CNT - Confederação Nacional dos
Transportes DB - Deutsche Bahn
ITL - Instituto de Transporte e Logística
International Certification in Management of Rail and Metro Rail Systems

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Reduction of number of Railroad Accidents with Locomotive as the main cause

Final Project

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

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ACKNOWLEDGEMENTS

We thank our families for staying by our side and understanding the moments of absence to dedicate ourselves to our course;

We also thank Rumo Logística and CDN for giving us the unique opportunity to participate in this course and to believe in our potential, Investment in our professional development.

We also thank the technicians and specialists of Rumo's locomotive department for the partnership in implementing new methods of Risk Analysis, Lean Methodologies and Agile thinking listed in this article.

To the institutions involved in this course, such as the CNT - National Transport Confederation, ITL - Institute of Transport and Logistics, and DB – Deutsche Bahn, a management that granted this great learning and provided all the necessary support for the perfect completion of the course.

We thank all the teachers for providing us with the knowledge in the process of perfecting our professional training, and what they are to nominate, they will have our eternal thanks.

Finally, we thank all those who have contributed in some way to our professional development.

ABSTRACT

As accidents, involving locomotives have high direct and indirect costs, this project aimed to investigate and treat the main mechanisms of derailment associated with locomotives in a Brazilian freight railway company. Thus, a multidisciplinary team carried out a process FMEA in the period from February 2018 to February 2019. Process FMEA is a specific and systematic method to evaluate the possible ways in which failures can occur in a manufacturing or assembly process. The main failure modes detected were related to the processes of: a) wheelset assembly; b) “Traction Motor Combo” assembly; c) “Traction Motor Combo” installation and; d) wheel machining. To solve these detected failures, procedures were improved or created, team was trained, new measurement equipments were bought and adopted and audit procedures were reviewed. As main results, we observed a significant reduction in the number of accidents with locomotives was major cause and their associated costs.

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LIST OF ABBREVIATIONS AND ACRONYMS

5S	5 Senses
ABNT	Associação Brasileira de Normas Técnicas
ANTT	Agência Nacional de Transportes Terrestres
CAPEX	Capital Expenditures
CNT	Confederação Nacional de Transporte
DB	Deutsche Bahn
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization”
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
GE	General Electric
ITL	Instituto de Transporte e Logística
MM	Million
NASA	National Aeronautics and Space Administration
OPEX	Operational Expenditures
P.O	Operational procedure
ROA	Return on Assets
RPN	Risk Priority Number
SCRUM	Agile Development, Software Development.
TEU	Twenty feet Equivalent Unit
TIR	Internal Rate of Return
TKU	Tonnage-Kilometer Useful
TQM	Total Quality Management
VSM	Value Stream Mapping
WACC	Weighted Average Cost of Capital

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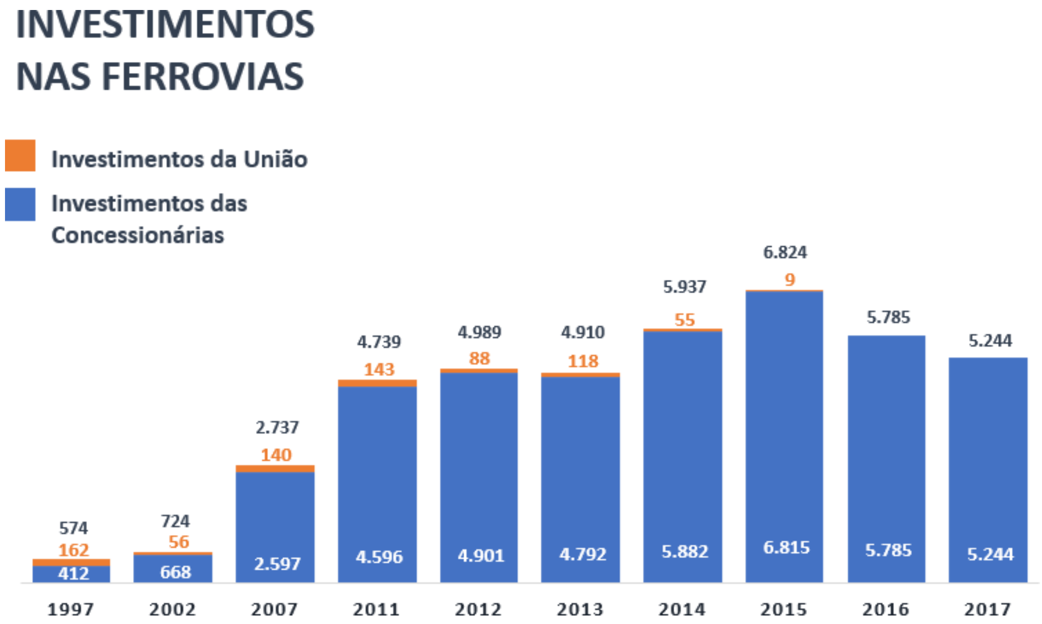
1 INTRODUTION

1.1 Initial considerations about Brazilian Cargo Railways

The Brazilian rail cargo sector since railroads were granted to the private initiative, a process started since 1996, rail freight transport has undergone a profound trans- formation. According to the ASSOCIACÃO NACIONAL DOS TRANSPORTADORES FERROVIÁRIOS - ANTF(2) Brazilian railroads productivity (in TKU) increased and have also gained efficiency in the concession period, which can be represented by the growth of railway production, which is calculated by the measure that indicates the number of tons of cargo moved to each kilometer. In 2017, Brazilian railroads transportes 375 billion TKU (tons per kilometer useful), a considerable increase of 9.9% over the result of 2016 (341 billion TKU). Since the beginning of concessions, growth has been more than 170%.

Since 1996/1997, when the concessions started, railroads have already invested more than R$ 92 billion, mainly destined for the improvement and recovery of the network, the purchase and the reform of rolling stock, as well as the acquisition of new technologies, professional qualification, qualification of the operations, among others. In 2014, investments hit a record, reaching R$ 6.81 billion. In 2017, R$ 5.24 billion was invested, enabling a significant growth in the fleet of rolling stock. In 1997, railroads had 1,154 locomotives. In 2017, they already totaled 3,268 units, representing an increase of 183%. In the same period, the number of wagons went from 43,816 to 109,160 - a high of 149%(2). The investiments done since 1997 can be seen in Graphic 1.

Graphic 1 – History of Investments in Railways in Brazil (R$ Million)

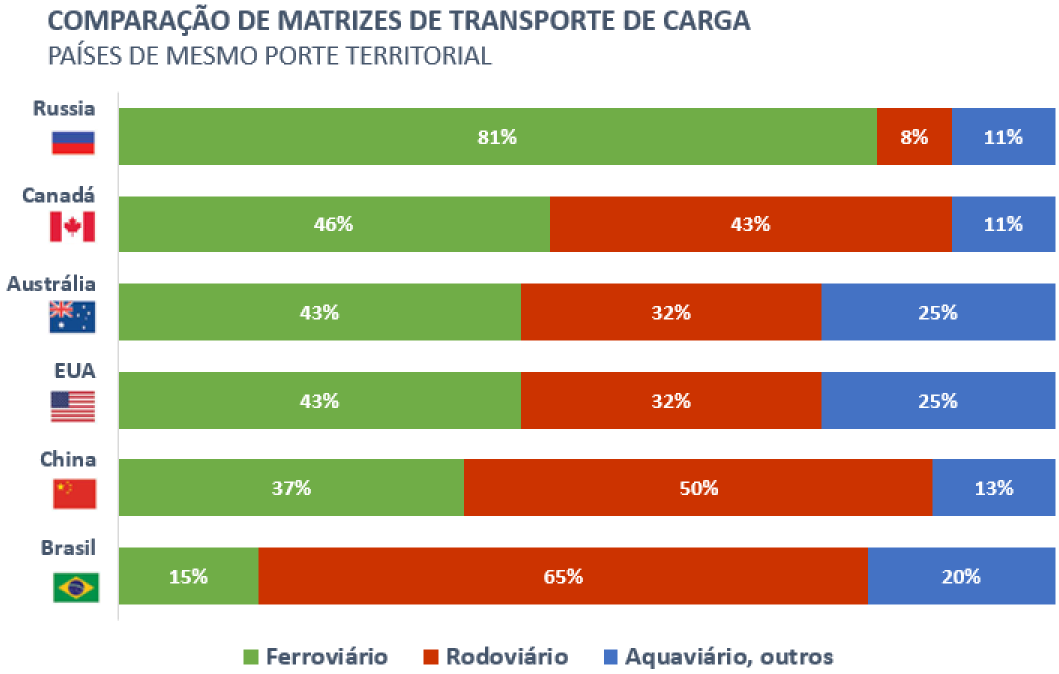


https://www.antf.org.br/informacoes-gerais/

The reduction of the accident index between 1996 and 2017, according ASSOCIACÃO NACIONAL DOS TRANSPORTADORES FERROVIÁRIOS - ANTF(2) was reduced the accident rate by more than 86%, maintaining international safety stan- dards.

In these more than 20 years of concession to the private initiative, the railroads increased the participation in the Brazilian transport matrix and account for about 15% of “share”. But there is still room to grow. Comparative data can be seen in the Graphic 2.

Graphic 2 – Compative of Cargo Transport Matrices in Brazil



https://www.antf.org.br/informacoes-gerais

To get an idea of the importance of railways in logistics, according ASSOCIACÃO NACIONAL DOS TRANSPORTADORES FERROVIÁRIOS - ANTF(2), more than 95% of the minerals reach the ports by rail. The modal is responsible for transporting more than 40% of the exported agricultural solid bulk, and in the case of sugar, this index is 46%.

Although the transportation of mineral and coal represents approximately 80% of the total volume, the railways have tried to diversify the transported loads. The movement of containers, for example, has shown a very positive expansion. Since 1997, container handling has grown almost 130 times. By 2017, more than 442,000 TEUs (equivalent to a 20-foot container) were transported by rail.

1.1.1 Rumo S.A.

Rumo is the largest rail operator in Brazil, offering logistic services for rail transportation, lifting in ports and stocking products. Currently, its asset base is composed of four concessions, totaling 12,000 km of railways, 1,000 locomotives and

27,000 railcars, as well as distribution centers and storage facilities. Railways are spread over six states and can be narrow gauge (1000mm) or broad gauge (1600mm).

As a result of a merger between Rumo Logística (Cosan Group) and the former América Latina Logística (ALL), the company now operates 12 transhipment terminals (both directly and in partnership) with a static storage capacity of approximately 900 thousand tons of grains, sugar and other commodities.

The Company has interests in six port terminals, five of them in the Port of Santos (SP) and one in the Port of Paranaguá (PR), with a capacity to store approximately 1.3 million tons and a cargo capacity of approximately 29 million tons per annum.

Figure 1 – Operation of Rumo S.A. in 2019

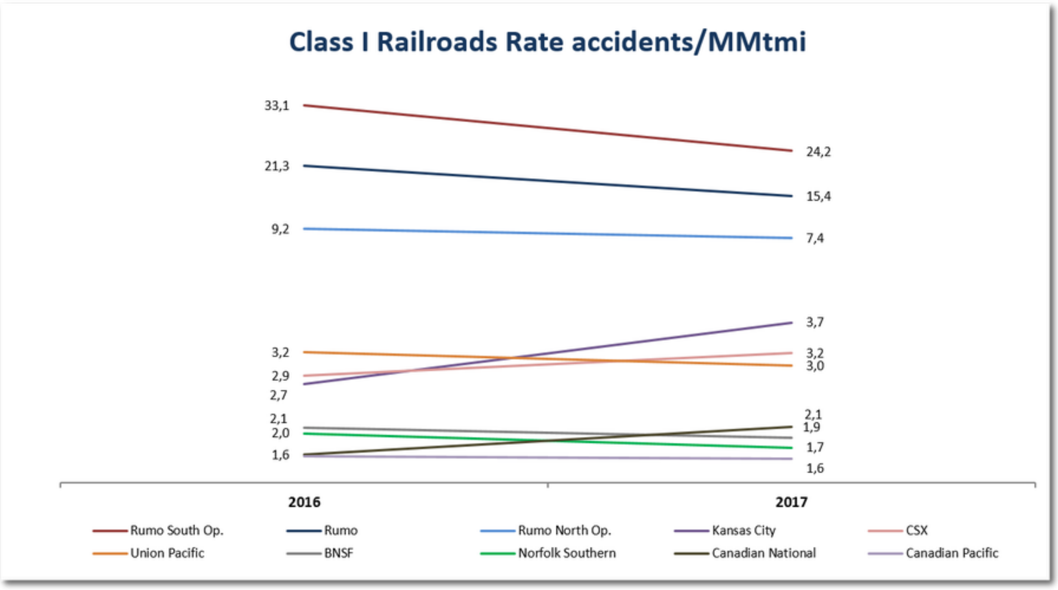
http://pt.rumolog.com/conteudo_pti.asp?idioma=0&conta=45&tipo=66433

In four years of operation, following the merger of Rumo, the railway accident rates continued to fall, reflecting a new conduct of the operation and a high value of investments applied in the railway network granted to Rumo.

