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Increase in Productivity of the Iron Ore Loading Terminal

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Abstract

This article aims to present the application of the LEAN method to enhance performance in loading iron ore wagons at Vale's Carajás Railway in Brazil, specifically at the Serra Leste loading terminal. This terminal annually transports 4.3 million tons, loading over 40,000 wagons, with a projected increase in transportation by 66% in the coming years, reaching 7 million tons. The Serra Leste loading terminal faces the challenge of reversing the scenario of lower mean weight of iron ore wagons on the Carajás Railway, thereby contributing to Vale's strategic objectives of productivity, sustainability, and competitive all-in cost. Thirty MURI, MURA, and MUDA deviations were identified, and the goal was set based on historical data to support the production budget. Processes were then mapped using Pareto analysis, sequential chart, box plot, and histogram. Causes were identified, wagon loading steps were mapped, and a future scenario projection was made with a 50% reduction in steps, incorporating LEAN assumptions. Subsequently, an effective action plan was implemented. The project yielded gains in productivity, sustainability, and cost, adding 3.92 tons of iron ore to each wagon, achieving the best Vale mean weight, resulting in a reduction in costs of US$ 141,043.10, a decrease in diesel consumption by 134,340 liters, and a reduction in emissions of 383,296 kg of CO^2 eq. The project brought stability, repeatability for over 16 months, and established new records for the mean weight of wagons at Vale.

Keywords
Loading, Productivity, Sustainability, Lean, Iron Ore.

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1.Introduction
Currently, the incessant search for practices that promote operational efficiency, increased productivity, sustainability and cost reduction has led organizations to internalize innovative management philosophies. In this context, Lean stands out as a holistic approach, based on the fundamental principles of eliminating waste, creating value and

promoting continuous improvement. The Lean system originated at the end of the Second World War and was implemented in Japanese companies with the aim of producing more at a lower cost and eliminating waste, giving rise to the Toyota Production System (TPS) which translates into a new philosophy for the production process. According to Liker (2011), Lean is not just a tool, but a change in mentality that must be cultivated at all levels of the organization.

This study proposes an analysis focused on the integration of the concepts of MURI, MUDA and MURA in the context of Lean, which through the reduction of fluctuations, reduction of overload and elimination of waste, can result in substantial gains in productivity, cost reduction and mitigation of carbon emissions. An integrated understanding of these elements enables an in-depth analysis of operations in general, with a view to systematically eliminating inefficiencies at different stages of the production process. Therefore, organizations that aim to achieve excellence and quality performance in relation to the competition must direct their efforts towards a thorough analysis of their processes, with the aim of reducing or eliminating losses and waste (ESTEVES et al. 2010).

We will explore the case study in the mining industry and exemplary practices that highlight how identifying and effectively addressing MURI, MUDA and MURA can result in remarkable improvements in operational productivity. In addition, we will highlight the positive economic impacts, including reduced operating costs, derived from eliminating waste.

In line with growing environmental concerns, this study also sets out to analyze how the effective implementation of Lean can contribute to reducing carbon emissions. By identifying and eliminating inefficient processes, it is hoped that economic gains and more sustainable practices will be achieved.

1.1 Objetives

The purpose of this article is to present the application of Lean practices in the mining industry, with a focus on reducing waste by eliminating it, and consequently optimizing the mean weight of wagons, specifically at Vale S.A. Lean, inspired by Toyota's production principles, has emerged as an effective methodology for improving operational efficiency and promoting sustainability in mining activities.

Our study will seek to analyze how the identification and elimination of MURA, related to irregularity in production; MURI, associated with overloading wagons; and MUDA, which refers to non-value-added activities, can significantly contribute to minimizing waste in the mining production chain. In addition, we will explore how the implementation of these Lean principles can result in substantial gains in overall process efficiency, because as we see in Womack et al. (1990), the most dangerous kind of waste is the waste we do not recognize.

Another central point of this article is to investigate how the Lean approach can be used to optimize the mean weight when loading wagons in the mining industry. The simplified application of Lean tools, such as the Value Stream Mapping (VSM) explained by Rother and Shook (1999), will allow for visualization and detailed analysis of all the steps involved in a process, allowing for in-depth analysis, identification of points for improvement and implementation of targeted changes to achieve a more efficient mean weight.

