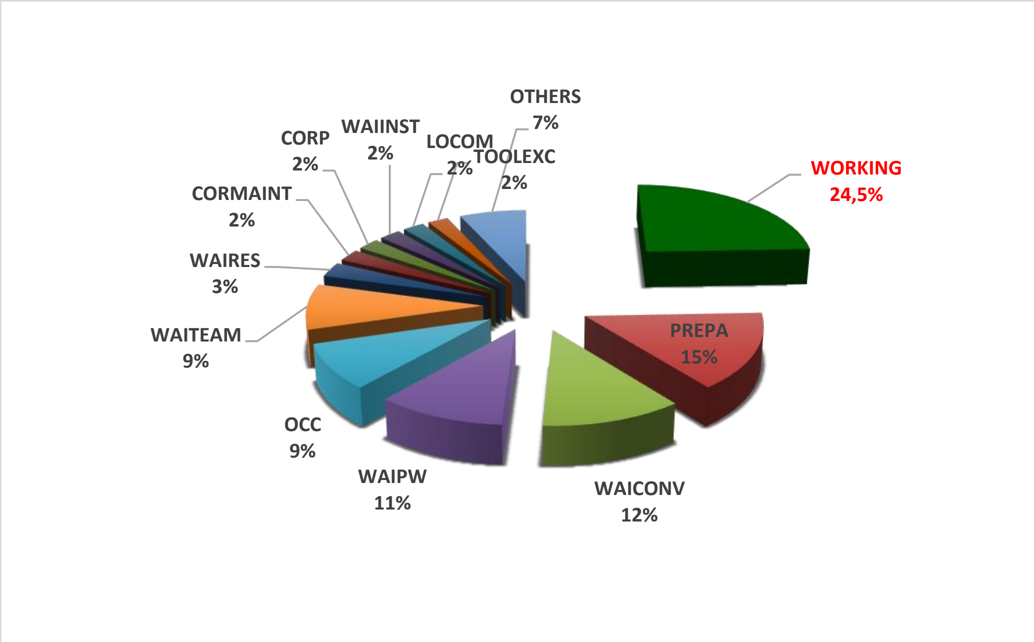
Analyzing the graph 6 below, previously presented, we discard the hypothesis of low reliability of the equipment, since corrective maintenance represents only 3% of the losses of the process. In the study, we did not evaluate the preventive maintenance, which occurs according to a maintenance strategy, which may be the object of future study.



Graph 6 – Distribution of Losses

4.2 HYPOTHESIS 02 – LOW PRODUCTIVITY OF THE EQUIPMENT

Analyzing the graph 7 below, the hypothesis of low productivity of the equipment is confirmed, since in only 24.5% of the total time of the machine available for use it is working, which generates an effective average productivity of 32 m/h. Today it has a gross productivity of 129 m/h. Being the most impacting for the low productivity in the sequence: Equipment Preparation and Waiting Conveyor Machine. However, as described earlier, equipment preparation is a non-value-adding activity, but it is necessary, so the biggest impact on productivity in the current model is the waits for the Conveyors.



Graph 7 – Distribution of Time

4.3 Hypothesis 03 – Logistic Wastes

Knowing that for each inversion trip, we must disassemble the equipment, travel to the shunt place, shunter the equipment, make the return trip, reassemble the equipment in the working mode, and the average time to perform this procedure is 1,5 days, surely the logistical waste of equipment handling is a hypothesis to be considered. Below we can see the wasted times (Table 6):

Table 6 – Inversion Trip Estimated 2019

DL1355 - Track Renewal 2019				
Trip 01				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
1:30:00	0:15:00	5:50:00	1:30:00	**9:05:00**
Trip 02				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
1:30:00	0:15:00	37:55:00	1:30:00	**41:10:00**
Trip 03				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
1:30:00	0:15:00	44:38:00	1:30:00	**47:53:00**
Trip 04				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
1:30:00	0:15:00	31:30:00	1:30:00	**34:45:00**
Trip 05				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
1:30:00	0:15:00	36:45:00	1:30:00	**40:00:00**
Total				
Disassemble	Inversion	Traveling	Assemble	**TOTAL**
7:30:00	1:15:00	156:38:00	7:30:00	**172:53:00**

Looking for the table, the total time lost for the inversion trip is approximately 7 days.