Comparing the indices of the north operation of Rumo, an operation with higher productivity, with the North American Class I (One) railroads (3) between

2016 and 2017, Rumo still has a high accident rate, but it shows a decrease in its rate, as shown in graphic 3:

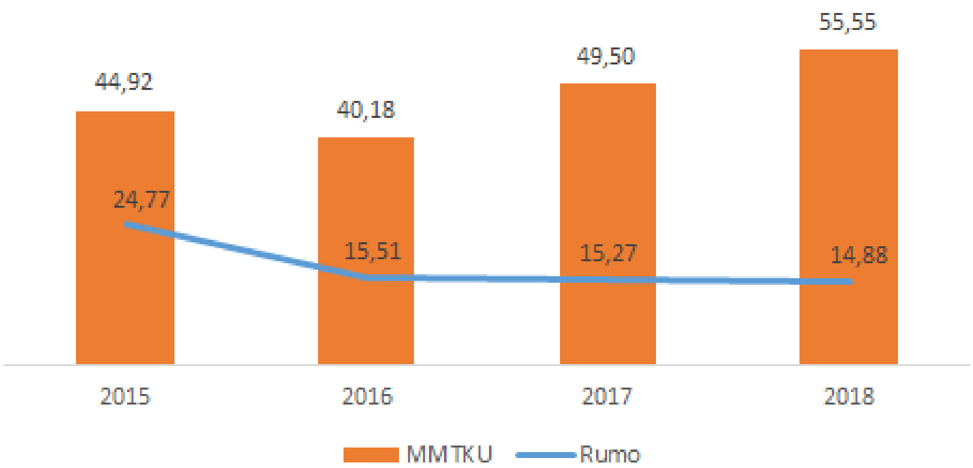
Graphic 3 – Class I Railroads Rate accidents/MMtmi



Security Operational Department at Rumo

According to ANTT - Agência Nacional dos Transportadores Ferroviários(4), the average number of rail accidents at Rumo’s four railway concessions between 2015 and 2018 was reduced by 39%, as graphic 4, even with the 24% increase in volume transported in the same period(5).

Graphic 4 – Average of the accidents index of the concessionaires Rumo, between 2015 and 2018. (MMtku)



ANTT - Agência Nacional dos Transportes Terrestres , 2019

Even with the significant reduction in the number of rail accidents in Brazil, ac- cording to ANTT - Agência Nacional dos Transportadores Ferroviários(4), and especially in the railways concessioned to Rumo(5), and large investments in the railway sector, mainly by the concessionaires, there are still gaps that must be studied for constant improvements, number and severity of accidents.

The constant search for reductions in number and severity of accidents at Rumo, causes all causes of these accidents to be understood and studied, to improve processes and procedures. Rail accidents have already cost about R$ 300 million to Rumo between 2016 and 2018, and these values could increase the company's results, instead of becoming costs.

1.2 Justificative

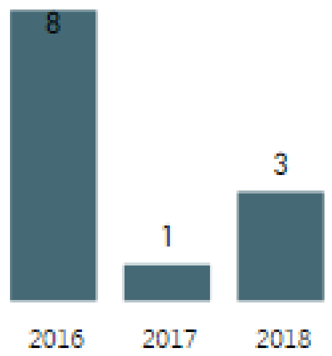
In the constant search for reduction of costs with rail accidents, a gap was identified regarding rail accidents caused by locomotive failures. The locomotive is one of the most relevant assets of a railroad, as it is the source of traction of the compositions and also because of its high cost and great demand for maintenance.

The railways make a great effort to keep their locomotives productive and with high reliability, but it is understood that there is an important gap to be filled when talking about railway accidents with root cause in locomotives.

Among all the causes of railroad accidents in the transportation of loads, we can mention that accidents involving locomotives have high associated costs. Some direct costs can be mentioned, such as: repair costs of components damaged in the locomotive, axis and locomotives, among others. Indirect costs are also observed in these accidents, such as: costs with the locomotive unavailability for the operation and penalty rate.

In Rumo north operations, focus of this work, locomotive root cause accidents represented a relatively low number, in comparison with the total number of accidents between 2016 and 2018, as graphic 5 .

Graphic 5 – Number of accidents with locomotive cause, in north operation



Rumo S.A. 2018

However, accidents with locomotive causes tend to be more severe and costly if the causes are not addressed in all the company's fleet. Rumo is estimated to have spent around R$ 4 million on locomotive-related accidents between 2016 and 2018.

Because of this, the application of methodology to solve problems is essential for the achievement of accident reduction goals, with locomotives cause.

1.3 Goals

The objective of this work is to present a method based on the concepts of risk analysis and reliability through tools such as cause and consequence analysis, fault tree analysis and FMEA type analysis. This last one tries to identify causes of the possible derailment with locomotive cause, and of this form assists in the proposition of actions of risk reduction that can be used in old systems or solutions that must have its implementation guaranteed in new systems for the reduction of the rate of occurrence of this event.

The focus of the work and the use of the tools mentioned above is to reduce the number of accidents / potential accidents and their associated costs, as well as to verify if the main mechanisms of derailment associated to the locomotives as main cause were investigated and treated.

1.4 Scope of work

This work focuses on the presentation of the method of risk analysis applied to the study of locomotive accidents in Rumo Logistica, North Operations (States of São Paulo and Mato Grosso in Brazil).

Investigations and treatments proposed in this work describe a real case of knowledge application, implemented between Feb/18 and Feb/19 during the modules proposed by DB, for the reduction of failures.

First, we discuss the method of analysis used, addressing fundamental concepts of reliability and some tools to analyze the cause of the locomotive defect, such as the cause and consequence diagrams and the FMEA and FTA analyzes. After the description of the method of analysis, the elements considered in the analysis of the locomotive defect event will be detailed, that is, the systems of the rolling stock (locomotive) will be approached succinctly, being able to cite the tricks, couplings, among others.

The various analysis tools will be applied to the study and, finally, the project actions and maintenance policies developed during the railway evolution that can be considered to avoid locomotive accidents will be discussed in order to make this event less likely to occur.

1.5 Structure

The work is structured in five chapters that address the following topics:

- Chapter I: Introduction, Initial Considerations, Justification, Objectives, Scope of work, structure;
- Chapter II: Bibliographic review, Research Results;
- Chapter III: Hypotheses, General Ideas, Risk Analysis, Cost Benefit Analysis;
- Chapter IV: Project Plan, Implementation Plan, Financial Plan;
- Chapter V:Presentation of the results obtained with work;
- Chapter VI: Final considerations about work.

2 LITERATURE REVIEW

2.1 FMEA - Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) was created by US Army but first formally applied by NASA in 1963 and spread to the automotive manufacturing industry, with the goal of quantify and order potential defects during the design stage so that they don't reach the customers(6). The FMEA was promoted by the aeronautics and automobile industry, since then it has been recognized as a tool of great importance, and is applied in the most diverse areas, from the electrical and electronic industries, chemical, petrochemical, pharmaceutical industries and even in hospitals (7).

According to STAMATIS(8), FMEA is a specific and systematic method to evalu- ate the possible ways in which failures, such as problems, errors, risks and concerns, can occur in a system, design, process or service. A properly and appropriated conduced FMEA leads to: a) identification of known and potential failures; b) identification of causes and effects of each failure mode; c) prioritization of failure modes according to its risks; d) follow up and correction actions.

Following new tendencies on risk analysis, FMEA focuses on prevention and emphasizes the mitigation of the probability or the effects of failures (8) to constantly improve the processes and products of the companies (7). So, once the failures were identified, their effects on performance and safety are recognized, and actions are taken to eliminate or minimize the effects of these failures. This tool has a predictive character of failures and can be applied even in the product development and in the design phases, in order to reduce the frequency of occurrences and to improve the efficiency in the detection of possible failures, reducing the need for rework in later stages (1).

A brief research in literature, points out that FMEA has been used in many contexts, like transports, mining sector, automotive, chemical and beverage industry and so on. Specifically in Brazilian railway operations, can be mentioned the application of FMEA by OLIVEIRA(9), FELIX et al.(10), HONG(11) and SCHUINA(12). OLIVEIRA(9) applied FMEA and other tools to propose a model to control the maintenance cycle and ensure the availability and reliability of railway equipments. FELIX et al.(10) used FMEA to identify the main personal insecure practices in the wagons maintenance activities. HONG(11) applied FMEA to make a risk analysis of derailment events. Therefore, the author analyzed each of these derailments causes: rail, rolling stock, linkage, brake and traction. The study of SCHUINA(12) used FMEA to increase the lifetime of the railway ballast.

The application of FMEA confers many advantages such as: answer to client specifications; cut of costs and launch times; quality and reliability improvements; greater safety during the manufacturing process; and more customer satisfaction (6).

As there are many fields of application, STAMATIS(8)described four types of FMEA: system; design; process; and service, but is more common the division in two kinds of FMEA: process and product. As the focus of this work is as process, it will emphasize this kind of FMEA, which is used to analyze manufacturing and assembly processes.

FMEA must be started as soon as possible. For the success of an FMEA, one of the most important factors is the timing of its execution: FMEA should be a “pre- event” action and not a “post-facto” exercise. However, its implementation should be reviewed whenever there are significant changes in the manufacturing process (13). In case of a process FMEA, it can be considered finished only when all operations have been identified and evaluated and all critical and significant characteristics have been addressed in the control plan. The FMEA has to be conducted by a crossfunctional and multidisciplined team, that works specifically in that project, avoiding biases based on the single perspective of an individual (8). Another crucial factor for a successful FMEA project is the commitment of Top Management (13).

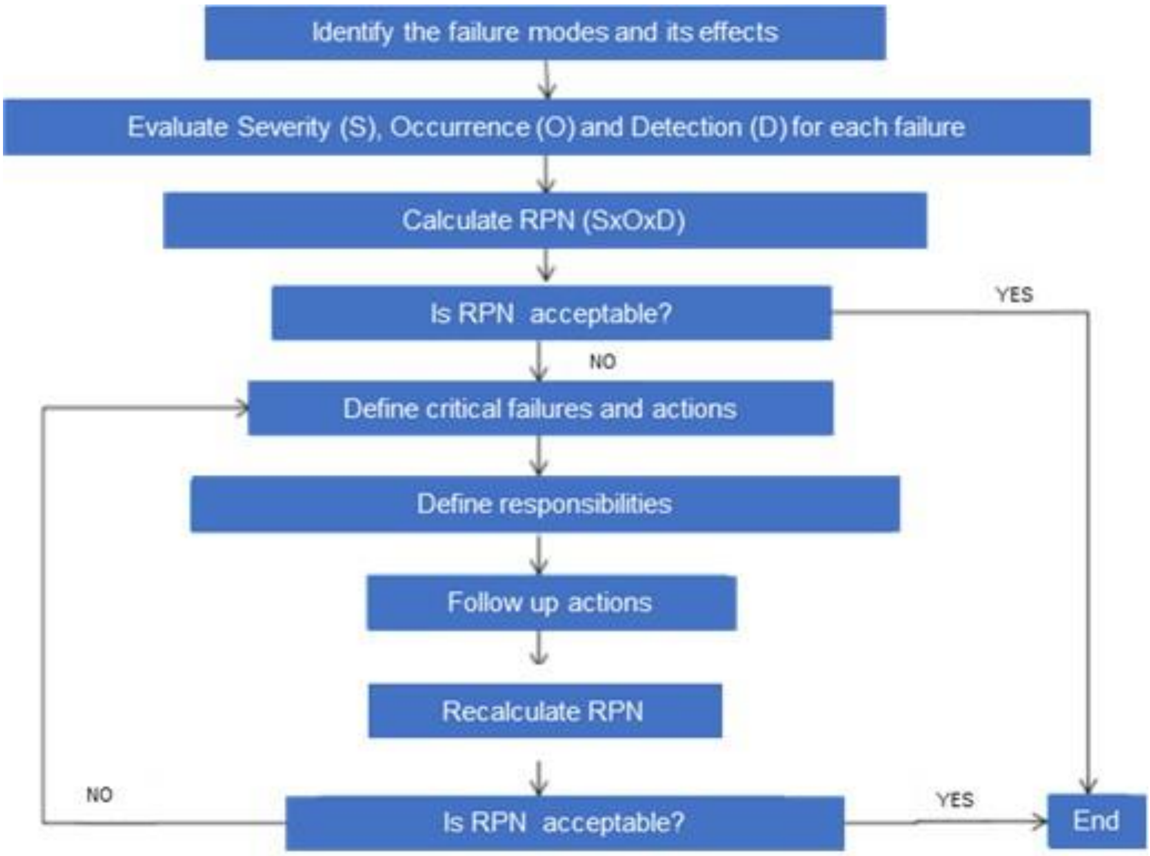
PUENTE et al.(6) point that FMEA, basically, consist of two stages. The first stage consists on identifying possible failure modes of a product or process and its prejudicial effects. The second stage aims to determines the risk score (RPN - Risk Priority Number[1]) of these failures, putting them in order and proposing the relevant modifications. The first stage starts with a flow chart in which the group describes the activity or function to be analyzed and all information about it.

REBELATO et al.(14)detail the process and consider that a FMEA should be conducted following nine steps:

- Identify the failure modes: Identify events that result in known or potential reduction of function and system performance objectives;
- Identify the effects of each failure mode and their respective severity;
- Identify the possible causes of each failure mode and its probability of occurrence;
- Identify the current means of control of the failure mode and its probability of early detection;
- Evaluate the Risk Priority Numbers (RPN) of each failure mode;
- Judge whether the RPN is acceptable or not;
- If RPN[1] is an unacceptable level, define measures for the elimination or reduction of RPN. This is achieved through actions that increase the chances of detection or reduce the probability of failure;
- Define those responsible for implementing improvements, monitoring deployment and recalculating RPN;
- If the new RPN is still at an unacceptable level, further improvement measures should be re-planed.

A flow chart with these steps is shown in Diagram 1:

Diagram 1 – Flow chart of FMEA process



Adapted from REBELATO et al, 2015

The information required to complete a process FMEA is in frame 1:

[1] RPN = Occurrence(O) x Severity (S) x Detection (D).

Frame 1 – Process FMEA worksheet(15)

												Action Result				
Process Step/ Function	Requirements	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes/ Mechanisms of Failure	Current Process Controls Prevention	Occurrence	Detection	RPN	Recommended Actions	Responsability /Target Date	Actions Taken	SEV	OCC	DET	RPN

Adapted from QUALITY-ONE INTERNATIONAL, s/d

The RPN can be defined by three components: a) Occurrence, that is the frequency of failure (O); b) Severity, that corresponds to the seriousness of the failure and (S); c) Detection, that is the ability to detect the failure before it reaches the costumer (D). Quantitative or qualitative guidelines are used to determine the value of these three components, so a ranking of what failures should be addressed first can be obtained by the product of the three components: O x S x D (8). To classify the risks can be used, for example, a scale ranging from 1 to 1000 points, in which "1" is a very low risk and "1.000" a critical risk to the user(14). RPN values should be recalculated after a certain time-blapse to identify if they have changed, and so to check the efficiency of the corrective action for each failure cause (6).