In concluding this study, we aim to provide valuable insights for professionals in the mining industry interested in improving operational efficiency, reducing waste and, at the same time, improving product quality through the effective application of Lean principles.

2. Literature review

The understanding of the concept of waste spans different eras, dating back to Henry Ford, and its definition has remained essentially unchanged. Any unnecessary process input or unwanted product on the production line is identified as waste (BARRETO, 2012). According to Dias (2011), waste and production losses are harmful in any scenario. The concept of waste covers a wide range in the literature examined and can simply represent raw materials or resources that cannot be processed or reused. In other words, it is anything that does not add value to the product from the customer's point of view.

LEAN thinking came to prominence through the Toyota production system, a people-based system in which employees were involved in continuous improvement, and the foundations of the system were leadership and encouraging autonomy through education and training (DAHLGAARD & DAHLGAARDPARK, 2006). According to Freitas et al. (2020), LEAN thinking, when applied, aims to develop organizations' ability to identify and eliminate waste.

For Almeida et al. (2017), the development of LEAN thinking is divided into four phases: the first, focused on cells and assembly lines; the second, concentrated on the shop floor; the third, focused on the flow of the value chain (VSM); and finally, the fourth, which from 2000 onwards, focused on value systems. Other approaches, such as Stone's (2012), break LEAN down into five phases, including discovery (1970-1990), dissemination (1991-1996), implementation (1997-2000), the business phase (2001-2005) and the performance phase (2006-2009).

In addition, there is a distinction between strategic LEAN and operational LEAN. The former focuses on LEAN thinking, while the latter is related to operations on the shop floor, going beyond being just a strategy for reducing waste. The efficiency of the Lean System has already been demonstrated by authors such as Womack (1991), Cusumano (2010) and Fujimoto (1999) and led Toyota to become the world's biggest car seller in the first quarter of 2007. Currently, studies also point to the positive results of using this production system not only in the automotive industry, but also in other sectors (SHOOK, 2008). Considered a management philosophy and strategy, LEAN seeks to create value for the customer by eliminating activities that do not add value or hinder the functioning of the system.

Faced with the countless wastes identified in a production process, the need for a comprehensive view of all the production stages becomes evident. The Lean tool that best meets this requirement is Value Stream Mapping (VSM). The primary objective of this tool is to provide a clear and precise understanding of the processes and their agents involved in the production chain. It is a management philosophy focused on reducing the seven types of waste: overproduction, waiting time, transportation, overprocessing, inventory, handling and defects. By eliminating these wastes, quality improves and production time and costs decrease. For Medeiros et al. (2010) the traditional production system is characterized by production based on a forecast of final demand.

3. Methods

The method used is a case study. According to Vergara (2004), a case study is a research approach that involves an in-depth and detailed analysis of a specific case, be it a person, a group, an organization or an event.

To achieve the objectives, the working method used the PDCA methodology, structured as follows: (i) identify the problem and establish goals and challenges to solve the identified causes, (ii) carry out a study to analyze the phenomenon to understand the behavior of the failure modes, (iii) apply methods to identify root causes, (iv) develop an action plan/proposal for improvements to eliminate the causes that generate the problem, including strategies and necessary resources, (v) verify the results and (vi) standardize the improvements made and the lessons learned throughout the process.
The treatment and arrangement of qualitative and quantitative data (graphs and figures/validations) will be presented throughout the stages of the PDCA.

4. Data collection

This article explored wagon loading patterns based on detailed observations of process flow/operational practices. During the collection period, the researchers interacted in the factory's daily routine by surveying times and movements, documenting processes, identifying critical points and capturing opportunities that may not be evident at first glance.

Using the statistical method, we quantified specific variables related to production, such as loading times, defect rates, mean wagon weight and train positioning speed. This data was extracted from the company's official system, providing a numerical and consolidated view of operations. Controlled practical tests were conducted to assess the impact of proposed modifications on operational processes. These experiments included gradual adjustments to key variables, monitoring the results and comparing them with historical performance.