5 GENERATE IDEAS

In this item, we discuss the alternatives for increasing the capacity of ballast cleaning process. The necessary premises will be established for these changes, for later analysis of the economic-financial viability of the proposals.

5.1 INCREASE PRODUCTION BY REDUCING WAITING FOR CONVEYOR MACHINE

5.1.1 Redimensioning Conveyors Machines Fleet

Considering the history, there is an average loss of 03h30min (15%) due to stop the ballast cleaning to waiting to unload the conveyors machines in the waste deposit.

Given a 6,500 m a location extension, it is estimated the number of trips to be made by the conveyors machines to the waste deposit:

$$\text{n} = \text{number of conveyors}$$
$$\ell = \text{locaton extension } = 6.500\text{m}$$
$$\text{P}_\text{y} = \text{probabilty of discharge being made with y conveyors}$$
$$\text{c}_\text{y} = \text{capacity of y conveyors}$$
$$n = \frac{\ell}{\Sigma(P_y \cdot c_y)}$$

The analyzed history provides the following values for capacity and statistics of the number of conveyors machines (Table 7):

Table 7 - Statistics of the transport capacity of the Conveyors Machines

Nº Conveyors Machines	Capacity (m)	%
3	138	82%
4	188	18%

$$n = \frac{\ell}{\Sigma(P_y \cdot c_y)} = \frac{6.500}{(85\% \cdot 138 + 18\% \cdot 188)}$$

$$n \cong 44{,}2 \text{ viagens}$$

The measured machine downtime for the discharge activity are shown in Table 8:

Table 8 - Statistical summary of the WAICONV event

Events Waiting Conveyor Machine	
Nº of events	135
Average Time	01h05min
Std Deviation	00h30min

Thus, the average loss with module discharge at a standard location can be estimated at:

$$\mathrm{T}_{\mathrm{WAICONV}} = 44{,}2 \times 01h05 \cong 48h\,;$$

From these values, one can see how the availability of the wagons affects the number of trips and, consequently, the duration of the event "Waiting for Reject Discharge". Therefore, the first proposal is to guarantee a minimum availability of 90% for the 05 current modules, and to reach it, the following measures are proposed:

- Restructuring of the Maintenance Plan of these equipment;
- Training / contracting of 02 other operators, currently we are limited to 03.

With these actions, it is expected to obtain a new availability profile, as presented in Table 9:

Table 9 – Desired Availability for Conveyors Machines

Nº Conveyors Machines	Capacity (m)	%
3	138	5%
4	188	5%
5	250	90%

Recalculating the estimated number of trips and their times:

$$n = \frac{\ell}{\Sigma(P_y \cdot c_y)} = \frac{6.500}{(5\%.138 + 5\% \cdot 188 + 90\% \cdot 250)}$$

$$n \cong 27 \text{ viagens}$$

$$\mathrm{T}_{\mathrm{WAICONV}} = 27 \times 01h05 \cong 29h$$

By improving the operational availability of tailings wagons, a reduction of up to 19 hours (40%) in downtime due to the unloading operation is estimated.

The natural complement of the actions presented would be the determination of the number of conveyors machines that guarantees the continuous operation of the ballast cleaning process. However, it was decided to carry out the sizing after the estimated times considering the changes already proposed, given the volume of investment required to acquire more conveyors machines.

5.1.1.1 Gains from the proposed alternative to Ballast Cleaning with 5 Conveyors Machines

In this step, the proposal for loss reduction will be presented, estimating the time to cleaning an average location of 6,500m. The cycle will consider the gains with the dimensioning of the conveyors fleet and its respective ballast renewal time (Table 10).

Table 10 – From-To the proposed solution

	From (3 Conveyors)	To (5 Conveyors)
Default Extension	6.500m	6.500m
Time	20h/day	20h/day
Wainting Conveyor	03h30min / day	02h05min /day
Time to Produce	16h30min / day	17h55min / day
Production	≅ 640	≅ 700
Ballast Cleaning Process	11 days	9 days

Thus, reducing waiting times for conveyors machines, increase daily production from 640 to 700m and reduce the ballast cleaning process time from 11 days to 9 days.