Table 1 – Correspondence map between severity, occurrence and detectability indexes and the qualitative scale for the importance associated with each evaluation criterion(1)

Level	*S* Index	*O* Index	*D* Index	*I* (S,O,D)
L_1	No	Almost never	Almost certain	No
L_2	Very slight	Remote	Very high	Very low
L_3	Slight	Very slight	High	Low
L_4	Minor	Slight	Moderate high	Minor
L_5	Moderate	Low	Medium	Moderate
L_6	Significant	Medium	Low	Significant

Level	*S* Index	*O* Index	*D* Index	*I* (S,O,D)
L_7	Major	Moderately high	Slight	Major
L_8	Extreme	High	Very slight	High
L_9	Serious	Very high	Remote	Very high
L_{10}	Hazardous	Almost certain	Almost impossible	Absolute

FRANCESCHINI; GALETTO, 2001

For Ammerman (1998 *apud* (6) the following order of priorities must be established for applying corrective action:

1) Eliminate the cause of the failure;
2) Reduce the frequency or probability of failure occurrence;
3) Reduce the severity of the failure;
4) Increase the likelihood of detection (increasing controls or improving the existing controls).

PUENTE et al.(6) alert that whereas reducing the frequency of a failure is a preventive measure, increasing detection controls is a contingent action and should only be used as a temporary solution till the problem can be resolved once and for all.

These authors also bring some criticism to the traditional FMEA, especially about RPN, that them, and other authors, consider as inadequate, as it doesn't considerate quantity produced, doesn't take in account different importance of “D”, “O” and “S” indexes and the impossibility of RPN to measure the effectiveness of proposed corrective measures(6). SILVA, HERMOSILLA e SILVA(16) made a research in an automotive industry and also considered that the definition of the RPN was subjective and the multifunctional team often used the tool only for the requirements of the technical specification and not as an activity that could add value to the company. SOARES(7) also refers to some limitations of FMEA like: there is very little interaction between the project FMEA and process; the process FMEA is executed late; and the FMEA does not promote a structured analysis of the whole manufacturing process.

SOARES(7)points out some recommendations to improve FMEA's results, such as: a) make sure that the defined actions are carried out until their completion; b) periodically review and update FMEA; c) prepare standard rating scales with examples for severity, occurrence and detection; d) use FMEA as a repository of engineering knowledge and e) use FMEA specific software.

2.2 Research Results

Diesel electric locomotives are complex equipment that have several systems, such as: Traction motor Combo, Diesel engine, Air brake system, Propulsion system, Structure, On-board equipment, etc. For FRA - FEDERAL RAILROAD ADMINISTRA- TION(3), Train accidents are frequently the culmination of a sequence of events, and a variety of conditions or circumstances that may have contributed to its occurrence and have met the dollar criteria for reporting.

For FRA - FEDERAL RAILROAD ADMINISTRATION(3), the main causes for Mechanical and Electrical Failure are:

- Brakes
- Trailer or Container on Flatcar
- Body
- Coupler and Draft System
- Track Components
- Axles and Journal Bearings
- Wheels
- Locomotives
- Doors
- General Mechanical Electrical Failure

According to Xiang, Saat e Barkan(17), evaluating the accident database of the(3) from 2001 to 2010, it is possible to relate the frequency and severity of each cause of accident. The main cause of accidents in the period is related to rails and welds fracture, responsible for 15.3% of the frequency and 22.7% of severity. Accidents with locomotive-related causes accounted for 1.4% of the frequency and 0.9% of gravity. Of these 1.4% of frequency, 1.1% are related to failures in trucks, wheels and bearings.

Table 2 – Derailment Frequency and Severity by Accident Cause on Class I Main Lines, Sorted by Frequency

Cause Group	Description	Derailments		Cars Derailed		Average Number of Cars Derailed per Derailment
		Number	Percentage	Number	Percentage	
08T	Broken rails or welds	665	15.3	8,512	22.7	12.8
04T	Track geometry (excluding wide gauge)	317	7.3	2,057	5.5	6.5
10E	Bearing failure (car)	257	5.9	1,739	4.6	6.8
12E	Broken wheels (car)	226	5.2	1,457	3.9	6.4
09H	Train handling (excluding brakes)	201	4.6	1,553	4.1	7.7
03T	Wide gauge	169	3.9	1,729	4.6	10.2
01M	Obstructions	153	3.5	1,822	4.9	11.9
05T	Buckled track	149	3.4	1,891	5.0	12.7
04M	Track–train interaction	149	3.4	1,110	3.0	7.4
11E	Other axle or journal defects (car)	144	3.3	1,157	3.1	8.0
03M	Lading problems	134	3.1	791	2.1	5.9
07E	Coupler defects (car)	133	3.1	771	2.1	5.8
13E	Other wheel defects (car)	129	3.0	668	1.8	5.2
09E	Sidebearing, suspension defects (car)	126	2.9	816	2.2	6.5
10T	Turnout defects: switches	118	2.7	601	1.6	5.1
11H	Use of switches	104	2.4	407	1.1	3.9
06E	Centerplate or carbody defects (car)	98	2.3	507	1.4	5.2
01H	Brake operation (main line)	95	2.2	881	2.4	9.3
12T	Miscellaneous track and structure defects	80	1.8	687	1.8	8.6
01T	Roadbed defects	67	1.5	665	1.8	9.9
07T	Joint bar defects	66	1.5	1,040	2.8	15.8
10H	Train speed	61	1.4	403	1.1	6.6
09T	Other rail and joint defects	56	1.3	1,132	3.0	20.2
19E	Stiff truck (car)	55	1.3	365	1.0	6.6
05M	Other miscellaneous	54	1.2	422	1.1	7.8
15E	Locomotive trucks, bearings, wheels	50	1.1	177	0.5	3.5
18E	All other car defects	47	1.1	248	0.7	5.3
06T	Rail defects at bolted joint	46	1.1	927	2.5	20.2
12H	Miscellaneous human factors	44	1.0	377	1.0	8.6
02T	Nontraffic, weather causes	43	1.0	331	0.9	7.7
02H	Handbrake operations	41	0.9	177	0.5	4.3
20E	Track–train interaction (hunting) (car)	40	0.9	419	1.1	10.5
05E	Other brake defect (car)	37	0.9	187	0.5	5.1
08E	Truck structure defects (car)	35	0.8	265	0.7	7.6
07H	Switching rules	30	0.7	198	0.5	6.6
02E	Brake rigging defect (car)	27	0.6	148	0.4	5.5
01E	Air hose defect (car)	19	0.4	148	0.4	7.8
01S	Signal failures	17	0.4	121	0.3	7.1
17E	All other locomotive defects	13	0.3	155	0.4	11.9
11T	Turnout defects: frogs	11	0.3	97	0.3	8.8
08H	Mainline rules	11	0.3	56	0.1	5.1
16E	Locomotive electrical and fires	10	0.2	28	0.1	2.8
04E	UDE (car or locomotive)	8	0.2	86	0.2	10.8
03H	Brake operations (other)	4	0.1	47	0.1	11.8
05H	Failure to obey or display signals	4	0.1	23	0.1	5.8
04H	Employee physical condition	3	0.1	41	0.1	13.7
06H	Radio communications error	3	0.1	13	0.0	4.3
14E	TOFC–COFC defects	2	0.0	2	0.0	1.0
03E	Handbrake defects (car)	1	0.0	2	0.0	2.0
	Total	4,352	100	37,456	100	8.6

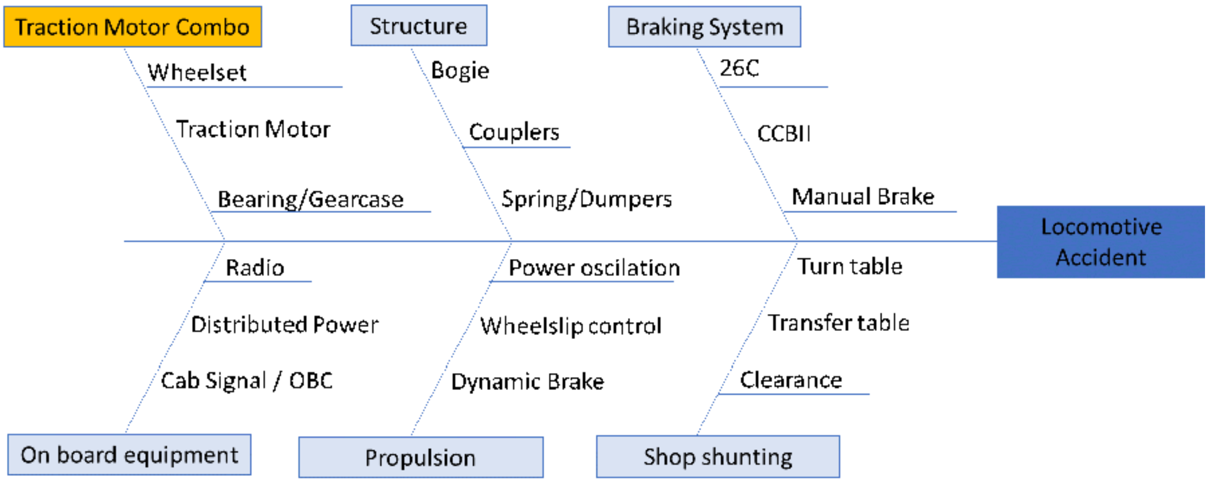
NOTE: UDE = undesired emergency (brake application); TOFC = trailer on flat car; COFC = container on flat car.

LIU, XIANG. Analysis of Causes of Major Train Derailment and Their Effect on Accident Rates. Detailed analysis of the train accident data supplied by the railroads to FRA of the U.S. Department of Transportation. Rail Transportation and Engineering Center, Department of Civil and Environmental Engineering, University of Illinois, 2012.

3 HYPOTHESES

The diagram 2 below lists the main locomotive systems or locomotive maintenance processes where there have been railway accidents in the last 10 years on the Rumo railway.

Diagram 2 – Ishikawa diagram for Rumo main Locomotive root causes

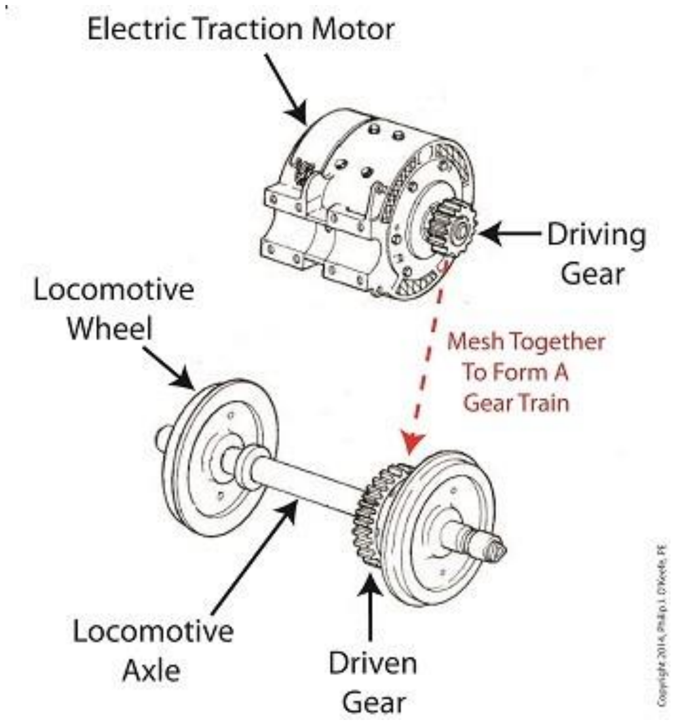


Rumo S.A. 2018

Among all the possible causes of locomotive-related accidents, it was possible to observe in the analysis 3 that the cause with the greatest recurrence is related to the ‘Traction Motor Combo’.

Figure 2 shows the main components of the so called ‘Traction Motor Combo’:

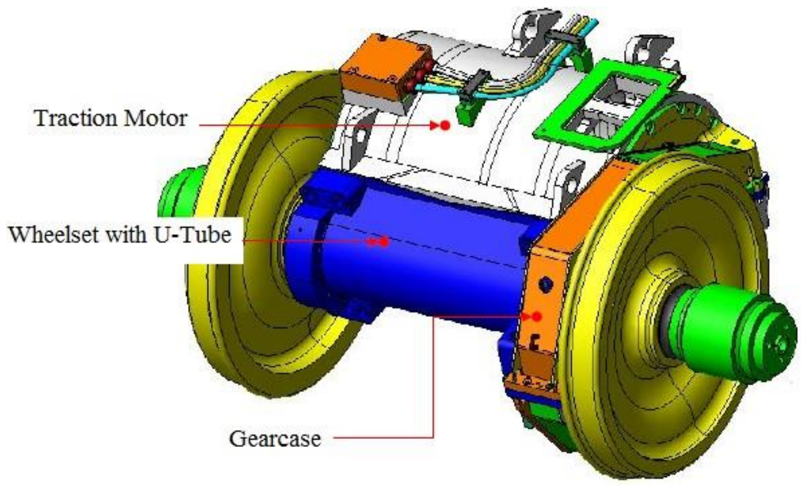
Figure 2 – Locomotive Traction Motor Combo main components(18)



EEWB, 2014

At Rumo North Operation the main locomotive fleet is composed by 221 units of GE AC44 locomotive. Figure 3 shows the GE AC44 Traction Motor Combo.