Interviews were conducted with key operators, providing valuable insights into subjective perceptions, challenges faced on a daily basis and suggestions for optimization. This qualitative approach will complement the quantitative analyses obtained through statistical methods. To validate the findings and test proposed solutions, a field simulation will be carried out. This practical approach will allow direct observation of the changes implemented, assessing their impact in a controlled environment before full implementation.

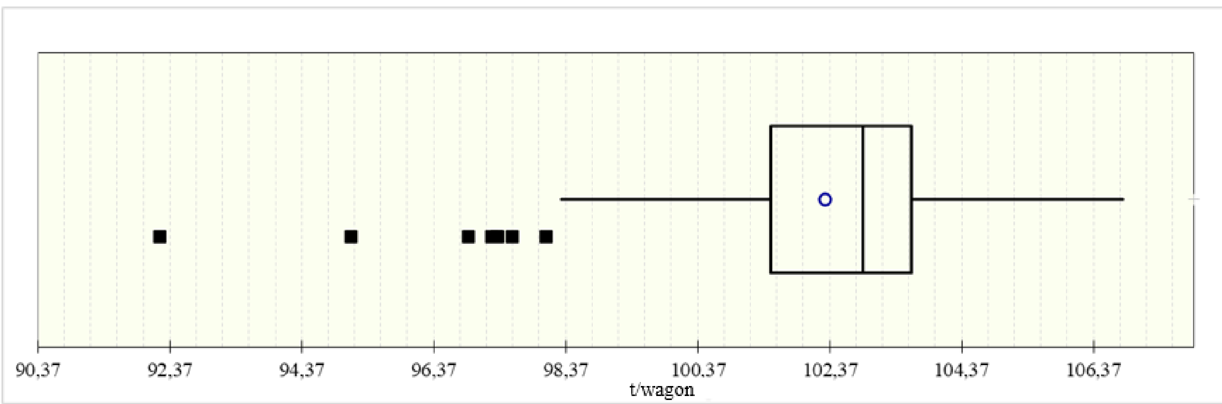
5. Results and discussion

The case study deals with the LEAN application at Vale S.A., one of the world's largest mining companies, headquartered in Brazil and operating globally. This case study was carried out at the iron ore wagon loading terminal in Serra Leste in the state of Pará, where the process is carried out with a wheel loader.

Problem identification stage

We surveyed the key performance indicator (KPI), mean weight, which measures the behavior of the process. This indicator reflects the mean number of useful tons loaded onto each wagon.
We analyzed the mean weight data of 179 trains, equivalent to 33,000 wagons loaded at the Serra Leste terminal, in order to understand the variability of the process and to meet the budgeted target for the baseline period (January to December 2021), as well as the challenge target for 2022 of 103.86 t/wagon.

Based on Figure 1, the mean executed process for the baseline period was 102.30 t/wagon, which did not meet the 2021 budget of 103.92 t/wagon. The process also shows high variability, as demonstrated by the standard deviation of 2.01 t/wagon, the amplitude of 14.61 t/wagon and the presence of outliers.



Variable	Data count	Mean	Standard Deviation	Minimum	First Quartile	Median	Third Quartile	Maximum	Range
Average Weight	179	102,30	2,01	92,22	101,48	102,88	103,62	106,83	14,61

Figure 1. Boxplot analysis of the mean weight realized in 2021 in Serra Leste

Phenomenon analysis stage

We sought to understand the characteristics that generated variability in the indicator, as well as the repetition of failure modes. Figure 2 shows the simplified Value Stream Mapping (VSM) of the loading process, which included 10 stages for loading the wagons. In analyzing the process, we found 30 deviations that increased lead time, generating rework and impacting on productivity. The deviations were classified as follows: 4 MURI deviations, 7 MURA deviations and 19 MUDA deviations.

