Rail Accidents Caused by Failure on the Permanent Way

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***Abstract*—This study aims to evaluate the potential of rail accidents due to lack of preventive maintenance of the permanent way or appropriate procedures for rail maintenance and fastening, especially in railways for the freight trains in Brazil. In recent years, the railway in Brazil increased significantly, from 389,000 Thousand of Tonnes (useful tonne) in 2006 to 450,000 Thousand of Tonnes in 2013. In despite of the increase of products transported in these railways, the number of accidents decreased from 1638 in 2006 to 866 in 2013, according to reports from the National Land Transport Agency of Brazil (ANTT). In spite of the reduction, it still constitutes a major concern due to increased travel time of trains. The main cause of these accidents, as ANTT report, is due to the permanent way, for lack of either maintenance or poor condition. The current state of railroad has been responsible for over a third of accidents in the period between 2006-2013, many of these accidents occur by the lack of appropriate procedures in preventive maintenance, and the lack of technical tests that allow more rigorous acceptance of the components, and most effective results of the maintenance procedures of the railways. This paper aims to emphasize the need for greater rigor in the selection of components and procedures for maintenance of the permanent way, and the potential of these components are not within the appropriate technical standards, which can cause serious accidents and long periods of interruption of the railroad.**

***Index Terms*—railway accident, fastening, rail bed**

I. Introduction

The increase in Brazilian agricultural production and the import and export agreements have generated the need for qualitative and quantitative improvement of the railway network in the country with expansion works encouraged by the Federal Government with the growth acceleration plan (Plano de Aceleração do crescimento–PAC). Thereat, projects for the construction of the North-South Railway and the connection between Alto Taquari and Rondonópolis cities in the state of Mato Grosso and other projects go to the the effective implementation phase.

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Only invest in the expansion of the railways is not enough to increase the amount of goods transported. In Brazil most of the railways for existing load transportation or in project, are single ways. It is necessary that the improvement of the operation is obtained by reduction of the track accidents which demand many hours of inactivity [1]. It was found that the lack of procedures for preventive and corrective maintenance of traction systems, communication, licensing and infrastructure of the permanent way that was, according to reports of the National Transportation Agency (Agência Nacional de Transportes Terrestres – ANTT), the leading cause of train accidents in Brazil between 2006-2013. These events have caused the railroad outages and consequently the decrease of the reliability and efficiency of rail transport.

It is necessary to a good maintenance firsty to check what the conditions of the permanent way are because some railways can not just apply the preventive maintenance. In such cases it will need to apply corrective maintenance, because the high flow of trains and with low investment in maintenance, degraded the permanent way as to be a need for replacement of many elements of the superstructure before apply a preventive maintenance plan. As a Heritage of Federal Railways Company Anonymous (Rede Ferroviária Federal Sociedade Anônima – RFFSA), some railroads have adopted the standard of maintenance using the Retains Cyclic Program (Conserva Cíclica Programada – CCP) which used a group of informations about the railroad to maintain maintenance and with this procedure was possible to define the processe in Total Review - RT or Out of Total review - FRT. Using the maintenance measuring made by maintenance crew and with the quantitie of transported tonnes, it was determined if would be used RT or FRT in the railway that needed maintenance [2].

With advances in technology, maintenance of permanent way has become more dynamic, using computational tools and advanced technologies to determine the important items, which now occur, since the ballast granulometry, to the interior of the rail ingot.

With the use of such tools as support, it was created the philosophy of maintenance cycles for the railroad, by

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definition of the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas ABNT), it is divided into preventive maintenance and corrective maintenance. The definition of preventive maintenance includes: a) inspections of the elements of the permanent way; b) Adjustments and conservation of the elements; and c) Elimination of small defects. The corrective maintenance is defined only as a repair of specific faults that occur by vandalismo actions or small events such as exchange of rail due to the unexpected drop, gauge opening to any occurrence of single derailment etc. The United Nations - UN has a different view from the view adopted in Brazil by ABNT, it divides the maintenance in two plans: A) Planned Maintenance, which includes the preventive and corrective maintenance; B) No planned, which includes the maintenance when occurs a single damage, out of the planning of maintenance and causing suspension in train movement [3].

