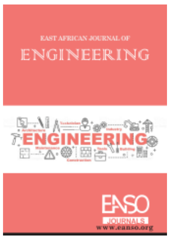


East African Journal of Engineering
eaje.eanso.org
Volume 5, Issue 1, 2022
Print ISSN: 2707-5389 | Online ISSN: 2707-5397
Title DOI: https://doi.org/10.37284/2707-5397

EASO
EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL

Dr. Frederic Bationo, PhD[1]& Zoewendbem Alain Ilboudo[2]*

[1] Institute for Research in Applied Sciences and Technologies (IRSAT) / National Center for Scientific and Technological Research (CNRST) of Burkina Faso, 03 BP 7047 Ouagadougou, Burkina Faso 03.
[2] University of Technology and Management (UTM), 01 BP 6445 Ouagadougou 01, Burkina Faso.
* Author for Correspondence Email: frederic.bationo@hotmail.com.

Article DOI: https://doi.org/10.37284/eaje.5.1.749

Publication Date:

12 July 2022

Keywords:
Traction Motor, Locomotive, Ishikawa, Operational Availability, Functional Analysis.

ABSTRACT

This document shows the difficulties encountered by railway companies in the operation of locomotives. He makes a special mention in the case of International African Transport Company by RAIL. To do this, the history of International African Transport Company by RAIL locomotive operating failures has allowed us to calculate their operational availability, their mean times of failure, and their average technical repair times. The analysis shows that out of twenty locomotives, 60 percent has an operational availability below the 95 percent reference value. Using the functional analysis method, the locomotive operating indicators are evaluated and represented in Operation Functional Specification showing the deficiencies and achievements. Ishikawa has also been used on the traction motor, the element at the origin of the unavailability of locomotives, to identify the major causes, allowing making proposals for solutions, to improve the operational availability of traction engines and, in turn, of locomotives.

APA CITATION

Bationo, F., & Ilboudo, Z. A. (2022). New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL *East African Journal of Engineering*, *5*(1), 131-141. https://doi.org/10.37284/eaje.5.1.749

CHICAGO CITATION

Bationo, Frederic, and Zoewendbem Alain Ilboudo. 2022. "New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL". *East African Journal of Engineering* 5 (1), 131-141. https://doi.org/10.37284/eaje.5.749.

HARVARD CITATION

Bationo, F., & Ilboudo, Z. A. (2022) "New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL", *East African Journal of Engineering*, 5(1), pp. 131-141. doi: 10.37284/eaje.5.1.749.

Article DOI: https://doi.org/10.37284/eaje.5.1.749

IEEE CITATION

F., Bationo., & Z. A., Ilboudo, "New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL," *EAJE*, vol. 5, no. 1, pp. 131-141, Jul. 2022.

MLA CITATION

Bationo, Frederic & Zoewendbem Alain Ilboudo. "New approach to maintenance based on functional analysis of traction engines: Case of Locomotives of the International African Transport Company by RAIL." *East African Journal of Engineering*, Vol. 5, no. 1, Jul. 2022, pp. 131-141, doi:10.37284/eaje.5.1.749.

INTRODUCTION

Rail transport is a means of transferring passengers and goods on wheeled vehicles running on rails in which rolling stock is guided. In rail transport, the stock involves all vehicles such as power locomotives, wagons, motor cars, baggage vans, and coaches on bogies/wheels, which moves on the rails [8]. The operation of locomotives on the railway naturally leads to the obsolescence of traction motors (TM) as well as other components and details which consequently increases the number of failures [13].

As a result, many railway companies continue to use the preventive maintenance system to repair locomotives, and this maintenance system requires considerable funding for repair work. Also, the quantity of repair work does not always correspond to the actual technical condition of the locomotive. Thus, the use of this approach in the maintenance organization can be considered morally obsolete [16].

The unavailability of locomotives due to inadequate spare parts remains a challenge in Africa. It is therefore imperative to review locomotives in Africa, establish current capacity and make recommendations to address gaps and extrapolated trends in the future [8].