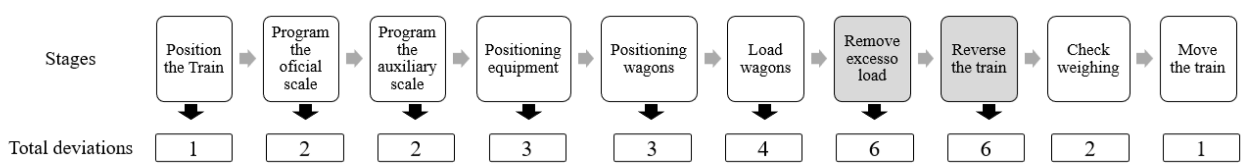


Figure 2. Value chain flow for loading wagons at Serra Leste and deviations by stage

Using the Pareto diagram of the faults in loading the wagons, two faults were selected to be the subject of this study: excess load on the wagon and the train backing up.
This defines the selected failure modes:
Overloading: always occurs when the maximum capacity of the wagons is exceeded, and the duration of the fault is the time required for the backhoe loader to correct the load on the wagon.

Train backtracking: occurs after the load has been corrected, and the duration of the fault is the time required for the train to backtrack and reweigh the wagons until it returns to the position to restart loading the other wagons of the train or until the train is free to maneuver if the train has finished loading the wagons.

Process analysis stage
Once the two focus failures had been defined, a cause and effect diagram was drawn up to identify the potential causes and the why method was used to prove the root causes. Figure 3 shows that the two proven root causes are: the official weighing scale and the software used are outdated compared to the technology used on other sites and there is no procedure for loading wagons with a wheel loader, with clear references for each step.

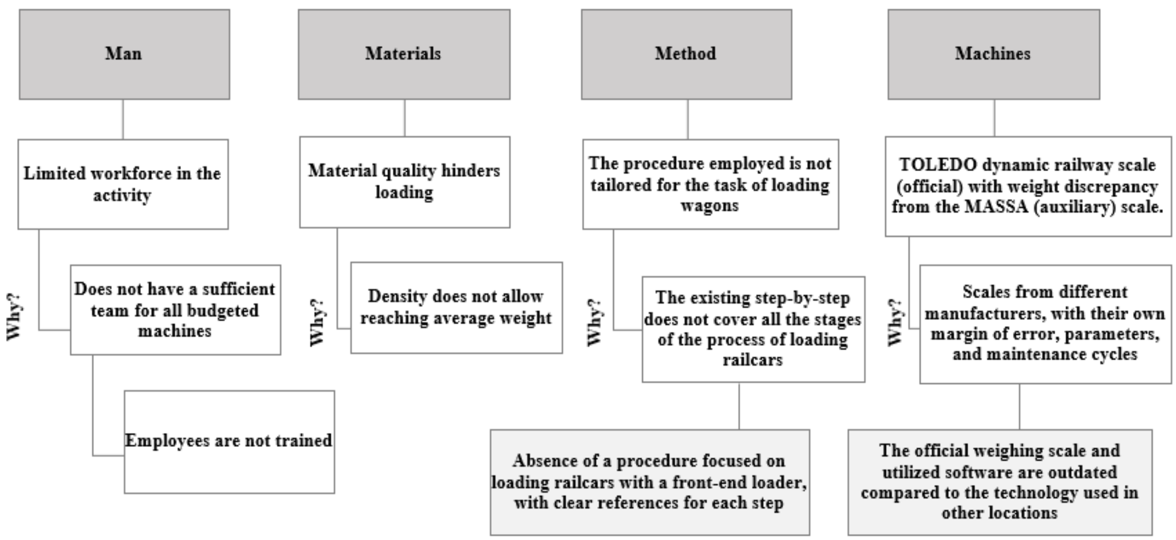


Figure 3. Cause and effect analysis/why test to identify root causes.

Action plan/improvement proposal stage
To eliminate the root causes of the focus problems, we listened to the stakeholders in the process and raised/validated the main ideas. We came up with 26 actions connected to MURI, MURA and MUDA. These actions were detailed and monitored on a daily basis using a 5W2H action plan (what, why, who, where, when how and how much). Figure 4 lists the actions, as well as their description, deadline for completion and the connection with the deviations found in the phenomenon analysis stage.