Any train accident indicates loss to the operation and usually occurs in fault function in the maintenance of some area of the company. And within the transport companies is said by maintenance crews, that "The accident is the most expensive training that exists" because despite of the big loss the accident brings a lot of learning and often indicates a lack of investment and training.

The superstructure of a railway consists of several coatings and between them, there are the rails, Flat plats, switchings, joint bar, ballast, sub-ballast, platform and the fastenings which are made to support the diverting movement and have the function of absorption and distribution of the efforts to ensure the rail geometry and the integrity of the railroad [4]. The technical standard used in Brazil for the maintenance of its rail system is the TB 116 [5], which defines "all necessary actions so that each item is maintained or restored in order to remain in accordance with a specified condition" [6].

Accidents often cause interruption of the railway, which causes big loss to the companies business and always when this occurs, the permanent way maintenance teams and motive power are triggered to start the work and make the railway resumes operation but this creates a lot of problems, because the aim of the operation is to get the circulation back as quickly as possible and even before the investigation team reach the other are already working and erase the evidence of the accident , preventing the investigation to analyze and treat the accident in the right way.

Another regular problem is the pressure from the Traffic Control Center – CCO, on the permanente way team to release the railway, which often causes use of inadequate materials to recovery the railway activitie that may lead to another accident at the time of the resumption. For an effective investigation it is ideal that the investigation team would be the first to arrive to the scene, or that the other teams wait their arrival. With this, you can check the Derailment Point – PD, without interference and to analyze the possible causes of the occurrence.

This paper aimed to analyze the rates of accidents caused by permanent way in Brazilian railroads. In addition, preventive and corrective maintenance procedures adopted were analyzed with respect to life, technical tests for qualification of subsystems belonging to the permanent way and the procedures that can be applied to prevent such accidents from occurring again.

II. Method

It was analyzed reports from National Transportation Agency – ANTT [7], accidents that occurred in the period from 2006 to 2013 in Brazil.

The accidents were classified in this paper into three subgroups: a) external events involving human error, vandalism and accidents caused by third parties; b) occurrences linked to the way superstructure: motive power and permanent way, in addition to roadway signs and problems related to communication; c) other causes, usually containing those accidents that could not be explained by some reason.

It was detailed occurrences between different companies that can operate in Brazil 1) América Latina Logística Malha Norte S.A. – ALLMN; 2) América Latina Logística Malha Oeste S.A. – ALLMO; 3) América Latina Logística Malha Paulista S.A. – ALLMP; 4) América Latina Logística Malha Sul S.A. – ALLMS; 5) Estrada de Ferro Carajás – EFC; 6) Estrada de Ferro Vitória a Minas – EFVM; 7) Ferrovia Centro-Atlântica S.A. – FCA; 8) Estrada de Ferro Paraná-Oeste S.A. – EFPO; 9) Ferrovia Norte Sul – FNS; 10) Ferrovia Tereza Cristina S.A. – FTC; 11) MRS Logística S.A. – MRS: e 12) Transnordestina Logística S.A. – TLSA [7].

It was made the detailing of the accidents due to problems in the permanent way and compared with other áreas, according to the report, this was a major cause of occurrences, which caused long periods of interruption on the railway. As a result, it was the major cause of delivery products decrease for transport in Brazilian ports.

The maintenance process of railways in Brazil as already mentioned, is based on the TB - 116 NBR [5] and its comparative analysis was also performed, with preventive and corrective maintenance processes of railway companies, the same rule also is used in all processes of industries and companies linked to service sectors, it is not a specific standard for railway maintenance [2].

Finally, it was analyzed some ABNT standard that are linked to elements of the railway superstructure, which define what are the standards for testing and maintenance of the parts of the railway superstructure standards developed by ABNT 7046-2014, 5564-2011 ABNT, ABNT 7511 -2013, ABNT 7991-2012, 7590-2012 ABNT, among others ABNT, 2014, are used to set up the procedures for preventive and corrective maintenance.