5.2 Construction of a Circulating Pear for Inversion of the Ballast Cleaning Train in the Middle of Railway

As shown previously, in the current mold, where we are limited to perform the inversion movement of the ballast cleaning machine at the beginning of the railroad, in RH03, and we have an average of 5 inversion for track renewal per year, which average 7 days lost to carry out this logistics.

In order to optimize the logistics for the train inversion and to evaluate a new location along the railroad to carry out this procedure, since we do not have this second option. The solution would be to construct a circulating pear in Governador Valadares, a yard located in the central region of railway, EH49/50. And this way we always have two options to perform the inversion. As shown in the figure 14.

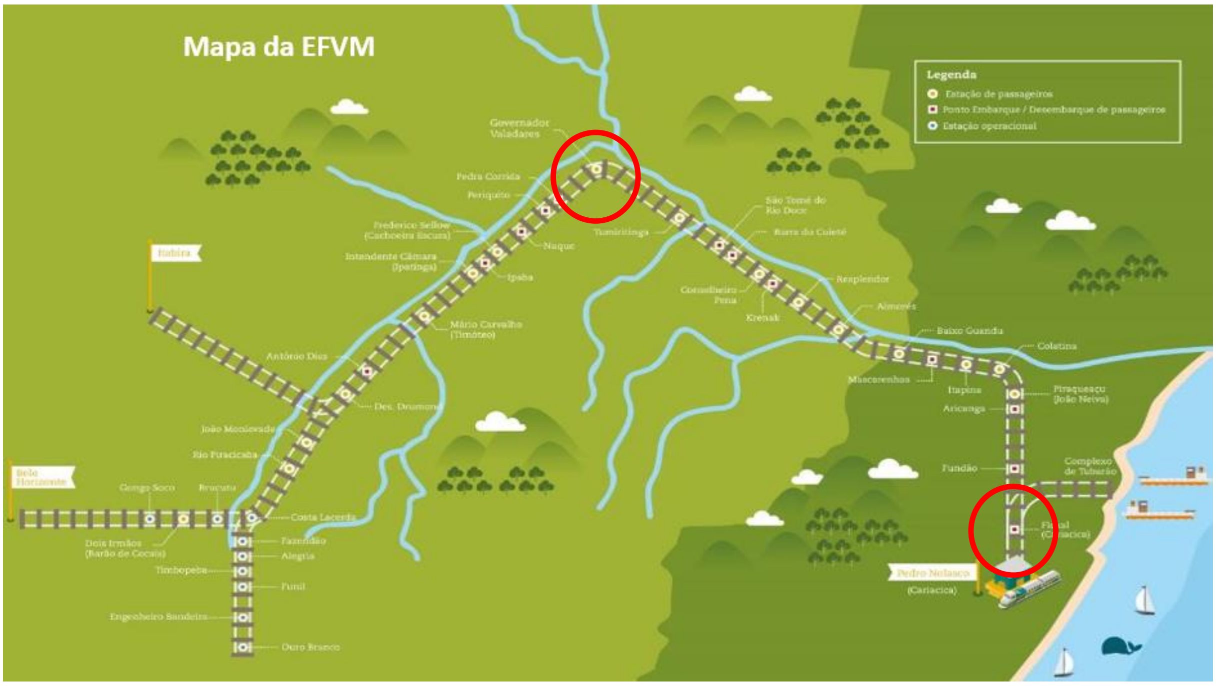


Figure 14 – Schematic Map EFVM – New Inversion Place EH49/50 and Old One RH03

After physically identifying where it could be the best place to build the railway pear, we began to calculate the possible gains, which are shown in the table 11 below:

Table 11 – Simulations of the trips

DL1355 - Track Renewal 2019									
Trip 01 (RH03)					Trip 01 (RH03)				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
1:30:00	0:15:00	5:50:00	1:30:00	9:05:00	1:30:00	0:15:00	5:50:00	1:30:00	9:05:00
Trip 02 (RH03)					Trip 02 (EH49/50)				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
1:30:00	0:15:00	37:55:00	1:30:00	41:10:00	1:30:00	0:15:00	10:30:00	1:30:00	13:45:00
Trip 03 (RH03)					Trip 03 (EH49/50)				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
1:30:00	0:15:00	44:38:00	1:30:00	47:53:00	1:30:00	0:15:00	17:13:00	1:30:00	20:28:00
Trip 04 (RH03)					Trip 04 (EH49/50)				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
1:30:00	0:15:00	31:30:00	1:30:00	34:45:00	1:30:00	0:15:00	12:15:00	1:30:00	15:30:00
Trip 05 (RH03)					Trip 05 (EH49/50)				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
1:30:00	0:15:00	36:45:00	1:30:00	40:00:00	1:30:00	0:15:00	9:20:00	1:30:00	12:35:00
Total					Total				
Disassemble	Inversion	Traveling	Assemble	TOTAL	Disassemble	Inversion	Traveling	Assemble	TOTAL
7:30:00	1:15:00	156:38:00	7:30:00	172:53:00	7:30:00	1:15:00	55:08:00	7:30:00	71:23:00
									101:30:00
									4 days

Thus, constructing in the middle of the railway a circulating pear, we can reduce by up to 60% the times spent to do the inversion procedure. Reducing from 7 to 3 days.

5.3 INCREASING THE CAPACITY

Once the possibilities of increasing line renewal capacity through increased daily production have been studied, improvements will be implemented to reduce waiting times for wagons (conveyors) and by making the ballast cleaning more agile, reducing the circulation times of the trains to perform the procedure of reversing the machine, we will add the improvements and understand the total gain possible in the annual renewal process (Table 12).

Table 12 – Annual Capacity Estimate – From -To

Item	Current Model	Future Model
Non-productive days (Preventive Maintenance + Rain Period)	78 days	78 days
Movement of The Ballast Cleaning Machine (Between renewal plans + Traveling for Inversion)	13 days	**9 days**
Process Cycle	21 days	19 days
Number of Locations	$\text{Prod. year} = \frac{365-78-13}{21}$ $\text{Prod. year} \cong 13\,\text{locations}$	$\text{Prod. year} = \frac{365-78-9}{19}$ $\text{Prod. year} \cong 15\,\text{locations}$
Capacity	≅ 91 km	≅ 105 km

With the improvements suggested, we could increase the number of renewals from 13 to 15 and the capacity of renewal of annual line from 91 to 105 km.

6 PROJECT IMPLEMENTATION PLAN

The study contemplates two distinct solutions; therefore, we will be treating like two distinct projects, below Figure 14 the project 01 - Construction of the Circulating Pear and in Figure 15 the project 02 - Redimensioning of the Conveyors Machines Fleet.