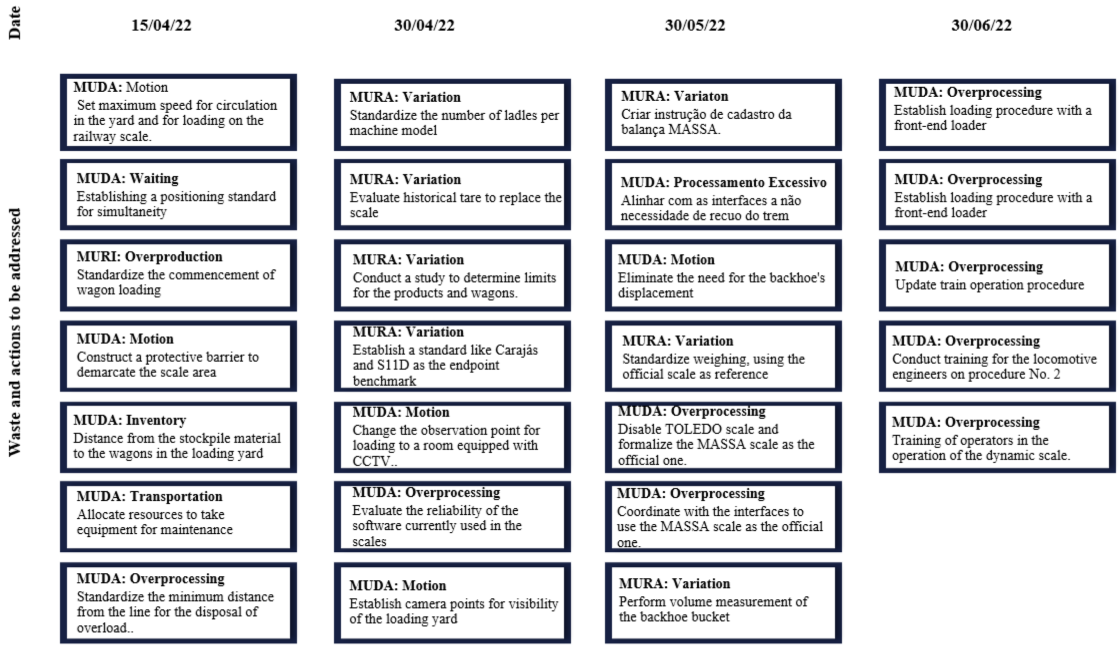


Figure 4 . Plan for eliminating waste.

With the implementation of the action plan, we eliminated waste using LEAN tools (application of functional 5S, normal vs. abnormal condition, standardized work, automation, change over, quality at source, production leveling, work pace and talk time), which can be seen in Figure 5.

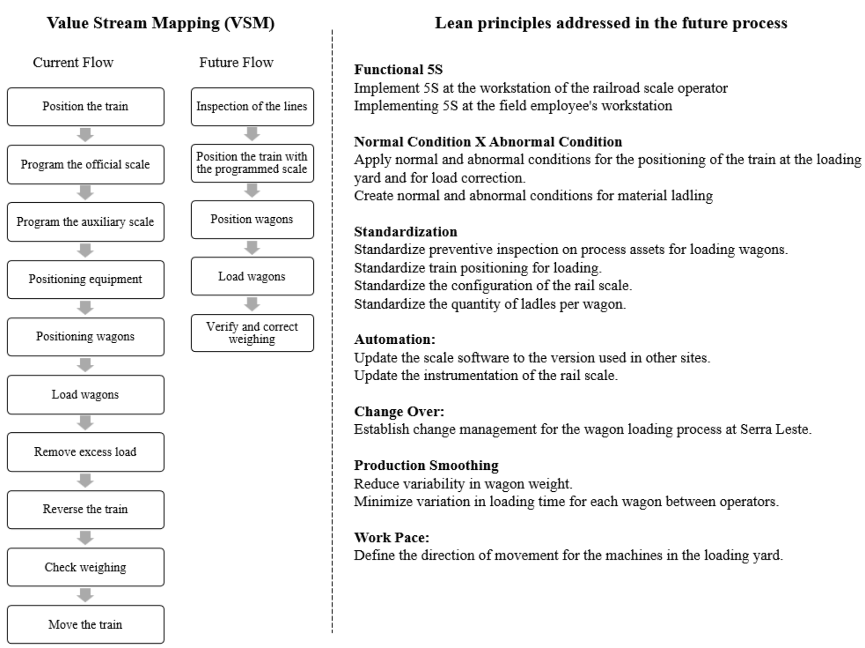


Figure 5. Current flow and future flow with a view to LEAN assumptions

Execution stage

To ensure adherence to the implementation of the actions, we used the "S" curve. All the planned actions were monitored monthly to ensure compliance and effectiveness of the results. Figure 6 shows the adherence of the 26 actions planned and carried out. It is understood that some of the actions were not carried out on schedule, but all were completed within the project deadline.