III. Results and Critical Analysis

Accidents are registered by their own railway dealers, monthly, in a computerized system and developed in partnership between the National Transportation Agency

– ANTT and the Federal University of Santa Catarina (Universidade Federal de Santa Catarina – UFSC). The system, called RAAF - Registration and Accident Monitoring Rail (Registro e Acompanhamento de Acidentes Ferroviários) includes, among others, information on weather conditions, causes, severity, if there was an interruption of the permanent way and the type of cargo transported.

The information in RAAF system are summarized in Table I, which includes all accidents in companies that operated in Brazil, in 2006-2013, spread over large areas [7].

TABLE I. ACCIDENTS IN THE PERIOD 2006-2013

Causes	Total	%
Vandalism	26	0.30%
Human failure	805	9.21%
Third Party Interference	1393	15.94%
Subtotal – external causes	**2224**	**25.45%**
Track structure	3	0.03%
Roadway sign, telecommunications and Eletrotechnics	36	0.41%
Motive Power	1283	14.68%
Permanent Way	3315	37.94%
Subtotal - superstructure	**4637**	**53.06%**
Other causes	1877	21.48%
Total	**8738**	**100.00%**

Source: ANTT 2014 Report. There are 3 accidents involving passenger trains not counted in this table.

It may be noted that there is a high percentage of accidents which causes were not determined by the investigation team or are not classified in those more frequent and take part in “Other causes” that representes more than 21% of the cases.

Among the accidents with explicit causes, it can be noticed that almost a third of them refers to external causes to the railroad structure (vandalism, human failure and interference of third parties), while more than 2/3 are connected to the superstructure of the railway, with small percentage for roadway sign and electronic equipment, a significant percentage to motive power of the compositions and, in larger quantity, those linked to the permanent way that represents more than 1/3 of all accidents, or 71.5% of accidents related to superstructure Table I.

The number of accidents in the Brazilian rail network has decreased in recent years, but can still be considered high compared to other countries in the world that has as bentchmark, a Security Index of 1.44, far below the average registered in the country [8]. To get an idea of this fact, Table II shows the Security Index of national railways in the period determined by the number of accidents occurred per million train kilometers and railway. The data show a sharp drop between 2006 and 2007 and, from that date, small oscillations with a tendency to decrease, reaching in 2013, an average with twelve accidents / million train x km.

TABLE II. SECURITY INDEX FOR THE PERIOD 2006-2013

Year	N °Accidents/MTK	Total of Accidents
2006	23	1638
2007	14	1068
2008	15	1070
2009	16	983
2010	15	1136
2011	14	1024
2012	13	953
2013	12	866
TOTAL	15	8738

MTK: million train and kilometers of railroad; Source: ANTT 2014.

It can be seen from the table that the total number of accidents registered in 2013 was almost half that registered seven years earlier, in 2006. This result demonstrates the effort that is being done to improve the quality of freight transport in the country and this is due in large part to the establishment of goals by dealers, with incentives for compliance.

Data compilation of the accidents in 12 existing dealerships in the country, also in the period 2006-2013, is shown in Table III.

According to the Table, we may infer that the country, with over 30,000 km of railways in 2013, transported about 450 million tonnes. Of that total, 80% was made from three dealers (Carajás Railroad, Vitória-Minas and MRS), located in the region surrounding the northeast and the southeast of the country and is involved with the ore transport, which density is far superior to the grain, other important cargo carried by railways especially in ALL with soya beans and corn to export.

Despite this dominance on the amount of transported cargo, these railways together represent less than 12% of the country rail extension and occupy positions in three of the four most appropriate safety index of less than 10 and well below the mean reported in Table II. This demonstrates a maintenance profile that can be considered a positive pattern, rather than that observed, for example, by Transnordestina Logistics, who presented in 2013, IS = 81 (Table III).

Poiting out the average score for the Safety índex in 2013 were slightly higher than those presented in the report of [7] which deserves a deepening of these studies. These values are strongly influenced by the indices presented by TLSA, FCA and ALLMO-MP-MS, which together representes almost 80% of the length of railways in the country (Table III).

Accidents related to railroad superstructure, were the most significant in nine of the twelve dealers. On average, they represent 53% of all accidents and, in some cases, reached values above 75% (77.4% - ALLMO; TLSA - 76.8%).