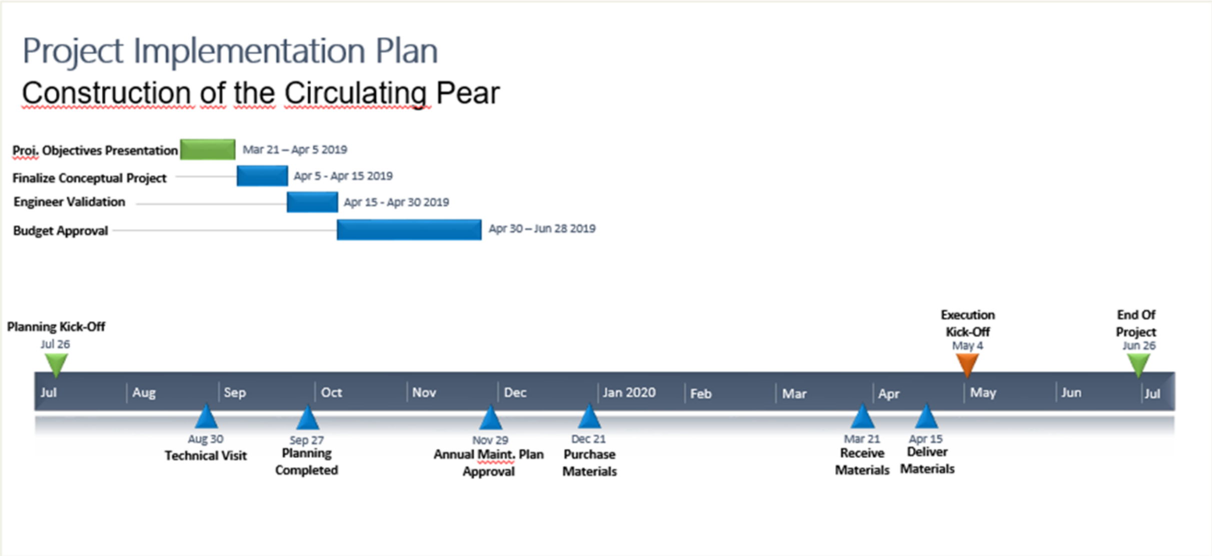


Figure 15 – Project Implementation Plan Construction of the Circulating Pear

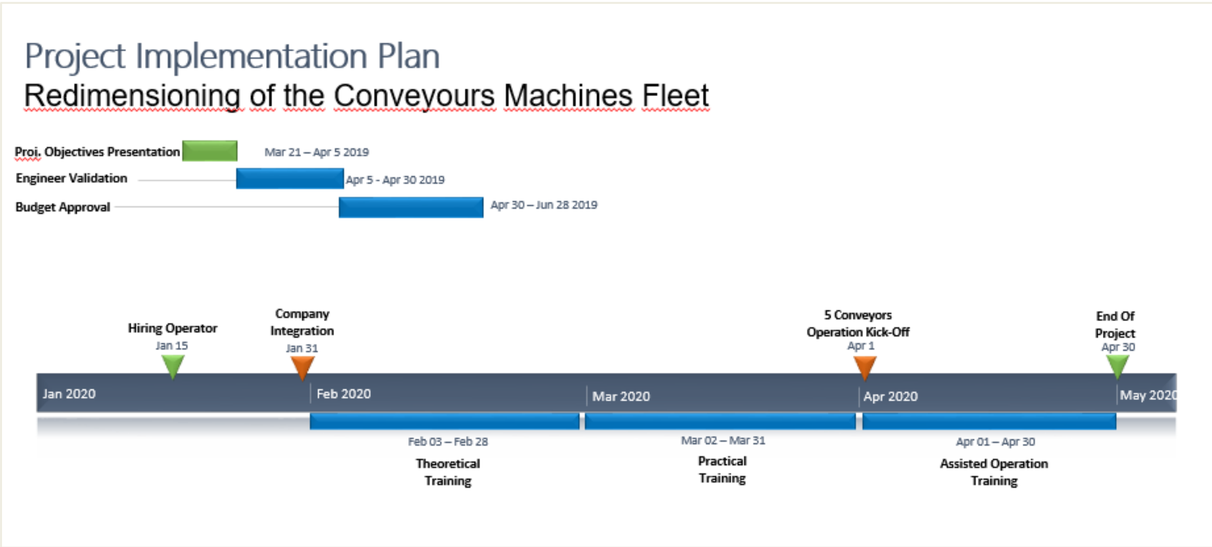


Figure 16 – Project Implementation Plan Redimensioning of the Conveyors Machines Fleet

7 RISK ANALISYS

As in the previous chapter, because the study contemplates two distinct projects, we performed two different risk analyzes, one for each project, tables 13 and 14.