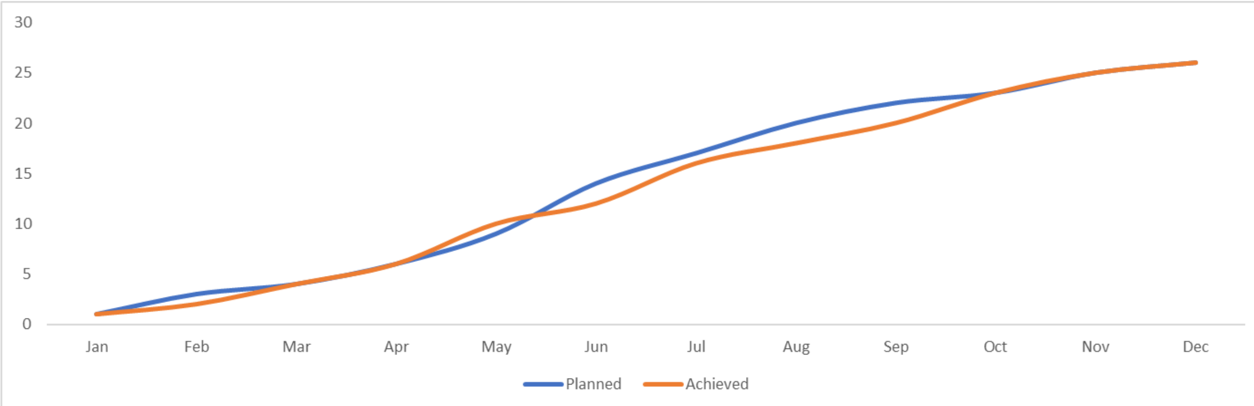


Figure 6. S-curve of shares

Results verification stage

The implementation of the actions proved sufficient to achieve and sustain the results. In addition, we exceeded the 2022 challenge target of 103.86 t/wagon for the verification period from July to December 2022 where we achieved an mean weight of 106.31 t/wagon. Figure 7 shows a comparison of the historical mean weight (baseline) and during the verification period. There is also a change in level and a reduction in outliers.

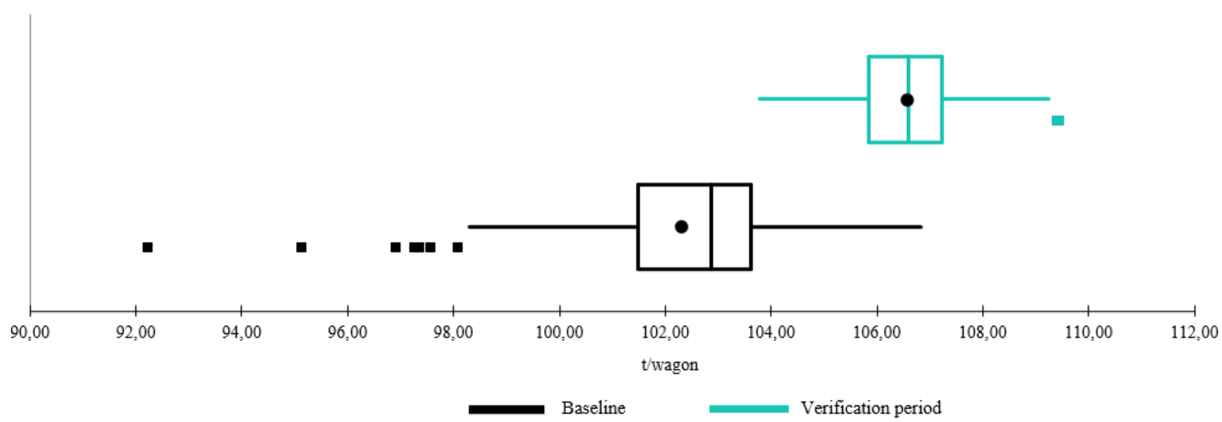


Figure 7. Boxplot comparative analysis of mean weight at baseline and during the verification period