Another highlight that should be given is the total number of accidents with "other causes" which, as already mentioned, refer more to the fact that the investigation occurs after the restoration of services and, therefore, not be possible to establish the real cause of them. This fact is significant in the FTC, where 2/3 of the accidents are attributed to "other causes". Also showed higher values MRS (38.6%), EFVM (29.1%) and OBE (28.2%), these railways with a low IS but apparently with difficulty in fast diagnostic action.

If we consider only accidents linked to the superstructure, the Permanent way was the major cause of accidents in nine of the twelve occurrences, followed by the motive power, with the other three occurrences, leaving accidents linked to the roadway sign and telecommunications with insignificante percentages close to 0.5% average.

The exception of MRS (6.9%) and with lower results of EFPO (13.6%), ALLMN (15.1%) and EFVM (19%), the permanent way represented more than 1/5 of all registered accidents. In some cases, such as ALLMO and TLSA, represented 61.2% and 60.7% of the total, respectively. This demonstrates the importance of this type of accidents and the need to determine their causes, detailing it in its components.

The permanent way in direct contact with the motive power is basically made up of: a) rails, b) fastening and c) switching.

TABLE III. ACCIDENTS OCCURRED IN 12 DEALERSHIPS IN 2006-2013

Description	**Company**												**TOTAL**
	ALLMN	**ALLMO**	**ALLMP**	**ALLMS**	**EFC**	**EFPO**	**EFVM**	**FCA**	**FNS**	**FTC**	**MRS**	**TLSA**	**GERAL**
Extensão (Km)	**617**	**1945**	**1945**	**7265**	**892**	**164**	**905**	**8066**	**2200**	**164**	**1674**	**4207**	**30044**
	2.1%	**6.5%**	**6.5%**	**24.2%**	**3.0%**	**0.5%**	**3.0%**	**26.8%**	**7.3%**	**0.5%**	**5.6%**	**14.0%**	**100%**
Cargo 2013 (million of TU)	**14.4**	**4.6**	**5.3**	**22.9**	**115**	**3.2**	**125.2**	**22.9**	**3.1**	**3.2**	**130.9**	**1.2**	**451.9**
	3.2%	**1.0%**	**1.2%**	**5.1%**	**25.4%**	**0.7%**	**27.7%**	**5.1%**	**0.7%**	**0.7%**	**29.0%**	**0.3%**	**100%**
Causes	**Accidents from 2006 to 2013**												
Vandalism	1	3	5	3	1	0	54	5	0	0	0	8	80
	0.3%	0.3%	0.5%	20.0%	0.3%	0.0%	15.6%	0.3%	0.0%	0.0%	0.0%	0.5%	0.9%
Human Failure	65	53	83	70	61	7	3	183	2	0	92	135	754
	16.3%	5.5%	7.6%	4.6%	19.7%	31.8%	0.9%	10.8%	10.5%	0.0%	10.2%	9.2%	8.6%
Third Parties	15	47	181	371	46	1	59	308	7	1	321	36	1393
	3.8%	4.8%	16.6%	24.6%	14.9%	4.5%	17.0%	18.2%	36.8%	4.5%	35.7%	2.5%	15.9%
Subtotal	**81**	**103**	**269**	**444**	**108**	**8**	**116**	**496**	**9**	**1**	**413**	**179**	**2227**
	20.4%	**10.6%**	**24.7%**	**29.4%**	**35.0%**	**36.4%**	**22.4%**	**29.3%**	**47.4%**	**4.5%**	**45.9%**	**12.2%**	**25.5%**
Motive Power	177	155	138	142	45	6	63	247	1	1	76	232	1283
	44.5%	16.0%	12.7%	9.4%	14.6%	27.3%	18.2%	14.6%	5.3%	4.5%	8.4%	15.9%	14.7%
Telecomunications/	7	2	11	1	2	0	1	7	0	0	2	3	36
	1.8%	0.2%	1.0%	0.1%	0.6%	0.0%	0.3%	0.4%	0.0%	0.0%	0.2%	0.2%	0.4%
Permanent Way	**60**	**594**	**509**	**538**	**67**	**3**	**66**	**517**	**5**	**6**	**62**	**888**	**3315**
	15.1%	**61.2%**	**46.8%**	**35.6%**	**21.7%**	**13.6%**	**19.0%**	**30.6%**	**26.3%**	**27.3%**	**6.9%**	**60.7%**	**37.9%**
SubTotal	**244**	**751**	**658**	**681**	**114**	**9**	**130**	**771**	**6**	**7**	**140**	**1123**	**4634**
	61.3%	77.4%	60.5%	45.1%	36.9%	40.9%	37.5%	45.6%	31.6%	31.8%	15.6%	76.8%	53.0%
Other causes	73	116	161	386	87	2	101	425	4	14	347	161	1877
	18.3%	12.0%	14.8%	25.5%	28.2%	9.1%	29.1%	25.1%	21.1%	63.6%	38.6%	11.0%	21.5%
TOTAL	**398**	**970**	**1088**	**1511**	**309**	**22**	**347**	**1692**	**19**	**22**	**900**	**1463**	**8741**
	100%	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Safety Index 2006	68	261	34	14	7	10	6	21	0	10	7	150	
Safety Index 2013	5	23	21	17	3	11	3	24	16	11	7	81	