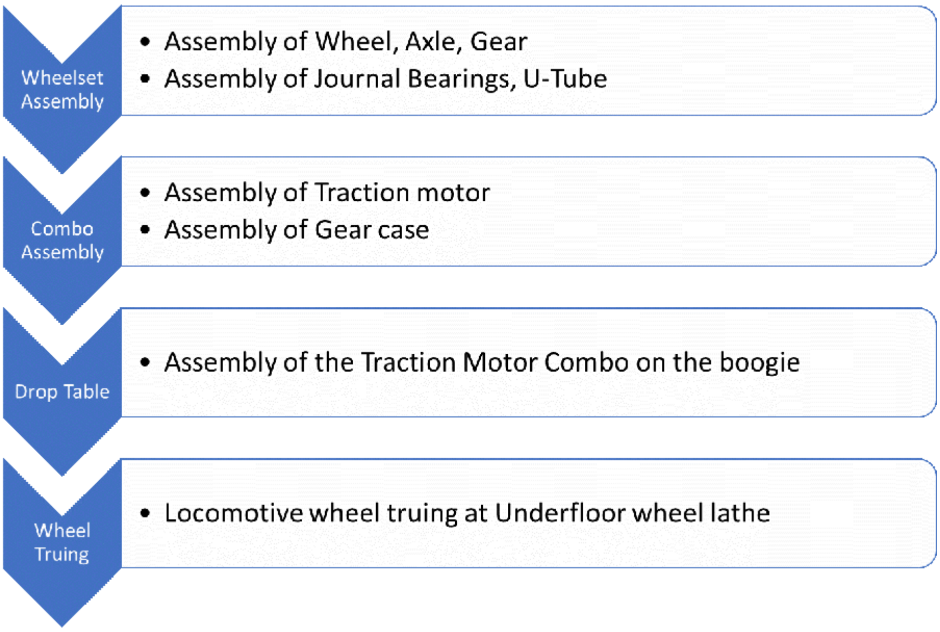
Figure 3 – GE AC44 Traction Motor Combo



EEWB, 2014

Further, detailing the analysis it was possible to observe that the 'Traction Motor Combo' is a set that passes through different sub-processes when analyzed the entire macro process of maintenance of locomotives. In the following figures (Diagram 3 and Figure 5 – 9) the sub processes are illustrated.

Diagram 3 – Rumo Traction Motor Combo sub-processes



Rumo S.A. , 2019

Figure 4 – Wheelset Assembly Process

Rumo S.A., 2018

Figure 5 – Wheelset Assembly Process.

Rumo S.A., 2018

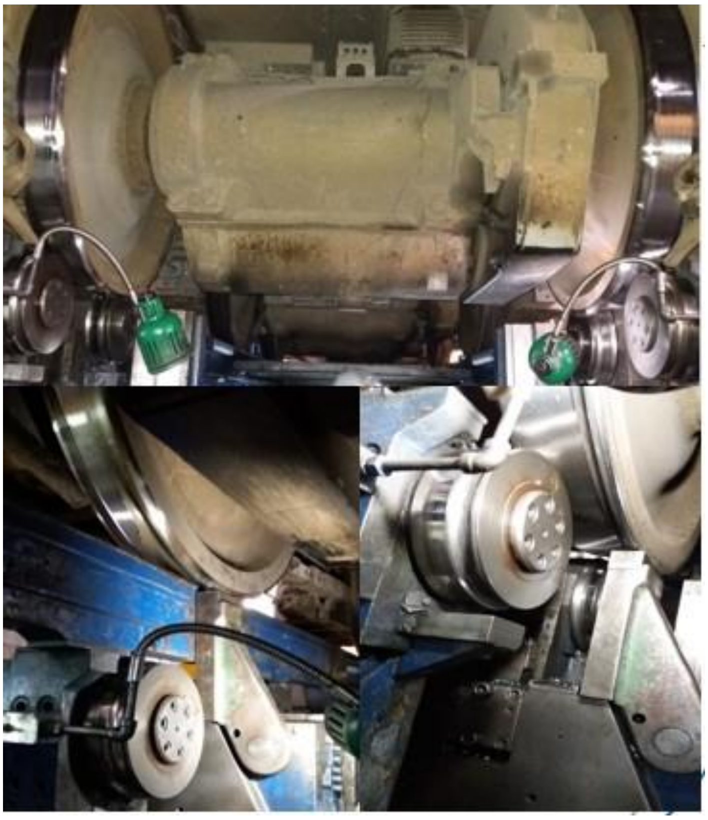
Figure 6 – Combo Assembly Process

Rumo S.A., 2018.

Figure 7 – Drop Table Process

Rumo S.A., 2018

Figure 8 – Wheel Truing Process on the Underfloor Wheelset Lathe



Rumo S.A., 2018

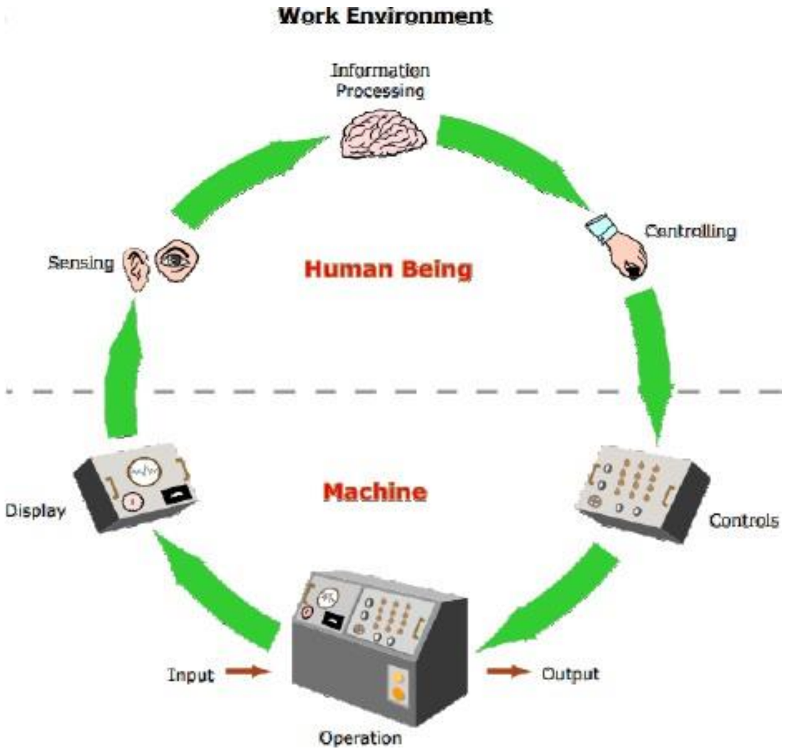
During the mapping of the ‘Traction Motor Combo’ subprocesses it was observed that over the last few years significant investments in equipment and technology have been made in order to reduce the risk of process failures. The investments made have in fact greatly reduced the frequency of accidents related to the Traction Engine Combo, however, even after these investments, this remains the main cause of railway accidents related to the locomotive.

Figure 9 – Equipment and technology implemented at Rumo for Traction Motor Combo risk reduction

Rumo S.A., 2019

Having greatly reduced the contribution of machine-related causes, the analysis showed that the focus of the work should be on improving processes and human being. According to RSSB(19) “Human Factors” means “all the ’people’ issues we need to consider assuring the lifelong safety and effectiveness of a system or an organization”.

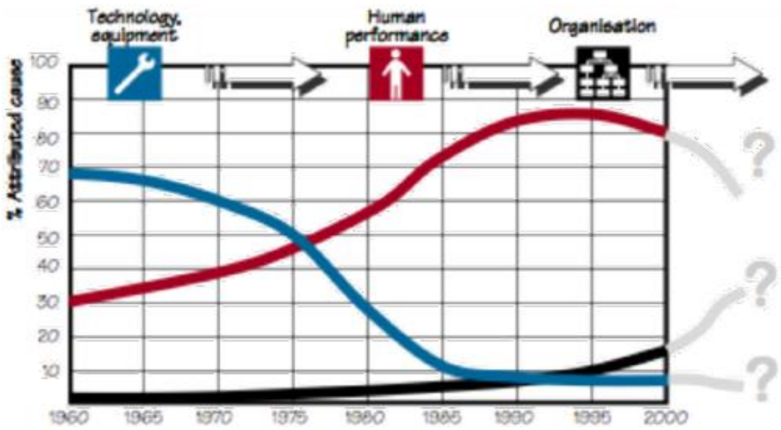
Figure 10 – Human Machine Interface



RSSB, UK's Rail Safety and Standards Board, 2008.

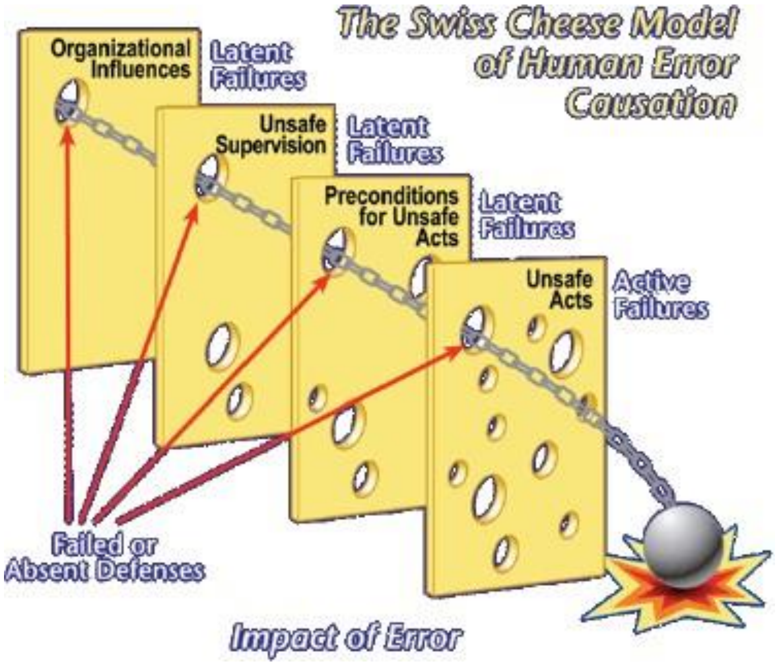
According to DEUTSCHE BAHN(20), causes of hazards and therefore accidents are caused by one or a combination of the following causes Technology/equipment, Human Performance, Organization.

Graphic 6 – Hazards caused by combination of Technology, Human Performance and Organization



DB, DEUTSCHE BAHN, 2018.

Figure 11 – The Swiss Chees Model of Human Error Causation



DB, DEUTSCHE BAHN, 2018.

Correlating the existing Models of Risk and Hazard Analysis the FMEA tool was selected as the most suitable for the improvement of the risk analysis related to the ‘Traction Motor Combo Process’.

Figure 12 – Models of Risk and Hazard Analysis

Methods	Risk Analysis	Hazard Identification	Hazard Analysis	Safety Case	IEC Standard
Event Tree Analysis (ETA)	Applicable	Not applicable	Possible		-
Failure Modes, Effects and Criticality Analysis (FMECA)	Only applicable for serial systems without redundancies	Applicable	Only applicable for serial systems without redundancies		60812
Fault Tree Analysis (FTA)	Possible	Not applicable	Applicable		61025
Hazard and Operability (HAZOP)	Not applicable	Applicable	Not applicable		61882
Markov-Model	Applicable	Not applicable	Applicable		61165
Reliability Block Diagram (RBD)	Not applicable	Not applicable	Only for non-repairable systems		61078
Common Cause Failure (CCF)-Analysis	Support	Not applicable	Support		-

DB, DEUTSCHE BAHN, 2018.

3.1 Generate Ideas

Considering the hypotheses, the focus is in the processes of assembly and installation of the motor traction combo.

Furthering the different applications of the FMEA tool it was observed that in order to analyze the risks associated to human behavior, as well as to the processes, the ideal application would be the process FMEA.

According to RAUSAND(21), ‘Process FMEA is focused in problems stemming on how the equipment is manufactured, maintained or operated’.

Strategy for reviewing the Tactical Railway Safety Plan for Locomotives:

- Training of risk analysis methodology (Process FMEA - Oct 18);
- Creation of three working groups:
  - Assembly of Wheelset;
  - Assembly of Combos;

- Machining Wheels on Underground Lathe.

- Weekly group meetings at the operational areas for 2 months until completion of Risk Analysis for each of the working groups.
- Prioritization of listed actions and dissemination of the Tactical Rail Safety Plan for Locomotives, also called Implementation Plan.

Figure 13 – Training of risk analysis methodology

Rumo S.A., 2018

3.2 Risk Analisys

After carrying out the risk analysis training with the use of the FMEA Process tool, the execution of the mapping and risk analysis was started in the processes of Assembly of Wheelset, Assembly of Combos and Machining Wheels on Underground Lathe. The risk analysis was based on information and stages of the processes evaluated in the field. Specialists from each process, together with the railway engineering team, followed the execution of the activities, and sought to capture the possible causes of process failure for each mode of failure. The procedures, tools, materials and training of the professionals involved in the Traction motor combo processes were evaluated.

Figure 14 – Risk Assessment during the Assembly of wheelset

Rumo S.A., 2018

The table below summarizes the use of FMEA in the wheelset assembly process. The table shows that the NPR was calculated from the severity of the effect, occurrence of the cause and detection of the current control.

Frame 2 – Risk Assessment during the Assembly of wheelset

Process	Subprocess	Type of fault	Effect	S	Cause	O	Control	D	NPR	Recommended actions	Responsbility	Target date
Assembly of the combined propulsion assembly	Wheel and axle inspection	Hollow or marked flange	Wheel impact or derailment	8	Procedural failure	2	Does not have	7	112	Create assembly procedure	Jânio Marreiros	21/12/2018
					Human failure	2			112	Insert item in assembly checklist	Anderson Trindade	04/01/2019
										Train team in procedure	Anderson Trindade	04/01/2019
	Timken bearing inspection	Timken bearing locked	Heating	6	Procedural failure	2	Does not have	9	108	Create assembly procedure	Jânio Marreiros	21/12/2018
										Insert item in assembly checklist	Anderson Trindade	04/01/2019
						3			162	Train team in procedure	Anderson Trindade	04/01/2019
	Seal installation	Misalignment of seal	Leakage of lubricant	4	Procedural failure	4	Does not have	10	160	Create assembly procedure	Jânio Marreiros	04/01/2019
					Human failure	8			320	Train team in procedure	Anderson Trindade	21/12/2018
	Gearbox installation and torque application	Misalignment, excess clearance, broken bolt and	Leaking lubricant, loosen the gearbox.	8	Procedural failure	6	Does not have	2	96	Create assembly procedure	Jânio Marreiros	21/12/2018
										Insert item in assembly checklist	Anderson Trindade	04/01/2019
	Ultrasound test	cracked axis	Axis break	8	Procedural failure	2	Assembly check list	5	80	Create assembly procedure	Jânio Marreiros	04/01/2019
					Human failure	2			80	Train team in procedure	Anderson Trindade	21/12/2018

Rumo S.A., 2018

In the tables appendix 6,7,8, 9,10, the FMEAS performed in the 4 sub processes of the Traction Motor Combo are shown in a complete way. It is possible to observe that actions were proposed according to the degree of criticality (NPR). Risks with low NPR did not have prioritized actions at first.