Through descriptive analysis, we can conclude that the terminal's performance has achieved unprecedented results. Table 1 shows that the amplitude of the base line (before) of 14.61 t/wagon was reduced to 8.65 t/wagon (after), and the reduction in the standard deviation of 2.01 t/wagon of the base line (before) was reduced to 1.56 t/wagon in the verification period (after). The median weight was 106.18 t/wagon.

Table 1. Descriptive analysis of mean weight before and after the project

Variable	Data count	Mean	Standard Deviation	Minimum	First Quartile	Median	Third Quartile	Maximum	Range
Baseline	179	102,3	2,01	92,22	101,48	102,88	103,62	106,83	14,61
Verification period	126	105,81	1,56	100,55	105,1	106,18	106,67	109,21	8,65

The overall gains of the project are detailed in Table 2, categorized by business dimensions: the environment, with a reduction in carbon emissions and fuel savings; productivity, with a reduction in train loading time and an increase in mean weight; and the cost dimension, with a reduction in the company's total costs.

Table 2. Project gains in terms of dimensions

Dimension	Description	Gains
Productivity	Increase in mean weight	2.45 t/wagon
Productivity	Reduction in loading time	2.80h
Productivity	Increase in transported volume	91,302 t
Environment	Reduction in carbon gas emissions	324.126 kg CO^2 eq.
Environment	Reduction in fuel consumption	US$ 28,450.00
Cost	Reduction in total company cost	US$ 152,849.37

Standardization stage

In order to control the process and guarantee the sustainability of the results, the wagon loading standards were revised with the inclusion of a step-by-step task, the inclusion of a new flow for registering the scale, the creation of technical references and layouts in the field for positioning the trains and the training of all the employees involved in the process. Figure 8 shows the revised standard with the improvements made to the procedure and, in particular, the standardization of the amount of material for each machine's ladle. With this definition we have established standardization, allowing uniform loading by all operators.

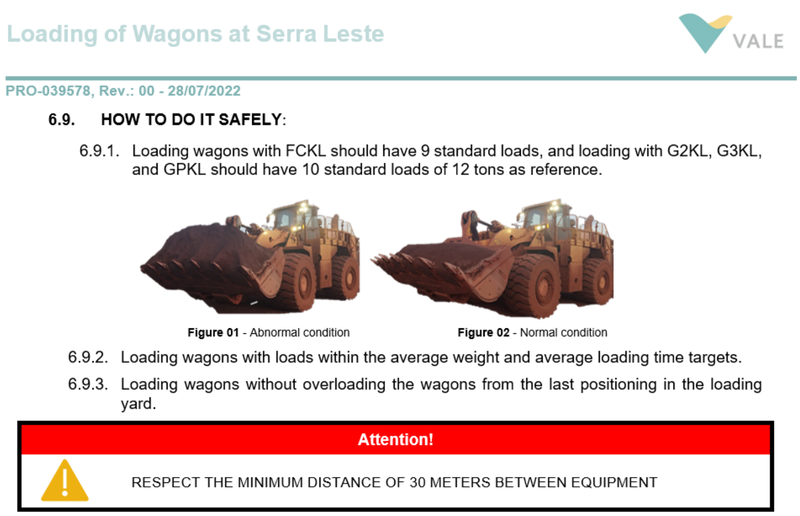


Figure 8. Activity procedure with emphasis on standardizing the amount of material per machine ladle

6. Conclusion

The aim of this article was to present the application of Lean practices in the mining industry, with a focus on reducing waste through elimination, and consequently optimizing the mean weight of wagons, specifically at Vale S.A. The results presented in the case study and the use of LEAN tools associated with the PDCA method showed that the objective was achieved.