Railway locomotive performance metrics were used to showcase railway systems in some African countries [8]. Indeed, the locomotive is one of the most relevant assets of a railway, as it is the source of traction for the compositions and also because of its high cost and the high demand for maintenance [17].

A visit to the International African Transport Company by RAIL depot in Abidjan, discussions with its managers, and the inspection of locomotives have made it possible to identify gaps which may contribute to the difficulties currently experienced by locomotives in relation to slippage, power loss, and traction motor failures [21]. The visit also made it possible to note a large number of damages to the traction motors with a significant increase. According to the information collected, a total of thirty-eight cases were reported during an operating year, resulting in the replacement of a TM in the majority of cases [21]. This confirms a major influence of the TM on the locomotive's operational readiness.

The unreliability of TM has become a significant issue for railways, as it remains the most important component of a locomotive. Most locomotive failures are the result of poor TM performance [5]. According to Souza et al. [2] the TM is the major factor negatively influencing locomotive availability. As a result, our study will focus on this component of the system, which aims to improve the operational availability of International African Transport Company buy RAIL locomotives.

MATERIALS AND METHODS

Materials

Rail equipment is the key component of the rail system. In common language, railway rolling stock is generally referred to as a "train", which is defined as one "engine vehicle(s) towing or not towing one or more vehicles". This definition refers to an assembly (or not) of vehicles, or railway convoy, designed to travel on a specific infrastructure: the railway [4]. This equipment is therefore guided along its entire route, which can be guided by a monorail or two or more rails.

Article DOI: https://doi.org/10.37284/eaje.5.1.749

International African Transport Company buy RAIL has a GT22LC-2 locomotive, towing MAR, VOY, or SCE trains [21].

As of 05 May, 2020, the IACTR fleet was as follows, in *Table 1* below.

Table 1: International African Transport Company buy RAIL Equipment and Infrastructure

Materials	Infrastructure
Twenty locomotives	1,260 kilometers of track
Fourteen locotractors for manoeuvering operations	1,675 structures
Fifteen construction railcars	Fifty-nine stations
Twenty public works and service vehicles	Two railroads multimodal platforms
Twenty passenger cars and more than 1,000 freight cars	A fibre-optic telecommunications system

Methods

Safe Operation of Locomotives

Operational safety is a system failure approach to identify, assess, estimate, and control the risks posed by these failures. Certified by ISO 9000, it represents "all the properties that describe availability and the factors that condition it: reliability, maintainability, availability and safety" [14].

Reliability is defined for the first time by the Advisory Group on Reliability of Electronic Equipment (AGREE) in 1957 in the United States and taken up in 1984 by AFNOR NF X 06-501 [9].

It designates “the characteristic of a device expressed by the probability that this device performs a required function under given conditions of use and for a determined period of time”. It is characterized by two (2) indicators, namely, the Mean Time Between Failures (MTBF) and the failure rate (λ), expressed by:

$$\lambda(t) = \frac{1}{MTBF} \quad (1)$$

$$MTBF\ (h) = \sum_{n=1}^{1} \frac{PFT}{N} \quad (2)$$

With PFT: Proper Functioning Time and N: Number of failures

This equality is valid if λ(t) is constant, that is, the probability density of failures f(t) indicates an exponential law.

Maintainability: Kapur and Lamberson (1977) produce maintainability as being “the probability of a device being maintained or restored under given conditions, during a given time interval” [12].

The maintainability indicators are the repair rate μ(t), introduced in a similar way to the failure rate of failures λ(t) and Mean Time To Repair (MTTR). They are represented by the following formulas:

$$\mu(t) = \frac{1}{MTTR} \quad (3)$$

$$MTTR\ (h) = \sum_{n=1}^{1} \frac{RTT}{N} \quad (4)$$

With RTT: Repair Technical Time and N: Number of Failures

Availability: reliability and maintainability help define the notion of availability to accomplish a function required under given conditions and at a given moment. It can be broken down into intrinsic availability which refers to the designer and Operational Availability (OA) which refers to the user [10].