Source: Relatório ANTT 2013 e 2014.

A. *Rails*

At the top of the railway is the element that allows the wheels rolling of cars or locomotives and responsible for charge the cargo to the other components, called rails. The rails are part of the railway superstructure, remain in parallel position and are made of steel, leading the wheels of cars and locomotives [9]. Is the rolling surface of the vehicle that, over the years, was modified as to their shape and weight [10]. The rail profile used was actually created by Vignole, who devised a rail that allows proper fastening as resistance efforts, being termed as Vignole profile, which consists of three parts: A) Railhead, receives the load of the wheels must have adequate contact area to reduce the pressure and allow deterioration, B) Rail Foot, which transfers load to ties and C) Rail web, connecting the railhead to the Rail Foot and its height determines the inertia and hence much of the resistance of the profile to the maximum axle load.

The rails have two world standards: one determined by AREA - American Railway Engineering Association and other determined by the UIC - Union Internationale des Chemins de Fer - International Union of Railways. What determines the profile of the rail is the weight per unit length, which can be represented by kg / m (kilograms of rail per meter) or lb / YDA (pounds per Yard).

For the rail to be accepted at the time of receiving various items should be checked as shape, surface hardness and inside the profile, residual stress, tensile strength, ultrasonic testing and metallographic tests.

The limit of usage of the rails is something that concerns the companies that work with this kind of transport, it is not clear what is the cutoff point for usage of this element without affecting the safety of operation, while the costs for replacement are very high.

Some Brazilian railways accept a 12 mm vertical limit railhead deterioration for the main traffic routes, and 15 to 20 mm for the siding, sidetracks and maintenance lines. When we discuss the rail wear, admit that the wear angle can reach 32 ° to 34 °. When considering the weight loss of the rail the allowable value is up to 10% for rails to 45 kg / m profile and 15 to 20% for heavier rails. But normalization value determined by AREA that may be admitted up to 25% to the Railhead area, which can lead to different combinations of horizontal and vertical wear.

There is disagreement among authors about the limits of vertical and horizontal wear set for the Railhead, but we can not say that there is a direct relationship between them and the value of 25% used as a limit on the railway, as in field research is concluded that if theRailhead wear is at an angle of 32 °it representes a loss of Railhead area in separate rails profiles, which represents 32% for the track TR - 45, 31% for the track TR - 50 to 29% to track TR - 68 [11]. Thus the value of 25% is only valid when analyzed to track TR - 57, which is determined as derailment limit [12]. The replacement rail when it reaches 25% loss in slip area may be premature, as it limits the vertical and lateral wear correspond respectively to the loss of 28% to 29%. Thus occurring simultaneously the vertical and lateral wear, loss may reach 45% area of the Railhead [10].

B. Fastenings

Tarabadgi and Thompson [13] observed that the proposal of fastening systems is to serve as a restraint for rails against the ties and resist to the vertical movements, longitudinal, lateral and rotational. These movements are generated by the passage of soil bearing and the effect of temperature on rail. Note that the Flat Plat play a essencial role in transfer of efforts to the wood ties in a appropriate way, providing a permissible contact pressure on wood and protecting it against the mechanical wear. To the role of mechanical protection the size of the board also makes influence. Inadequate size of the boards can speed up the process of rupturing and premature deterioration of ties.