The LEAN tools proposed in the literature affirm their potential to eliminate waste in the production process. The case study demonstrates the efficiency of these tools and the proposal resulting from the analysis made it possible to optimize the performance of the Serra Leste terminal with: (i) an increase in mean weight of 2.45 t/wagon, (ii) a reduction in variability, (iii) a reduction in the loading cycle time, (iv) more agility in train detour and (v) standardization of technical references to stabilize the process.

Despite the simplified analysis of the Value Stream Mapping (VSM), it was clear that the process had a lot of rework. The application of the future flow connected with LEAN assumptions reduced the stages of loading wagons by 50% and enabled the elimination of 30 deviations, 4 of which were MURI, 7 MURA and 19 MUDA.

As a continuation of the theme, process mapping has opened up the prospect of further research. One obvious need is to investigate the failure modes of the physical availability of wheel loaders. The physical availability of the machines is a key factor in achieving key indicators at the terminal, especially the time it takes to load the wagons. Another research alternative is the arrangement of the products in the loading bay, since the travel time of the machines changes depending on how the products are allocated in the loading bay. Finally, we also suggest an analysis of the length of the loading area, seeking to optimize the number of machines and make equipment manoeuvring more flexible.

Throughout this study, we devoted our attention to implementing creative, low-cost measures aimed at substantially improving the mean loading weight of wagons used to transport iron ore. The results obtained not only achieved the target set, but also point to significant advances in the operational efficiency and sustainability of rail transportation. The evaluation of performance indicators, including operational efficiency and cost reduction, has shown that the improvements in mean weight are not just numerical, but have practical and tangible implications for the day-to-day running of rail operations.

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Biographies

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Araujo, Manoel M. da S. has been in the railway industry for 19 years. He graduated in Biology from the State University of Maranhão, Brazil, and he is specialized in Environmental Management from the Atenas Maranhense College and in Railway Engineering from the higher education institution IPOG, Brazil. He has been involved in complex railway projects such as dynamic helper where train coupling occurs in motion, increasing the speed of ore trains with a model of 330 wagons, merging freight trains, and implementing long trains with 440 and 660 wagons. He is a Yard Control Center Coordinator responsible for the main loading terminals in Vale's North Corridor in Brazil with 6 years of experience in people management and in developing projects to enhance railway operations, including train maneuvering, and loading and unloading of wagons at the terminals of the Carajás Railway.

Nunes, Thiago C. has been in the railway industry for 14 years. He has experience as a Specialized Inspector Instructor and he is part of the technical team from Estrada de Ferro Carajás responsible for performance improvement studies, process restructuring in the loading silos, for training new operators and participating in highly complex projects, such as implementation of New Iron Ore Loading Silos for the main loading terminals in Vale's North corridor in Brazil. He is completing his undergraduate degree in Production Engineering at Uninter, Brazil, in 2024.

Pinheiro, Thiago de O. is currently the Operations Manager of the Carajás Railway at VALE S/A. He graduated in Mechanical Production Engineering from the Federal University of Paraíba, Brazil, and he is specialized in Port Logistics from the Federal University of Maranhão, Brazil, and an MBA in Business Management from Fundação Getúlio Vargas, Brazil. Throughout his 16 years of professional experience, he has worked in the areas of Logistics, Supply Chain, Integrated Planning, and Operations. From 2019 to 2022, he was the Planning and Scheduling Manager at Vale, where he participated in the implementation of the Integrated Operations Center project integrating the medium and short-term planning of the operations of Mines, Railway, and Port in the North Corridor. Prior to working at VALE, he was employed at AMBEV and Ultragaz S/A.

Sobrinho, Valdeilton N. has been in the railway industry for 9 years. He graduated in the technology field with a background in Systems Analysis and Development from Unicesumar University, Brazil, and he has technical training in mining at CTP Institute, Brazil. He has been involved in mine planning, product transportation, iron ore dispatch with manual loading into wagons using a loader, and at the plant. He Worked at the largest mining complex in Vale's history, the S11D Eliezer Batista Complex. and provided operational management support in Carajás, Brazil. Currently, he is a mine operations supervisor at Serra Leste, Brazil, at VALE S.A. and is responsible for the transportation of iron ore from the production plant to the railway loading terminal.