Table 13 – Risk Management Analysis - Construction of the Circulating Pear

Risk Management Analysis

Project: Construction of the Circulating Pear

Category	Description	Causes	Impact	Probability	Risk	Owner	Actions
Thecnical Project	Not Engineering Approval	Failure to meet the railway technical parameters	Very High	0,4	0,32	Marcos Roberto	Detail the conceptual design for presentation to Engineering
Management	No Budget Approval	Reduction of investment costs - company scenario	Very High	0,6	0,48	Francisco Trópia	Presenting the NPV to the Executive Manager
Planning	Unavailability of personnel due to prioritization of other projects	Problems in running other projects	Medium	0,4	0,16	Fábio Benevenuto	Conduct peer and managerial resource negotiation
Planning	Budget overflow	Error in calculating resource scaling	Low	0,2	0,04	Marcos Roberto	Review the technical project and carry out a field visit to calculate material in conjunction with the Plan Cordinator
Materials	Increased Costs	Exchange Rates	Medium	0,6	0,24	Maxwell Angeli	Follow the process of purchasing materials from Supplies
Materials	Delay in delivery	Vendor issues	Medium	0,4	0,16	Maxwell Angeli	Follow the process of purchasing materials from Supplies
Materials	Delay in purchase	Internal bureaucracy in the purchase procedure	Medium	0,4	0,16	Maxwell Angeli	Follow the process of purchasing materials from Supplies
Materials	Delay in delivery for execution	Logistics problems with the Distribution Center	High	0,2	0,12	Jadismar Rogerio	Follow the submission process with the DC
Materials	Out of specification	Engineering Project Error	Very High	0,2	0,16	Simone Issomura	Review the technical project
Materials	Out of specification	Error in the supplier's production process	Very High	0,2	0,16	Ricardo Koehler	Make direct receipt to the supplier
Execution	Delay in project execution	Little experience in this type of work	Low	0,2	0,04	Eduardo Gomes	Manage the project in the same way as the Large Maintenance

Table 14 – Risk Management Analysis - Redimensioning of the Conveyors Machines Fleet

Risk Management Analysis

Project: Redimensioning of the Conveyors Machines Fleet

Category	Description	Causes	Impact	Probability	Risk	Owner	Actions
Thecnical Project	Not Engineering Approval	Do not understand the gain from the project	Very High	0,2	0,16	Fábio Benevenuto	Presenting the NPV to the Engineering
Management	No Budget Approval	Reduction of investment costs - company scenario	Very High	0,4	0,32	Francisco Trópia	Presenting the NPV to the Executive Manager
Human Resouces	not find operators in the market	Lack of skilled labor	Low	0,2	0,04	Braulio Martins	Realizar capacitação interna
Management	Budget overflow	Error in budget defense	Low	0,2	0,04	Braulio Martins	Review staff budget for 2020

8 FINANCIAL PLAN

Next, the results of the proposed projects are analyzed considering the economic and financial viability of their respective cash flows.

In this Flow, we will consider input (positive values) the gains with:

- Corrective maintenance reduction with an annual increase of 14 km of line renewal;
- Reduction of Diesel, Train Driver Hour and Logistic Costs of Train Driver to carry out trips for train inversion;
- Reduced equipment wears during travel.

Exits will be considered (negative values):

- Acquisition of Special Alligator for construction of the Railway Pear;
- Cost of personnel to carry out the work

The method to be used in the feasibility analysis will be the Net Present Value (NPV).

8.1.1 Out Values

The investments will be considered according to Table 15.

Table 15 - Investments

Financial Economic Viability - Premisses

Current Investment

Project: Construction of the Circulating Pear

Investiments

Description	Accounting	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Frog	20	250000									
Personal		26347									
Sleepers (w ooden)											
Rail											
Gravel											
Total de investimentos R$		276.346,77	-	-	-	-	-	-	-	-	-

Conservatively, we disregard depreciations as well as residual values at the end of the term analyzed, since we will not have investments in depreciable assets.

8.1.2 Input Values

The reduction of costs will be considered according to Table 16.

Table 16 – Cost Reductions

Financial Economic Viability - Premisses

Current Investment

Project: Construction of the Circulating Pear

Cost Reductions

Description (R$)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Diesel + Train Driver	19313	19313	19313	19313	19313	19313	19313	19313	19313	19313
Equipment Wear	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
Corrective Maintenance	23033	23033	23033	23033	23033	23033	23033	23033	23033	23033
Total Cost Reduction R$	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22

8.1.3 Cash Flow and NPV Analysis

For the preparation of the cash flow and NPV analysis, it was considered:

- Study period from 2020 to 2029;
- Rate of return on capital invested with a value of 12%;
- All investments in equipment and parts will occur in the first year of analysis.