Readiness is defined by:

Article DOI: https://doi.org/10.37284/eaje.5.1.749

$$OA = \frac{MTBF}{MTBF+MTTR} \tag{5}$$

Data collection was carried out by a visit to the Diesel Block (DB) workshops in Abidjan and maintenance depots (Abidjan, Bouake, Bobo-Dioulasso and Ouagadougou), by inspecting locomotives in line during driving services and by analysing the maintenance methods in use at International African Transport Company buy RAIL. This provided a history of twenty locomotive failures over a period of eighteen months of production (12960 hours) [21].

Locomotive Maintenance Approaches

The locomotive is the main source of power for a train and plays a strategic role in the success of the rail transportation system in meeting the rail travel plan [11].

A locomotive has six TM grouped together in three different ways. These are the series-parallel groupings (3 TM in series and in parallel with the others), parallel (6 TM in parallel) and parallel series (2 TM in series and in parallel with the others). A TM is defined as an electrical device that performs the torque of the machine to drive the wheels of a locomotive [4].

Worldwide, work has shown the use of the Reliability Based Maintenance (RBM) concept to develop or optimise a maintenance program for locomotives. Indeed, Suweca et al. [9] used it with Pareto to show that the sub-chassis contributes to the highest probability of failure in a locomotive. This type of maintenance can be applied to corrective maintenance, spare part optimization, and logistical considerations [15]. It is an approach that uses tools such as FMEA (Analysis of Failure Modes, their Effects and their Criticalities) [6].

The Ishikawa and Pareto tools analysed the root causes of the locomotive’s primary Fiat Bogie external source failure. From this work, the major problem with the system is the failure of the spring (suspension). Ishikawa has limitations in finding solutions [18].

To improve the efficiency and reliability of locomotives, it is necessary to constantly monitor the operating process. The introduction of modern automatic control and monitoring systems on locomotives not only shows a deviation from the established condition of the equipment, but also an effective and efficient way to process measurement information that can detect changes in the technical state of key parts [22].

In rail transportation, the consequences of a locomotive failure are not limited to the affected machine. In addition to the cost of the machine itself, delays are caused and eventually propagated by the rail network, making the cumulative cost of a single incident unpredictable. To avoid failures, Planned Maintenance (PM) can be used. Predictive maintenance is intended to replace existing maintenance processes (e.g., time-based preventive maintenance) with practical corrective maintenance planned through the operation of the underlying deterioration processes [20].

The locomotive is the main part of a train and, like any other mechanism, maintenance and troubleshooting are crucial. With the exception of corrective and preventive maintenance, the new trend in all industries is the prognosis of failure, also known as predictive maintenance, which is intended to detect a future failure [19]. In particular in Brazilian rail operations, mention can be made of the application of FMEA by [5], [7], [17]. Indeed, Oliveira [17] applied it with other tools to propose a model to control the maintenance cycle and ensure the availability and reliability of the railways.

To build Ishikawa, a work team composed of six different skills including the Head of Towed Equipment Division, the Maintenance Depot Manager, the Head of DB Electrical Section, a DB Skilled Worker, the team leader daily maintenance depot visits and a design engineer has been set up. The same team previously performed the functional analysis of a locomotive operating perspective.

Article DOI: https://doi.org/10.37284/eaje.5.1.749

Most failures result from damage to engine components such as switches, brushes, and insulation. The causes of the damage are mechanical, electrical, and thermal overloads that come from high vibrations, slippages, moisture, and cooling of filter fouling. Statistics indicate that 37 percent of TM failures result from insulation [5]. The signals used for on-line continuous monitoring of TM status are motor current and voltage, vibration, temperature, induced voltage in the search coil, etc. Research has shown that corrective maintenance is associated with high costs and considerable time consumption. However, there is a preventive maintenance method that performs the tasks defined on technically correct systems to avoid failure [1].