3.3 Cost Benefit Analysis

After all the investments made at Rumo in high level equipment, in 2018 two accidents happened at North Operating having locomotives as main cause, with high gravity. The cost of these two accidents was R$ 1,34 million (61% in railway recuperation, 35% in rolling stocks recuperation and 4% in other spends).

In addition to these costs, the impact on the operation is enormous. There are an increasement in the unavailable of railway assets and rolling stock assets, risks of safety with the accidents, and environmental risks.

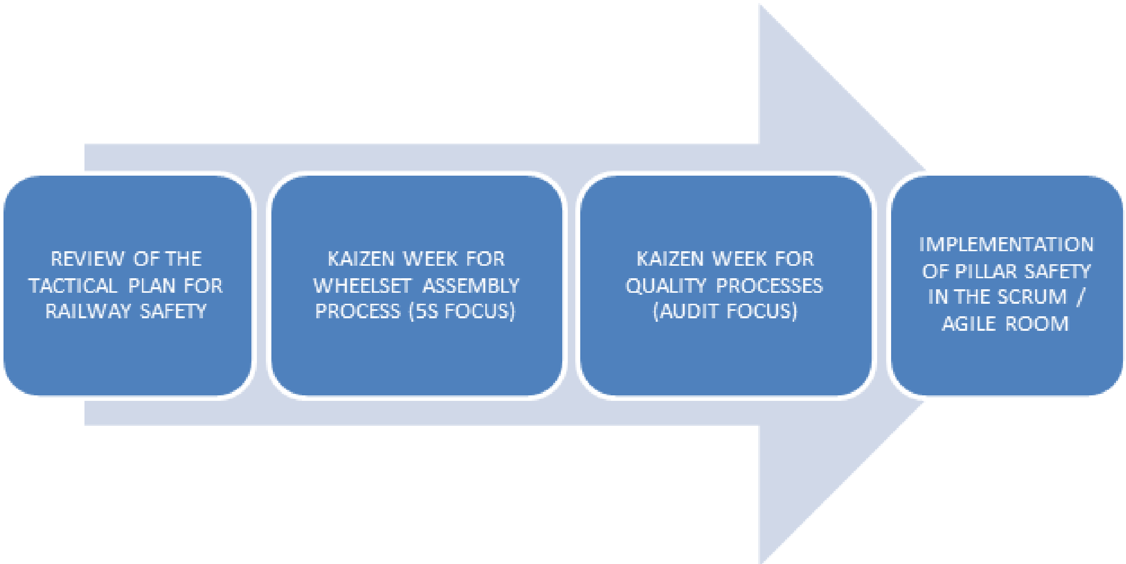
There is still the potential risk of this type of accidents. In the past, Rumo spent about R$ 6 million recovering just one locomotive failed.

4 PROJECT PLAN, IMPLEMENTATION PLAN

As mentioned, after the elaboration of the risk analysis using the FMEA tool, the Locomotive Tactical Safety Action Plan was revised. The actions created in this action plan have different degrees of implementation difficulty, as well as implementation time, with short, medium and long-term actions.

With conventional techniques of change management, Rumo would take a lot of time to implement the actions mapped in the risk analysis and established in the Locomotive Tactical Safety Action Plan. In this way Rumo look for modern tools that accelerate changes and also the fast delivery of actions.

Diagram 4 – Implementation plan Steps



Rumo S.A., 2018

Kaizen weeks are a good way to capture quick gains in processes. The next two steps were the realization of kaizen weeks in the wheelset assembly processes and also in the quality process.

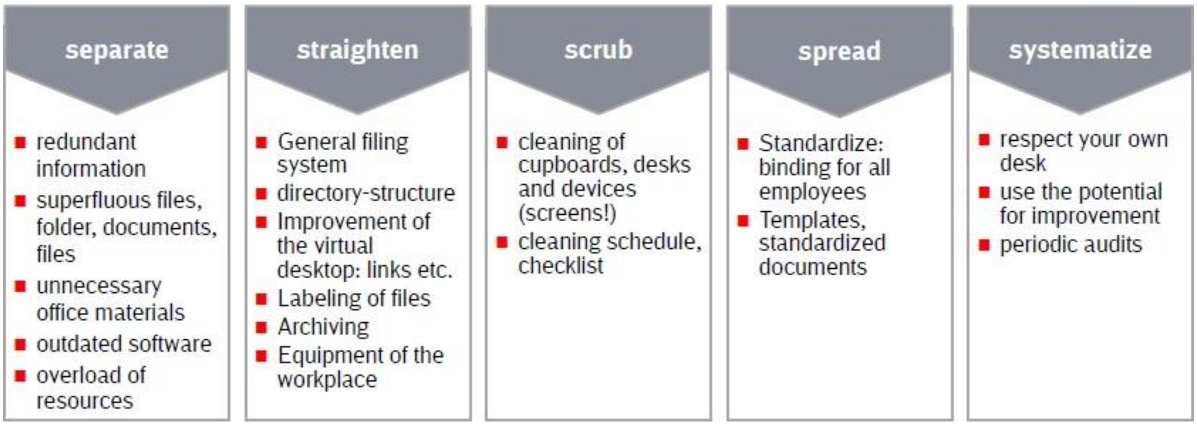
4.1 Kaizen Week for Wheelset Assembly Process (5S Focus)

The wheelset assembly is possibly the most critical process regarding railroad locomotive safety. This fact occurs because the first interface between the locomotive and the railroad occurs in the contact between the wheels and the rails. Basic parameters such as flange angle, flange dimensions, gauge dimensions must be fully controlled. Like the wheel, all the quality and dimensions of the shaft, the gear and the U-tube must be checked during the wheel mounting process (wheel + shaft + gear + U-tube). Precision tools should be used, preferably electronic, for traceability of the information, to ensure proper recording of the entire process. Considering the criticality of the wheelset assembly process, it was established the need to perform the kaizen week of the wheelset assembly with focus on 5S.

According to BRESCO(22), the method of 5S is one way to engage people and contribute to culture change. 5S is a visually-oriented system of cleanliness, organization, and arrangement designed to facilitate greater productivity, safety, and quality. It engages all employees and is a foundation for more self-discipline on the job for better work and better products.

According to DEUTSCHE BAHN(20), as diagram 5, 5S consists of separate, straighten, scrub, spread and systematize.

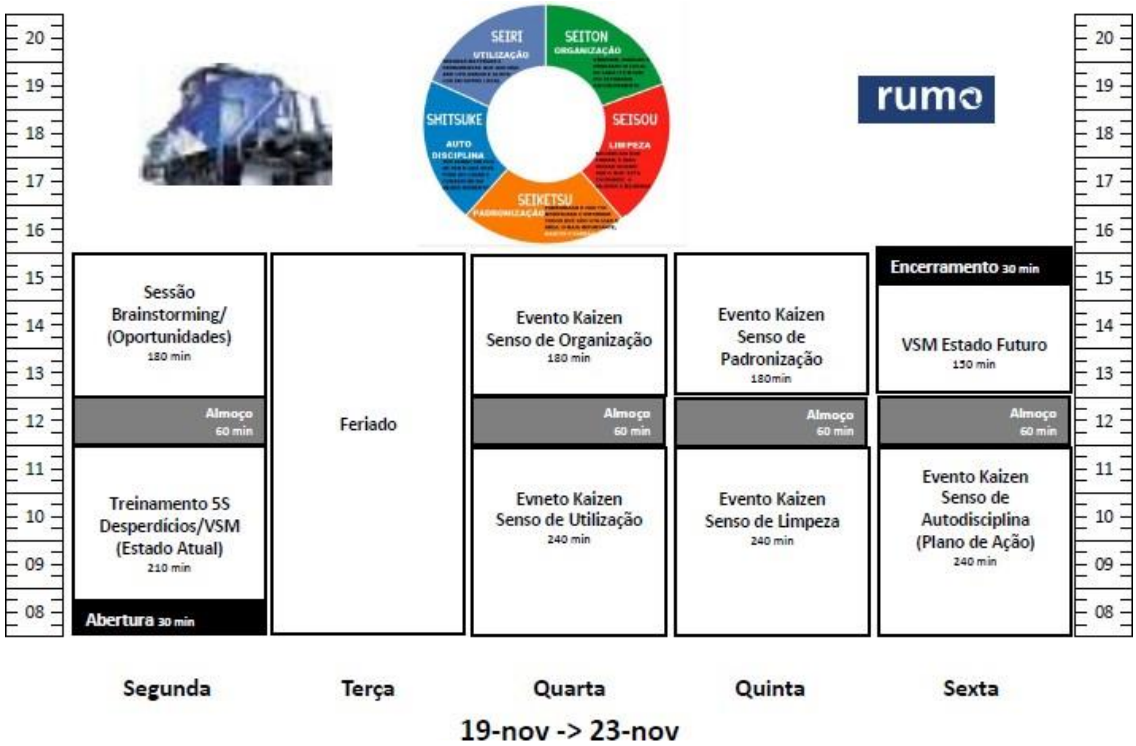
Diagram 5 – 5S actions to reduce waste in management process



DB, DEUTSCHE BAHN, International Training Program – “Rail Transportation Management”, 2018.

The kaizen week was organized according to diagram 6 , with pre-defined agenda for each day and period. Techniques for value stream mapping (VSM) were applied, as well as for evolution in the 5 senses of 5S.

Diagram 6 – Kaizen Week for Wheelset Assembly Schedule



Rumo S.A., 2018

The following figures 15, 16, 17, 18, 19illustrate the observed changes in the operational area as each step of 5S was applied:

Figure 15 – 5S Observed changes day 1 – separate

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Figure 16 – 5S Observed changes day 2 – straighten

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Figure 17 – 5S Observed changes day 3 – scrub

Rumo S.A., 2018

Figure 18 – 5S Observed changes day 4 – spread

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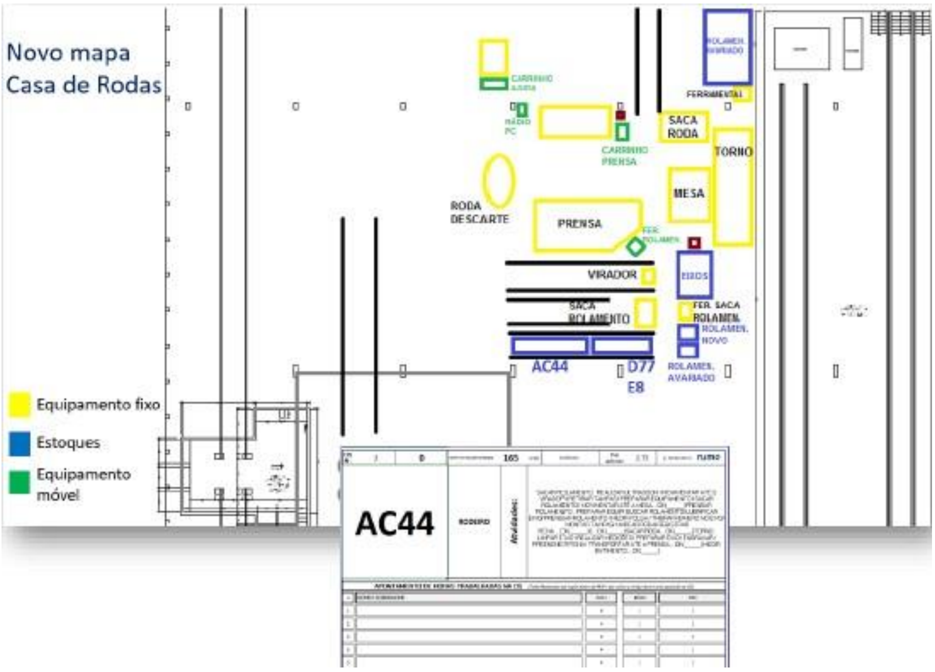
Figure 19 – 5S Observed changes day 5 - systematize



Rumo S.A., 2018

Figure 20 – 5S Observed changes day 5 - systematize

Ferramentas no Carrinho de Saca Rolamentos - Carrinho Verde	
GAVETA 1	**GAVETA 4**
Chave Mista 15/16	Arco de serra
Chave Mista 7/8	Calibre
Chave Mista 13/16	Chave de força
Chave Mista 3/4	Adaptador de rolamento U20
Chave Mista 5/8	
Chave Mista 9/16	**GAVETA 5**
Chave Mista 12	Chave combinada 5/8
Chave Mista 11/16	Chave combinada 3/4
Chave Mista 19	Chave combinada 15/16
Chave Mista 7/16	Chave combinada 1 1/4
Chave estrela 1 5/16 - 1 1/4	Chave de fenda 3/16 x 4"
Chave Mista 3/8	Chave de fenda 7/32
	Chave de fenda 1/4 x 6"
GAVETA 2	Alicate de bico
Alicate de corte	Alicate de bico de abrir
Alicate universal	2 chave para trocar escova
Alicate de pressão	
Chave Allen 1/2	**GAVETA 6**
Chave Allen 9/16	Retifica Pneumatica
Chave Allen 14	Chave griffo 24
Chave Allen 10	macho 7/8
Chave Allen 10	macho 7/8
Chave Allen 6	Macho 7/8
\chave allen 9/16	2 escovas 60
Chave Allen 3/4	Escova de aço 7/8
Kit chave Allen	
Soquete 1 5/32	**GAVETA 7**
Soquete 1 5/16	Caixa de tipos Alfabéticos
	Parafusadeira
GAVETA 3	Carregador Parafusadeira
Martelo de pena	Chave Allen 3/4
Torquimetro 1/2 - 15 - 150 lbf/ft	Desandador
Lima	
Calibre de engrenagem 83	**TRASEIRA CARRINHO**
Calibre de engrenagem 74	Torquímetro 3/4 - 60 - 440 lbf/ft
Talhadeira	Pé de cabra
9 Tipos numericos	Alavanca
4 Tipos alfabéticos	Gabarito de bitola