Table 17 – Cash Flow and NPV

Financial Economic Viability - Cash Flow

Current Investment

Project: Construction of the Circulating Pear

FINANCIAL INDICATORS (R$)

NPV	-54.373,88
TIR	5,7%
Payback	7,00

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Period	0	1	2	3	4	5	6	7	8	9
Costs Reduction (R$)	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22
Increase in Revenue (R$)	-	-	-	-	-	-	-	-	-	-
Increase in Costs (R$)	-	-	-	-	-	-	-	-	-	-
Asset Off (R$)	-	-	-	-	-	-	-	-	-	-
EBITDA (R$)	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22
Depreciation (R$)	-	-	-	-	-	-	-	-	-	-
Taxable (R$)	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22	53.146,22
IRPJ (R$)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)	(13.286,56)
Social contribution (R$)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)	(4.783,16)
Investments (R$)	(276.346,77)	-	-	-	-	-	-	-	-	-
Recovery PIS / Cofins Investt (R$)										
Divestments (R$)	-	-	-	-	-	-	-	-	-	-
Net cash flow (R$)	-241.270,26	35.076,51	35.076,51	35.076,51	35.076,51	35.076,51	35.076,51	35.076,51	35.076,51	35.076,51
Accumulated (R$)	(241.270,26)	(206.193,76)	(171.117,25)	(136.040,75)	(100.964,24)	(65.887,74)	(30.811,23)	4.265,27	39.341,78	74.418,28

9 CONCLUSIONS

The following is a summary of the main issues addressed in this paper, grouped according to the proposed objectives.

9.1 BALLAST RENEWAL PROCESS

In EFVM, Ballast Renewal occurs together the replacement of sleepers, within a process called Track Renewal. In the current process, the duration depends on factors inherent to the condition of the track (number of waste deposits, existence of tunnels, viaducts, bridges, condition of sleepers, etc.); and productivity of service fronts (replacement of sleepers, cleaning of ballast, geometry and ballast stabilization).

In view of the trend projected for the Ballast Renewal service, from which it can be established:

- Average service life of 21 days, with an estimated annual capacity of 91 km.
- Main steps: Replacement of Sleepers, Ballast Cleaning, Geometric Correction and Ballast Stabilization.

And Ballast Cleaning was identified as the most critical, given the uniqueness of its resource (ballast cleaning train) and its execution time (11 days). The main productivity loss factor mapped in the Ballast Cleaning stage was:

- Sub dimensioning of the fleet of conveyors machines, considering the low operational availability of the same.

Another factor observed that is related to the Track Renewal, but externally to the execution time, are the times spent between renewal plans, in this interval it is necessary to perform preventive maintenance according to the equipment maintenance strategy and also to move the resources (equipment) from one front of service to another, and in 40% of cases, it is necessary to travel with the unloader until and RH03 (beginning of the railroad) to realize the inversion of the work direction of the equipment.

Therefore, the object of study of the work was carried out on the dimensioning of the fleet of conveyors machines and the logistics of handling the ballast cleaning train.

9.2 PROPOSED SOLUTIONS AND THE GLOBAL PRODUCTIVITY GAIN OF THE PROPOSED MODEL

With the suggested improvements: implementation of the solution to cleaning ballast with 05 Conveyors Machines and construction of the Pear Railway in Governador Valadares, increasing the number of renovations from 13 to 15 and the capacity of renewal of the annual track from 91 to 105 Km, we would get very close to estimated demand for engineering of 106 km from 2020.

9.3 FINANCIAL-ECONOMIC VIABILITY OF THE SOLUTIONS

For the project of construction of the railway pear, analyzing the calculated numbers, we conclude that the project is paid from the seventh year. When it comes to railway, where most of investments and asset life are long term, we can classify the project as viable.

However, in order to make it viable, it will be necessary to carry out the construction with the permanent reuse path materials: sleeper, rail and ballast.

Regarding the project to redimensioning the fleet of conveyors machines, we did not calculate the feasibility because we understood that having only the cost of the addition of 03 Operators, we were able to absorb internally, balancing the jobs.

9.4 FINAL RECOMENDATIONS

- ❒ We recommend a study to analyze internally in the Plan of Track Renewal, the times of preparation of the machine, that today correspond to 20% of the daily hours;

- ❒ Externally to the Plan, we recommend analyzing the preventive maintenance times between plans, in the current model, are dedicated 5 days for this maintenance.