The literature informs us of the use of several maintenance concepts to improve the operational availability of locomotives. Indeed, RBM, FMEA, Ishikawa and Pareto tools, preventive, corrective, and predictive maintenance are already offered. However, railway transport companies are still struggling to meet profitability targets, like International African Transport Company buy RAIL. Thus, in order to make our contribution, we used the functional analysis method to evaluate the operating performance of locomotives with a functional specification. The analysis work took place in 2018, as part of the preparation of a master’s degree in industrial engineering at the Private Higher Institute of Technology of Burkina [21].

RESULTS AND DISCUSSION

Locomotive Reliability, Maintainability, and Operational Availability Analysis

Using the data collected at International African Transport Company buy RAIL, calculations of MTBF, MTTR and OA were made and represented in *Table 2* below:

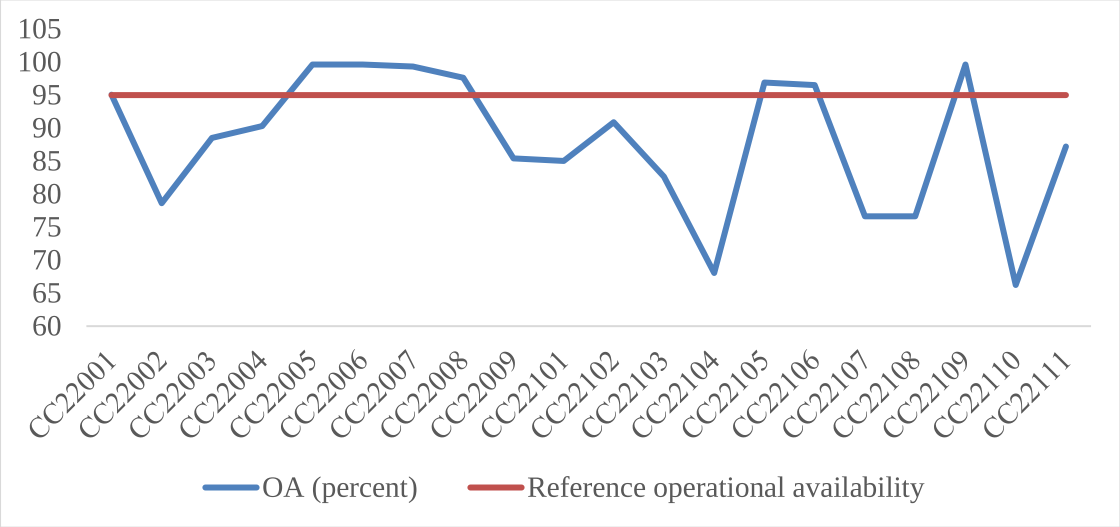
Table 2: Calculation of MTBF, MTTR and OA

Locomotives	TST (h)	RTT (h)	PFT (h)	N	MTBF (h)	MTTR (h)	OA (percent)
CC22001	13152	648	12528	7	1789,71	92,57	95,08
CC22002	13152	2808	10344	20	517,2	140,4	78,64
CC22003	13152	1512	11640	8	1455	189	88,50
CC22004	13152	1272	11880	23	516,52	55,30	90,32
CC22005	13152	48	13104	8	1638	6	99,63
CC22006	13152	48	13104	6	2184	8	99,63
CC22007	13152	84	12312	10	1231,2	8,4	99,32
CC22008	13152	312	12840	8	1605	39	97,62
CC22009	13152	1920	11232	43	261,20	44,65	85,40
CC22101	13152	1968	11184	10	1118,4	196,8	85,03
CC22102	13152	1200	11952	15	796,8	80	90,87
CC22103	13152	2280	10872	25	434,88	91,2	82,66
CC22104	13152	4200	8952	29	308,68	144,82	68,06
CC22105	13152	408	12744	23	554,08	17,73	96,89
CC22106	13152	456	12696	7	1813,71	65,14	96,53
CC22107	13152	3072	10080	28	360	109,71	76,64
CC22108	13152	3072	10080	6	1680	512	76,64
CC22109	13152	48	13104	2	6552	24	99,63
CC22110	13152	4440	8712	12	726	370	66,24
CC22111	13152	1680	11472	18	637,33	93,33	87,22

Total Study Time = TST, h = time in hour

Article DOI: https://doi.org/10.37284/eaje.5.1.749

Figure 1: Change in Locomotive Operational Availability



Under ideal conditions of equipment use, readiness should be geared towards 1.