Rumo S.A., 2018

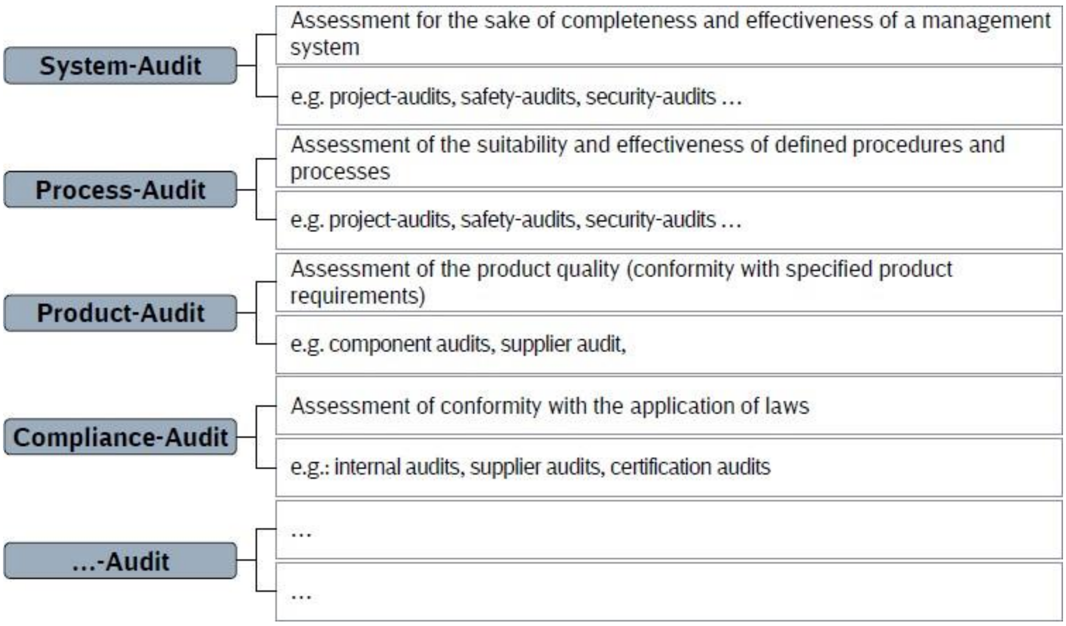
4.2 Kaizen Week for Quality Processes (Audit Focus)

The maintenance of locomotives in the Rumo railroad encompasses various maintenance processes such as inspections, preventive maintenance, corrective maintenance, predictive maintenance, as well as specific processes of locomotive components, such as the traction motor combo process and so on. All these processes have specific flows, locations, procedures, tools and professionals.

In addition to the maintenance execution teams, a quality area was also established, composed of the best specialized technicians in each area of operation (mechanical / pneumatic / electrical), who monitor the quality of the execution teams. During the FMEA analysis, several risks of process deviations that could be reduced with and improvement of the quality processes were observed.

According toDEUTSCHE BAHN(20), audit process serves to check what are the aspects in which the management system or the process can be improved. Audits can be classified into the following types: System Audit, Process Audit, Product Audit, and Compliance Audit. Based on this knowledge, the Rumo Quality and Improvement team was challenged to implement specific Process Audit and Product Audit processes. Another expected aspect of the team was the development of the teams of execution, through the performance of the specialized technicians as tutors. The improvement of the quality team's audit processes encompasses, besides the traction motor combo process, all other locomotive maintenance processes, with direct gains in safety, quality and productivity.

Figure 21 – Types of Audits

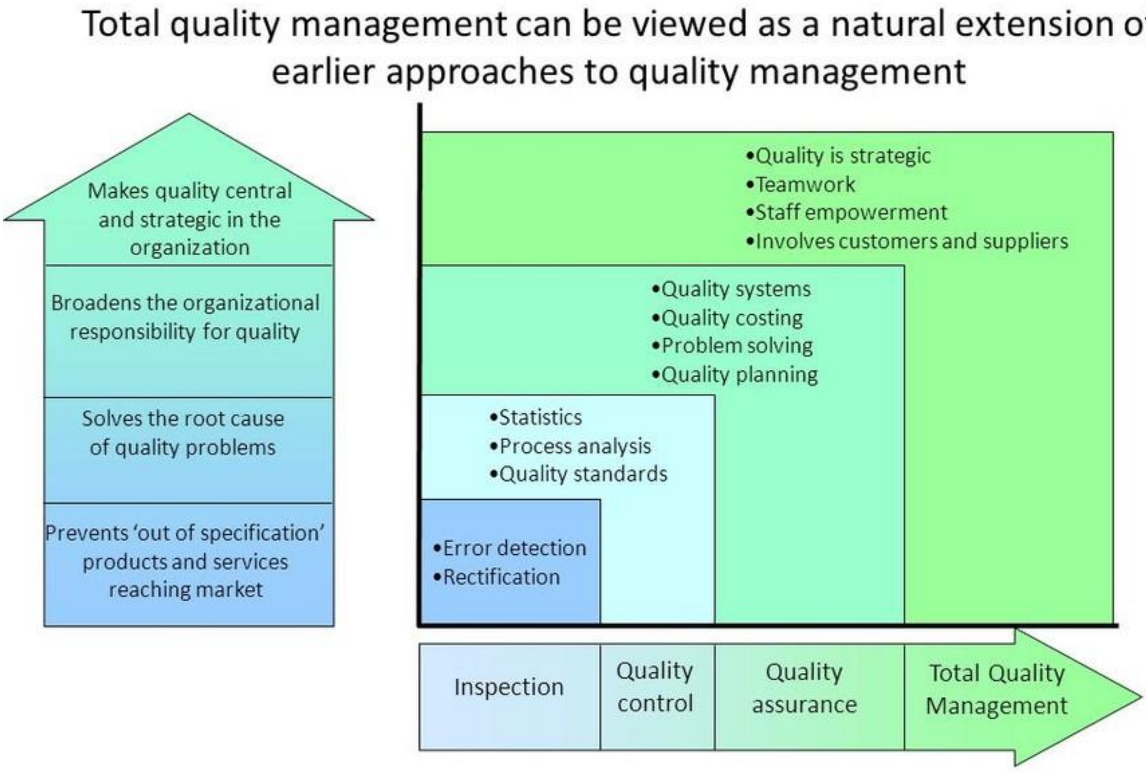


DB, DEUTSCHE BAHN, International Training Program – "Rail Transportation Management", 2018.

Given the challenge made to the quality and improvement teams, kaizen quality week was established. During the kaizen quality week the TQM (Total Quality

Management) tool was studied. The goal was to advance the TQM from the "Inspection" level to the "Quality Control" level.

Diagram 7 – Total Quality Management (QTM) evolution

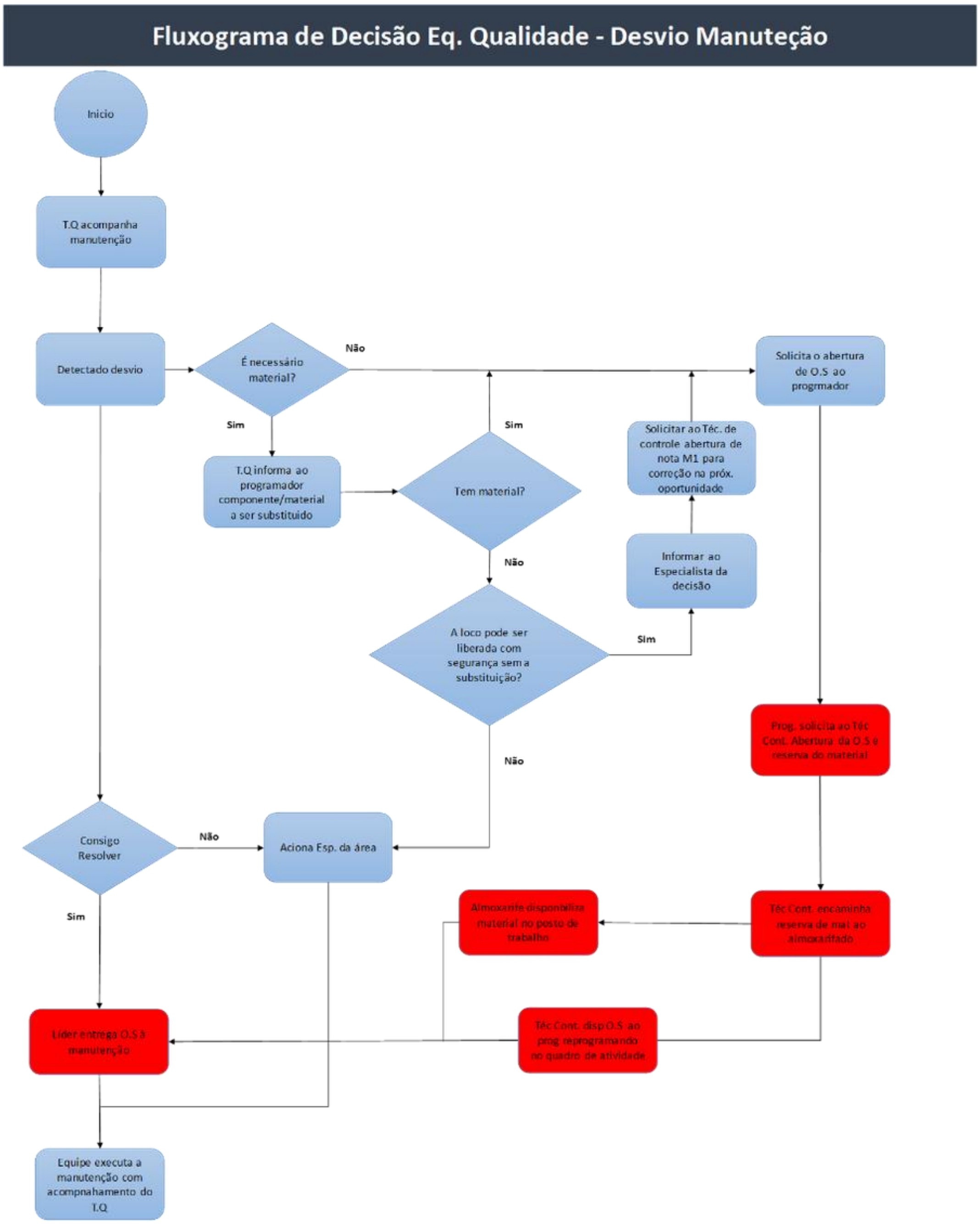


https://slideplayer.com/slide/5667640/

In the kaizen quality week several actions were established, the main ones being listed below:

A) Review of the quality team decision flows for observed maintenance deviations:

Diagram 8 – Quality team decision flows for observed maintenance deviations



Rumo S.A., 2018

B) Routine definition of the quality teams, with deliverables related to process audits, product audits and certification training:

Frame 3 – Routine definition of the quality teams

Quantidade	Elétrica	Mecânica	Pneumática	HxH Semana
N/D			Aud. De Processo de usinagem Pós-Torno (40 min)	40 min
2	Aud. Patinação de Rodas (15 min)			30 min
2	Aud. Processo ou Produto (120 min)	Aud. Processo ou Produto	Aud. Processo ou Produto	240 min
1	Formulário de Acompanhamento (150 min)	Formulário de Acompanhamento	Formulário de Acompanhamento	150 min
1	Kamishibai (40 min)	Kamishibai	Kamishibai	40 min
1	MAQ por oportunidade (40 min)	MAQ por oportunidade	MAQ por oportunidade (40 min)	40 min
1	Treinamento de certificação	Treinamento de certificação	Treinamento de certificação	240 min

Rumo S.A., 2018.