Fastenings can be identified as rigid, elastic and semi-elastic, which have the function of ensuring the physical connection of the rail with the tie and ensuring that the railway gauge is maintained.

The rigid fastening is still used in some Brazilian railroads and is divided into spikes and screw. The spikes are divided into two types: A) Cheap Wing "*Asa de Barata*" and B) Dog Head "*Cabeça de Cachorro*". To make the application of the spikes can be in two ways, directly in tie setting the Rail Foot, or using Flat Plat, however in both cases it is necessary to make a pre-drilling on tie, and after applying the nail, which can be mechanized or manual. The screws are also divided into two types: A) common screw that is made of steel 1030 and B) galvanized screw. The application of screw as well as spikes can be manual or mechanical. These elements come from the factory with a lubricant to facilitate its setting in wood and can be directly applied to the tie or using Flat Plats [10].

Semi-elastic fastening has two main types GEO and Elastic Pawnshop: A) Fastening GEO little used in Brazil, is well accepted by the other countries, with the advantage of better conditions of longitudinal tension and B) Elastic spikes, which were developed in order to be in constant contact between the fastening and the Rail Foot, which despite being a rigid fastening, the way the nail is bent provides a light flexibility. This kind of fastening fell into disuse a few years ago.

Elastic fastenings have a very specific feature, that despite the movement of rail cars, regardless of weight, as soon as it end to pass the Rail Foot contact fixation with the Rail Foot is taken in steady and balanced setting, regardless of the length of the rail bar. Many elastic fasteners are available in the market and they all have the same characteristic, that is a twisted steel clip, which is installed under pressure on the Rail Foot, the most common are Deenik, Pandrol, Vosloh, RN and Fast clip [2].

C. Switching

Steffler [4] mentions that the switching are a universe within the studies on railroads, for its large amount of elements generates a great demand in maintenance, and a lot of training. The main function of AMV is to run the removal of a total train from one to another making efficient railway operation.

The switching is made up of rail, Emergency Guardrail, switch and crossing, and all other fastening items. This element can be divided by its derivations that can be a) side, b) symmetrical, and c) asymmetric. As for the derivation of the permanent way may, depending on the weight of the train, which the operation speed of each type of switching.

Currently, a large number of switchings being automated in Brazilian railroads, just to speed up the operation and often direct the train by the way which has the best performance, or where the permanent way of deviation (siding) is with the best condition for speed and security.

The switchings that most present indicative of accidents within the railways are those that make up the railways with mixed gauge, (those that have two gauges on a single way), because this type of switchings not only works with two needles but with three and settings by maintenance teams are more complex because these railways the key indicator for circulation is when the roadway sign indicates failure with an opening of 2 mm.

Given these characteristics, it is extremely important to check the type of rails, fastenings and switching - switching in different Brazilian dealeers and what are the tolerances of each of the maintenance work. This will be the next step of this project, to identify whether there is a more appropriate type or that enables a smaller number of occurrences, which may contribute to repair maintenance, preventive maintenance and the expansion of the railway in the country.

IV. Conclusions

With the privatization of Brazilian railways, a number of companies have made concessions, and each of these companies adopted a maintenance plan. Some inherited the process of maintaining the old RFFSA, other company brought other maintenance processes of other railroads around the world and even some created their maintenance process. With this, we can see a big difference between companies, with some of them in proportion with low accident rates, while in others they are still numerous and this shows that we should research to improve planning and maintenance. This work was possible to identify and differentiate the railroads that are hitting in the maintenance process and investigation of accidents, other apparently walking in counter flow, and making a fragile railroad transport to be chosen as usable modal to transport production.

With this, open up doors for research of maintenance processes in different railroads in Brazil, especially those which are rated high in accidents caused by permanent way, using the procedures of the companies that had significant reductions as a model to be followed, with the use of your plans of preventive maintenance, corrective and accident investigation processes to learn from them. This analysis may, ultimately, allow to establish a more standardized process within the Brazilian territory and increase the comparability analysis and the use of successful experiences, helping to reduce even further the number of accidents on railways.

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