In the case of SITARAIL, to take into account factors related to maintenance, operation, the environment and the age of the locomotives, the reference operational availability is 95% out of eighteen (18) months of continuous operation [17].

OA Comments represented by *Figure1* above:

CC22002, CC22003, CC22004, CC22009, CC22101, CC22102, CC22103, CC22104, CC22107, CC22108, CC22110, CC22111 of twelve (12) locomotives have an OA of less than 95 percent and represent 60 percent of the locomotive fleet.

Locomotives CC22001, CC22005, CC22006, CC22007, CC22008, CC22105, CC22106, CC22109 with an OA greater than 95 percent represent 40 percent of the locomotive fleet.

Comments on MTBF and MTTR

- Locomotive CC22109 has an MTBF well above the other twenty locomotives. The majority of locomotives with good OA also have good MTBF, with the exception of locomotive CC22105.
- The CC22005, CC22006 and CC22105 locomotives have the best MTTR. It should also be noted that all locomotives with the best OA have the best MTTR.

In order to increase the profitability of International African Transport Company buy RAIL, it is necessary to improve the OA by acting on the reliability and maintainability of locomotives with an OA of less than 95 percent.

Locomotive Operating Functional Specification (OFS)

The profitability of freight and/or passenger freight operations is highly dependent on locomotive performance. Advances in technology have led to an increasingly sophisticated form of locomotive operation. This leads to an increase in the cost of ownership, which affects the profitability of locomotives and, by extension, the competitiveness of International African Transport Company buy RAIL. It is therefore clear that one of the best ways to increase profitability is to maximize the overall efficiency of locomotives. The latter is a result of several factors, namely technical, organizational and economy.

The functional analysis method is used to assess the operational failure of International African Transport Company buy RAIL locomotives. Thus the OFS of an efficient operating system is represented in *Table 3* below:

Article DOI: https://doi.org/10.37284/eaje.5.1.749

Table 3: Locomotive Operating Functional Specifications

Functions	Criteria	Level	Limits/flexibility	Observations
FP1: ensure the traction of vehicles (cars and/or passenger cars)	C01: power	2250 horsepower	±10 percent	RAS
	C02: offered load	• 300 TB for goods • 600 TB and up to 20 vehicles	±5 percent	RAS
	C03: braking rules	• PFAN PFAR and last braking vehicle for freight trains and similar • Either 08/10th of the axles are made and the last vehicles brake	PCCC order	RAS
FP2 : cut red tape	**C06**: easing of tensions between the farm and the equipment; between the store and the equipment	• speed in managing misunderstandings: 48 hours	±5 percent	to improve
FC1 : have fuel in quantity and quality	**C07** : hydrocarbon	24h/24	1hour	RAS
FC2 : qualify personnel (drivers and technicians)	**C08** : engine control	more than one course/year	no	to improve
FC3 supply the store with compliant and real-time spare parts	**C09** : availability	95 percent	±5 percent	to improve
FC4 : comply with the customer's specifications	**C10** : ensure safety and travel times	application of RGS and LMTr	±5 percent	to improve
	C11 : loyalty	90 percent	±10 percent	RAS
FC5 : respect the axle load	**C12** : tonnage	16 tonne	5 percent	RAS
FC6 : allow movement of the convoy	**C13** : Consequent hardness of the rail in relation to the wheels.	10 percent	5 percent	RAS
	C14 : correspondence of the metric spacing	1meter	+15mm and -10mm	RAS
FC7 : easily maintain	**C15** : gear standardization	80 percent of the vehicles	5 percent	RAS