C) Definition of audit forms, specifying whether the audit is process or product audit:

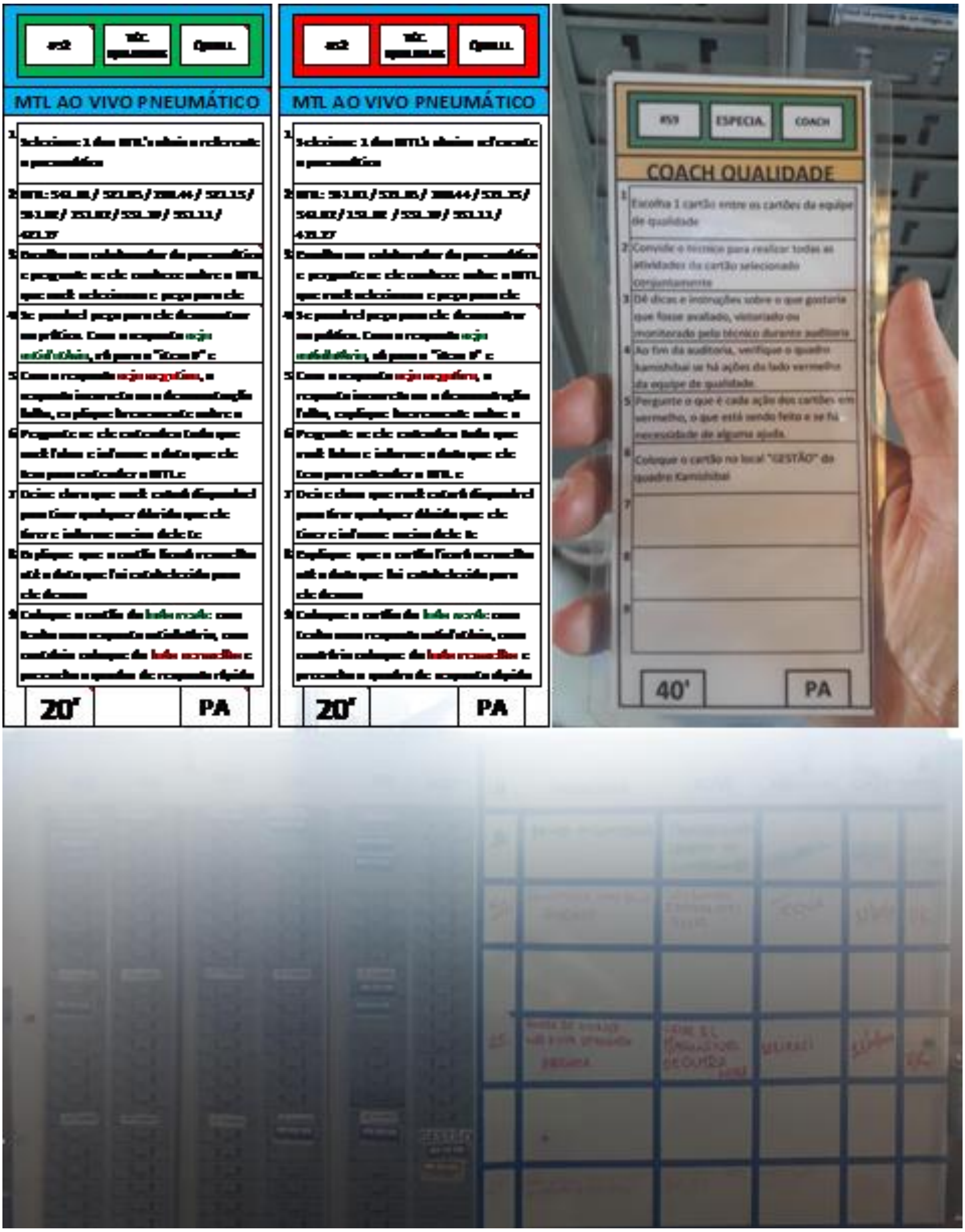
Figure 22 – Quality audit form: Process x Product Audit

rumo FORMULÁRIO DE AUDITORIA DA QUALIDADE	Processo ☐	Produto ☐
TAREFA:		
PO OU MTL RELACIONADO	DATA:	
AUDITOR:	AUDITADO:	
ÁREA:	CARGO:	
RECURSOS NECESSÁRIOS	CONFORME	NÃO CONFORME
EPIs:	( )	( )
Ferramentas comportamentais SIGO: AIR, OPA, AST e CL pré uso	( )	( )
Ferramentas:	( )	( )
Observações e comentários:		
PRINCIPAIS PASSOS	CONFORME	NÃO CONFORME
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
	( )	( )
CUIDADOS NA EXECUÇÃO	CONFORME	NÃO CONFORME
	( )	( )
	( )	( )
	( )	( )
AÇÕES CORRETIVAS	CONFORME	NÃO CONFORME
	( )	( )
	( )	( )
	( )	( )
Observações e comentários:		
Foi identificada alguma oportunidade de melhoria no PO ou MTL?	Sim (Qual?) / Não	
ASSINATURA AUDITOR	ASSINATURA AUDITADO	

Rumo S.A., 2018

D) Implementation of quality cards in the Kamishibai auditing system, a lean tool created for auditing and maintaining standards:

Figure 23 – Kamishibai Quality Cards



Rumo S.A., 2018

4.3 Implementation of Pillar Safety in the Scrumm/Agile Room

In addition to the kaizen weeks, Rumo needed a tool to accelerate the delivery of the actions of the Locomotive Tactical Safety Action Plan. Since the beginning of 2018 is used in the management of productivity projects of locomotive maintenance of Rumo Agile thinking through the Scrum tool. This idea arose from a benchmarking carried out at the Contagem-MG unit of the General Electric Locomotive Factory in Brazil.

Figure 24 – SCRUM Room at GE

Rumo S.A., 2018. Benchmarking at GE Contagem-MG.

In Rumo the Scrum room was being used with the focus on the productivity pillar, where projects were treated as the increase of the availability of locomotives and also the reduction of the time of permanence of the train in yards.

In order to accelerate the delivery of the actions of the Locomotive Tactical Safety Action Plan the railway safety pillar was established in the scrum room, in this way, sprints of 15 days are made to enter the actions mapped in the Locomotive Tactical Safety Action Plan.

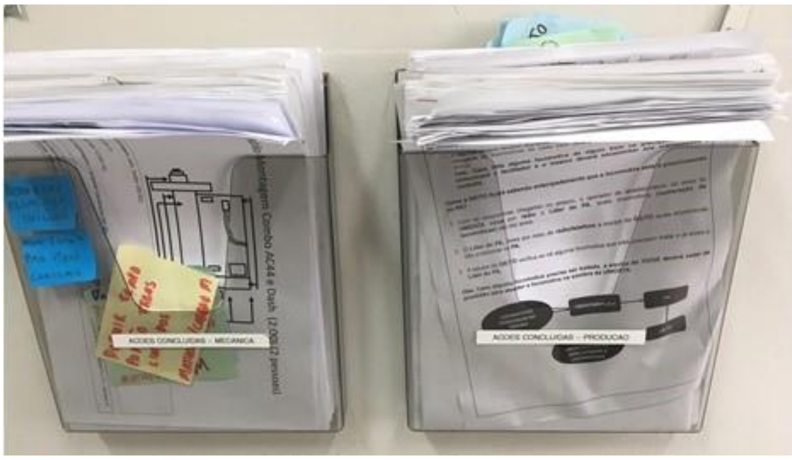
Figure 25 – SCRUM Room at Rumo

Rumo S.A., 2018

Figure 26 – SCRUM Room at Rumo

Rumo S.A., 2018

Figure 27 – SCRUM Room at Rumo



Rumo S.A., 2018

4.4 Financial Plan

In order to build our Financial Plan, we considered all what was learned in Economic classes.

According to Poter's value chain management, the margin of a company can be increased separating following above:

Diagram 9 – Deutsche Bahn presentation E C CNT ITL m7 presentation day 1 interactive

Deutsche Bahn, 2018.

The study concentrates in the operations block. It was identified that Rumo has a costs control per accident, registered in specific counts opened in the accident moment. This practice is very positive, helping the company to have better future decision and to elaborate its business plan. In this case, we will work with a business case, instead of the impact in the business plan of the company, because it would be necessary to study the improvement in the assets availability, and the demand of the new volume to be transported with improvement. But, it is obvious that we would have in the ROA (return on assets) and ROCE (return on capital employed).

In each accident, in average, the cost was R$ 673 thousand recovering assets, and other costs like collection the products. These costs could be avoiding.

With the process shown above, the estimative is reduce 50% of accidents in the first year after the implementation and 100% in the next years, according the table table below, reducing the costs of the company.

Table 3 – Cost Avoid

	Year 2019	Year 2020	Year 2021	Year 2022	Year 2023
Number of accidents last year	2	1	0	0	0
Reduction in the year	1	1	0	0	0
Average costs per accident	R$ 672.700	R$ 672.700	R$ 672.700	R$ 672.700	R$ 672.700
Avoided cost	**R$ 672.700**	**R$ 1.345.401**	**R$ 1.345.401**	**R$ 1.345.401**	**R$ 1.345.401**

Rumo S.A. 2018

On other hand, some new costs are necessary (opex), as some investments (capex), how we can see above.

Table 4 – Opex (New Costs)

OPEX (R$)	Initial Expenditure		Year 2019		Year 2020		Year 2021		Year 2022		Year 2023	
Rugosimeter	R$	3.000	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity		1		0		0		0		0		0
Unit Value (R$/Equipment)	R$	3.000	R$	-	R$	-	R$	-	R$	-	R$	-
Defining of microt-cracks treatment criteria with qualtity team	R$	2.720	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity (Man-Hours)		40		0		0		0		0		0
Unit Value (R$/Hour)	R$	68	R$	-	R$	-	R$	-	R$	-	R$	-
Ultrasound and Rugosimeter operation	R$	7.000	R$	7.000	R$	7.000	R$	7.000	R$	7.000	R$	7.000
Quantity (employee)		1		1		1		1		1		1
Unit Value (R$/Employee)	R$	7.000	R$	7.000	R$	7.000	R$	7.000	R$	7.000	R$	7.000
Create operational procedure for assembly of combos (AC44 / C30 / D9) and train assembly teams	R$	29.920	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity (Man-Hours)		440		0		0		0		0		0
Unit Value (R$/Employee)	R$	68	R$	-	R$	-	R$	-	R$	-	R$	-
Review operational procedure for installation of combos and train team	R$	5.440	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity (Man-Hours)		80		0		0		0		0		0
Unit Value (R$/Employee)	R$	68	R$	-	R$	-	R$	-	R$	-	R$	-
Create and operational procedure for ultrasound testing and team training	R$	16.850	R$	16.850	R$	16.850	R$	16.850	R$	16.850	R$	16.850
Quantity (services)		1		1		1		1		1		1
Unit Value (R$/Service)	R$	16.850	R$	16.850	R$	16.850	R$	16.850	R$	16.850	R$	16.850
Review the whellset assembly procedure and train the teams	R$	29.920	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity (Man-Hours)		440		0		0		0		0		0
Unit Value (R$/Employee)	R$	68	R$	-	R$	-	R$	-	R$	-	R$	-
Review AC44 and C30 Check List (check list de abastecimento) for inclusion of mandatory wheel	R$	136	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity (Man-Hours)		2		0		0		0		0		0
Unit Value	R$	68	R$	-	R$	-	R$	-	R$	-	R$	-
TOTAL OPEX	**R$**	**94.986**	**R$**	**16.850**	**R$**	**16.850**	**R$**	**16.850**	**R$**	**16.850**	**R$**	**16.850**

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Table 5 – Capex (Investments)

CAPEX (R$)	Initial Expenditure		Year 2019		Year 2020		Year 2021		Year 2022		Year 2023	
Tool for electronic wheel diameter measurement	R$	15.000	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity		1		0		0		0		0		0
Unit Value (R$/Equipment)	R$	15.000	R$	-								
Ultrasound	R$	128.000	R$	-	R$	-	R$	-	R$	-	R$	-
Quantity		1		0		0		0		0		0
Unit Value (R$/Equipment)	R$	128.000	R$	-								
TOTAL CAPEX	**R$**	**143.000**	**R$**	-	**R$**	-	**R$**	-	**R$**	-	**R$**	-

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With the premise of chain value management, we calculate the positive impact on the Profit, Cash Flow, and the return of the investment to the firm. In the attractivity rate, it was used 11,04% according the "NOTA TÉCNICA Nº 016/SUEXE/2015" divulged by ANTT - AGÊNCIA NACIONAL DOS TRANSPORTES TERRESTRES(23) , as a public Weighted Average Cost of Capital (WACC) for the concession processes.

Frame 4 – Financial Results

	Initial Expenditure		Year 2019		Year 2020		Year 2021		Year 2022		Year 2023
Cogs	-R$	94.986	R$	655.850	R$	1.328.551	R$	1.328.551	R$	1.328.551	R$	1.328.551
Depreciation	R$	-	R$	14.300	R$	14.300	R$	14.300	R$	14.300	R$	14.300
EBIT Impact	**-R$**	**94.986**	**R$**	**670.150**	**R$**	**1.342.851**	**R$**	**1.342.851**	**R$**	**1.342.851**	**R$**	**1.342.851**
Taxes	R$	32.295	-R$	227.851	-R$	456.569	-R$	456.569	-R$	456.569	-R$	456.569
Net income Impact	-R$	62.691	R$	442.299	R$	886.281	R$	886.281	R$	886.281	R$	886.281
EBITDA Impact	**-R$**	**94.986**	**R$**	**655.850**	**R$**	**1.328.551**	**R$**	**1.328.551**	**R$**	**1.328.551**	**R$**	**1.328.551**
Taxes	R$	32.295	-R$	227.851	-R$	456.569	-R$	456.569	-R$	456.569	-R$	456.569
Change in workin capital	R$	-	R$	-	R$	-	R$	-	R$	-	R$	-
Capex	-R$	143.000	R$	-	R$	-	R$	-	R$	-	R$	-
Free cash flow	-R$	205.691	R$	427.999	R$	871.981	R$	871.981	R$	871.981	R$	871.981
Perpetuity											R$	7.898.382
Total with perpetuity	-R$	205.691	R$	427.999	R$	871.981	R$	871.981	R$	871.981	R$	8.770.363
Atractivity rate		11,04%										
Growth		0%										
NPV (net present value)	R$	7.292.851										
IRR (Internal rate of retorn)		278%										

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In short, the study demonstrates a financial improvement, and a return of the R$ 7,3 million of the net present value.

5 RESULTS AND DISCUSSION

5.1 Results

With the implementation of this project, the main results observed were: Qualitative results: improvements in the operational area due to 5S implementation; more capacitated and involved employees; improvement of the quality team's audit processes.

Quantitative results: reduction in the number of accidents and a financial improvement and a return of the R$ 7,3 million.

6 FINAL CONSIDERATIONS

The investments made in railways over the last 20 years have enabled a drastic reduction of accidents in the concessioned Brazilian railways. All the investment in assets, infrastructure and training of labor, has brought the railway to reliable and safe levels, but the occurrence of accidents is still great, when compared with other countries.

Such accidents require a deeper understanding of cause and use of specific methodology to achieve the desired reduction results. Given the importance of railway safety for railroads, both in the area of safety in the surrounding communities, business security and costs, all causes must be investigated, studied and remedied, mainly using a methodology that ensures that the causes are no longer recurrent.

In the case of the present study, the use of specific management tools such as 5S, Kaizen, Scrum Method and FMEA showed great efficiency in the procedures for the maintenance of locomotives, in the north operation of Rumo SA, focused on problems that have already generated rail accidents .

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Appendix

Table 6 – FMECA for Drop Table Subprocess

PROCESS	SUBPROCESS	TYPE OF FAILURE	EFFECT OF FAILURE	SEVERITY	CAUSE	OCURRENCE	CONTROL	DETECTION	NPR	CORRETIVE ACTIONS	OWNER	TIME	STATUS
DROP TABLE PROCESS	Install Guide Tiles	Excess clearance between the bearing housing and the pedestal	wear of bearing housing and pedestal	2	Labour failure	2	Installation Check List	1	4				
	Inspect Springs	Poor cushioning	Wheel Impact	3	Labour failure	2	Installation Check list/MTL exists for referencing (215.02)	7	42	Train team in MTL after upgrade	José Lucas	25/01/2019	
					Procedure failure	1			21	Create P. O to install combo/review MTL 215.02	Jânio Marreiros/ José Lucas	30/11/2018	
	Lifting the MT and fitting the Mt nose into the trick structure (dog bone)	Misalignment of the MT in the car of the false ditch	Collision in trick structure	2	Labour failure	3	Installation Check list/MTL exists for referencing (215.02)	1	6				
					Equipment failure	5			10				
	Inspect spring acentamento of bearing housings	Undocked Spring	Poor cushioning	3	Labour failure	1	Doesn't have	6	18	Append item in Installation Check list	José Lucas	25/01/2019	
					Procedure failure	1			18	Create P. O to install combo/review MTL 215.02	Jânio Marreiros/ José Lucas	30/11/2018	
	Installing and twisting guide tile retaining blocks	Drop block retention and guide tile	Wear adapter bearing and pedestal, crimping wear.	2	Labour failure	4	There is MTL for referencing (215.02)	1	8				
					Material failure	1			2				
					Instrument failure	1			2				
	Fitting and attaching the air duct to the MT	Lack of refrigeration in the MT	MT Overheat	4	Labour failure	2	Installation Check list/MTL exists for referencing (215.02)	2	16				
					Material failure	10			80	Monitoring with GE to substitution of faulty signalized ducts.	Denivaldo		
	Fasten the lower MT buffer bolts (dog bone)	Lack of MT fixation	Derailment	8	Labour failure	2	There is MTL for referencing (2015.02)	1	16				
					Equipment failure (torque)	1			8				
	Installing and twisting the brackets of the sandboxes	Fall of the sanding bracket	Derailment	8	Labour failure	1	There is MTL for referencing (2015.02)	1	8				
					Labour failure	1			8				
	Fix Vertical Damper	Deficient lateral cushioning	Improper lateral movement	1	Labour failure	1	Installation Check list/MTL exists for referencing (215.02))	1	1				
					Equipment failure (torque meter)	1			1				
	Connect MT cables, and rotation sensor	Inverted link/poorly connected rotation sensor	Axle Locked/Wheel skating	3	Labour failure	5	Installation Check list/MTL exists for referencing (215.02)	1	15	Train team in MTL after upgrade	José Lucas	25/01/2019	
					Procedure failure	5			15	Create P. O to install combo/review MTL 215.02	Jânio Marreiros/ José Lucas	30/11/2018	
	Fuel gear Box Lubricant	Lack of lubrication	Premature wear of gear and pinion/tooth breakage	5	Labour failure	3	There is MTL for referencing (215.02)	2	30	Train team in MTL after upgrade	José Lucas	25/01/2019	
	Graduate CF	Adjustment out of tolerance	Wheel heating	6	Labour failure	5	Doesn't have	6	180	Add Item to Installation Check List	José Lucas	25/01/2019	
					Procedure failure	5			180	Create P. O to install combo/review MTL 215.02	Jânio Marreiros/ José Lucas	30/11/2018	

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Table 7 – FMECA for Wheelset Assembly Subprocess

PROCESS	SUBPROCESS	TYPE OF FAILURE	EFFECT OF FAILURE	SEVERITY	CAUSE	OCCURENCE	CONTROL	DEECTION	NPR	CORRETIVE ACTIONS	OWNER	TIME
WHEELSET ASSEMBLY	Perform axial clearance measurement of the "U" tube;	"U" tube with slack outside the specified tolerance;	Wheel Locking	6	operator failure	1	Wheelset assembly form	4	24			
					Procedure failure;	7	Using GE procedure	2	84	Review Assembly P. O of Wheelsets	João/Érick	
										Train team in P.O assembly of Wheelsets	João Hermelindo	
					instrument failure;	1	Use of calibrated measuring instruments;	1	6			
					Equipment failure;	1	own machine for measurement of clearance;	1	6			
	Inspect axle;	Axle with superficial breakdown;	Axle break	8	operator failure	1	Item on the assembly sheet of the wheelset;	1	8			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	8			
	Gear inspection;	Gear with trinced/broken teeth;	Wheel Locking	6	operator failure	8	Visual inspection	5	240	Acquisition of Washbasin Tank	To be defined	
					Procedure failure;	5	P.O ENG-LC-PRO-BK1501	3	90	Review Assembly P. O of wheelsets	João/Érick	
										Train team in P.O assembly of Wheelsets	João Hermelindo	
	Perform ultrasound test on the axle;	Trinced Axle;	Axle break	8	operator failure	2	Ultrasound test	1	16			
					Procedure failure;	2	P.O.	4	64	Create procedure for locomotive axis ultrasonic testing	João/Érick	
					Instrument failure	1	Standard block Calibration	1	8			
	Carry out measurements on the axle sleeve;	Axle sleeve out of measure;	Axle break	8	operator failure	1	Measured according to tolerances in the procedure and the Assembly plug of the wheelset	1	8			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	8			
					instrument failure	1	Measurement of the micrometer annually.	4	32			
	Measure vibration of tube "U";	"U" tube bearing defective;	Wheel Locking	6	operator failure	1	Assembly Check List	1	6			
					Procedure failure;	9	Using GE procedure	2	108	Request GE PO	João/Érick	
					Procedure failure;	9	Using GE procedure	2	108	Review Assembly P. O of Wheelsets	João/Érick	
					Instrument failure	1	Measurement with own equipment for measuring	1	6			
	Measure axle Gable;	warped axle;	Derailment	9	Operator failure	2	Has item in the Assembly check list of wheelsets	1	18			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	9			
					Instrument failure	1	Calibration of the comparator clock every 1 year	1	9			

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Table 8 – FMECA for Wheelset Assembly Subprocess

PROCESS	SUBPROCESS	TYPE OF FAILURE	EFFECT OF FAILURE	SEVERITY	CAUSE	OCCURENCE	CONTROL	DEECTION	NPR	CORRETIVE ACTIONS	OWNER	TIME
WHEELSET ASSEMBLY	Polishing the "U" tube	"U" tube bearing defective;	Wheel Locking	6	Operator failure	1	Has item in the Assembly check list of wheelsets	1	6			
					Procedure failure;	2	GE procedure	1	12			
	Carry out measurements at the wheel seat on the axle;	Seat of the wheel on the axle outside the measure;	Crank or wheel break	9	operator failure	1	Has item in the assembly check list wheelsets	1	9			
					Procedure failure;	2	P.O ENG-LC-PRO-BK1501	1	18			
					Instrument Failure	1	Micrometer calibration every 1 year.	3	27			
	Measure the internal hub of the wheel (Ø) – (wheel X axle interference);	Internal measurement of the cube out of tolerance;	Crank or wheel break	9	operator failure	1	Has item in the assembly check list wheelsets	1	9			
					Procedure failure;	2	P.O ENG-LC-PRO-BK1501	1	18			
					Instrument Failure	1	Micrometer calibration every 1 year.	3	27			
	Sanding wheel seat and measuring roughness;	Drag wheel/axle material;	Superficial alteration with material loss	1	operator failure	9	Has item in the assembly check list wheelsets	1	9			
					Procedure failure;	3	P.O ENG-LC-PRO-BK1501	2	6			
					Instrument Failure	1	Rugosimeter Instrument annually	1	1			
	Sanding wheel hub and measuring roughness;	Drag wheel/axle material;	Superficial alteration with material loss	1	operator failure	9	Has item in the assembly check list wheelsets	1	9			
					Procedure failure;	3	P.O ENG-LC-PRO-BK1501	2	6			
					Instrument Failure	1	Rugosimeter Instrument annually	1	1			
	Apply "muscle" lubricant to the wheel seat and wheel hub;;	Drag wheel/axle material;	Change the pressure value of the shaft and drag.	1	operator failure	1	Pressing graph	1	1			
					Procedure failure;	2	P.O ENG-LC-PRO-BK1501	1	2			
	Wheel axing;	Wheel out of specified pressure;	Crank or wheel break	9	operator failure	1	Control through pressure graph of the axle;	1	1			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	1			
					Equipment failure;	2	Control through pressure graph of the axle;	1	2			
	Check gauge during axle;	Wreck out of gauge;	Derailment	9	operator failure	1	Assembly Check List	1	1			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	1			
					Instrument Failure	1	Use of 3 measuring instruments (laser Trena,	1	1			
	Check wheel beat (lateral and axial);	Wheel out of axial and radial beats.	Derailment	9	operator failure	1	Assembly Check List	1	1			
					Procedure failure;	1	P.O ENG-LC-PRO-BK1501	1	1			
					Instrument Failure	2	Measurement performed with calibrated and laser measuring comparator clock	1	2			

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Table 9 – FMECA for Wheel Truing Subprocess

PROCESS	SUBPROCE SS	TYPE OF FAILURE	EFFECT OF FAILURE	SEVERITY	CAUSE	OCCURRENC E	CONTROL	DETECTIO	NPR	CORRECTIVE ACTION	OWNER	TIME
MACHINING OF LOCOMOTIVE WHEELS	Adapt the Bandage	Loss of measurement in wheel machining	Reduction in Wheel service life	1	Manual adjustment of the Chapelone by the operator	5	Use of variable Chapelone	2	11			
				1	Blackout	2	Doesn't have	1	2			
			Impact on asset release time	1	Insert Break	2	Replace insert	1	2			
				1	Wear of the Chapelone	2	Change of chapelone in preventive maintenance	3	6			
				1	Operation failure	4	Doesn't have	10	40	Create/revise wheel machining P. O in the underground lathe	Jânio Marreiros	
	Fit the Crimping	Poor surface finish	Derailment	9	Voltage Oscillation	2	Reductor Motors Current Ammeter verification	1	18			
				9	Insert Wear	4	Replace insert	1	36			
				9	Hydraulic leakage	1	Semi-annual preventive	1	9			
				9	Operation failure	4	Doesn't have	9	324	Carry out a study to improve the surface finish with the executing company in the lathe.	Jânio Marreiros	
		Fit angle of crimping Wheelset	Derailment	9	Operation failure	1	Use of the Profilometer	1	9			
				1	Copier head failure	2	Preventive maintenance of the copier cylinder head semiannually	1	2			

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Table 10 – FMECA for Traction Motor Combo Subprocess

PROCESS	SUBPROCESS	TYPE OF FAILURE	EFFECT OF FAILURE	SEVERITY	CAUSE	OCCURRENCE	CONTROL	DETECTION	NPR	CORRECTIVE ACTIONS	OWNER	TIME	STATUS
TRACTION MOTOR COMBO ASSEMBLY	Cleaning and qualification gear box.	Excess slack between the box and misalignment	Lubricant oil leakage	4	Procedure failure	9	Item is listed in the Assembly	1	36				
					Labour failure	9			36				
	MT BEARING inspection.	Excessive slack.	Locking bearing MT.	5	Labour failure	2	Item is listed in the Assembly checklist		30				
					Instrument Failure	1			15				
					Procedure failure	2		3	30				
	Inspection Wheelset gear and MT.	Gear with broken teeth/trinced	Wheel Lock	7	Labour failure	2	Doesn't have		42				
					Procedure failure	2		3	42				
	Inspection Wheelset.	Pit on the wheelset, crimp beaten.	Impact of wheels and derailment.	8	Procedure failure	2	Doesn't have	7	112	Create P. O. for Combo Assembly	Jânio Marreiros/ Anderson Trindade	21/12/2018	
									112	Insert inspection item of wheelset in assembly check list	Anderson Trindade	04/01/2019	
					Labour failure	2				Train Team Wheel inspection procedure.	Anderson Trindade	04/01/2019	
	Inspection bearing Tinken.	Bearing Tinken locked.	Heating	6	Procedure failure	2	Doesn't have	9	108	Create P. O. for Combo Assembly	Jânio Marreiros/ Anderson Trindade	21/12/2018	
										Insert Inspection Item bearing TINKEN Check list	José Lucas	04/01/2019	
						3			162	Train Team inspection procedure of the bearing tinken.	Anderson Trindade	04/01/2019	
	Wheelset installation on MT and torque application.	Breakage of the "U" tube bolts.	Wear gear Crown/pinion	2	Equipment Failure	1	Item is listed in the Assembly checklist		2				
					Labour failure	1			2				
					Material failure	1			2				
					Procedure failure	1		1	2				
	Installation sealing and seal.	Misalignment and bite gasket.	Lubricant leakage.	4	Labour failure	4	Doesn't have	10	160	Train team in the procedure of sealing/seal installation.	Anderson Trindade	04/01/2019	
									0				
									320	Create P. O. for Combo Assembly	Jânio Marreiros/ Anderson Trindade	21/12/2018	
					Procedure failure	8				Insert Sealing installation Item Check list.	Anderson Trindade	04/01/2019	
	Gear box installation and torque application	Misalignment, excessive slack, broken bolt and dued thread	Lubricant leakage, falling gear box.	8	Labour failure	2	Doesn't have	2	32				
					Procedure failure	6			96	Create P. O. for Combo Assembly	Jânio Marreiros/ Anderson Trindade	21/12/2018	
										Insert Gear Box assembly item in combo assembly check List	Anderson Trindade	04/01/2019	
					Equipment Failure	1			16				
					Material failure	1			16				
	Perform ultrasonic test.	Trinced Axle	Axle breakage.	8	Labour failure	2	Item is listed in the Assembly checklist	5	80	Train team Ultrasonic procedure.	Anderson Trindade	04/01/2019	
					Procedure failure	2			80	Create P. O. for Combo Assembly	Jânio Marreiros/ Anderson Trindade	21/12/2018	
					Instrument Failure	1			40				

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