Article DOI: https://doi.org/10.37284/eaje.5.1.749

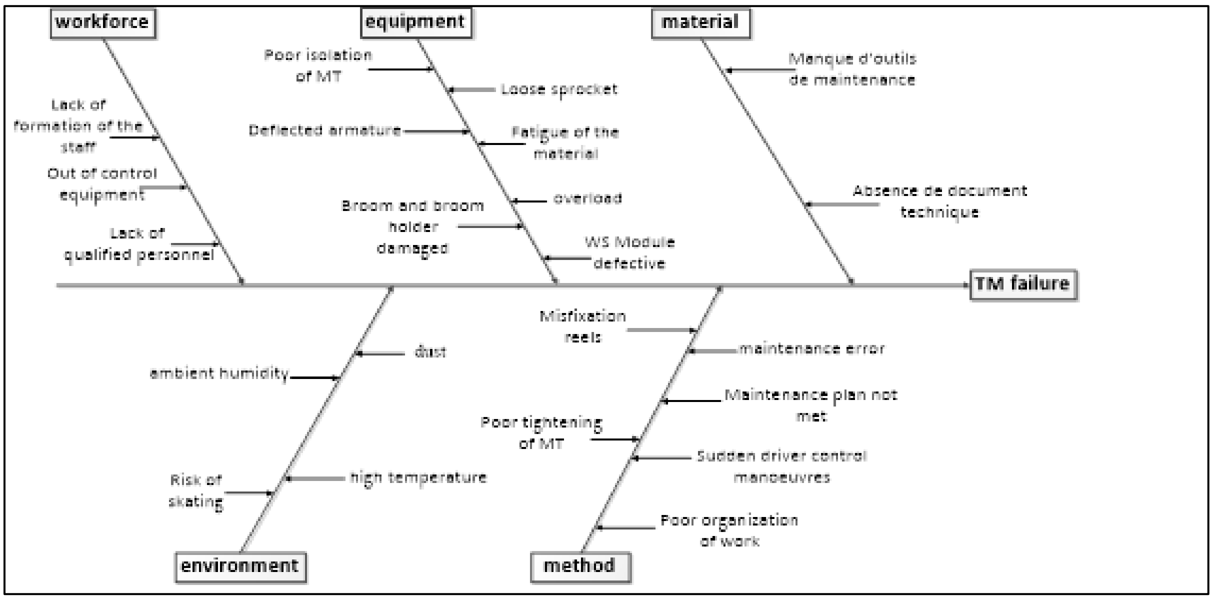
	C16 : modularity	70 percent of the system	5 percent	RAS
	C17 : interchangeability	70 percent of the vehicles	5 percent	RAS
FC8 : comply with SITARAIL requirements	**C18** : application of the RDM	95 percent	±5 percent	to improve
FC9 : ensure a good rotation of the machines	**C22** : good planning of crossings in stations	70 to 75 percent	• increase in the capacity of the reception channels; • opening of all closed stations; • double track	to improve
	C23 : respect of walking times according to the LMTr	70 percent	resumption of the alignment of the trains in the LMTr	RAS
FC10 : comply with environmental standards	**C24** : pollution and degradation	no pollution and degradation	no	RAS
	C25 : noise	10dB	±2dB	RAS
FC11 : increase traffic density / increase the number of trains	**C27** : cadence	15 trains/day	±10 percent	RAS

Article DOI: https://doi.org/10.37284/eaje.5.1.749

LMTr: Booklet on the Running of Trains; RGS: General Safety Reference System

In view of the shortcomings identified in the OFS, poor work organization constitutes the major handicap negatively impacting the operational availability of locomotives. The major consequences are the lack of spare parts in quantity and quality and the lack of qualified personnel.

Figure 2: Cause-effect diagram of TM



TM Fault Investigation with Ishikawa

The multidisciplinary team set up for this purpose met and through a brainstorming produced the data used for the construction of the Ishikawa diagram shown in *Figure 2* below:

Results from the TM failure analysis show that the “Hardware” and “Method” branches are more loaded on the other five. Indeed, out of a total of twenty-two cases found, they represent thirteen, or about 60 percent.

The causes contained on the “Material” branch have the consequences of burning collector blades, runaway TM and stoppage. Those contained in the "Method" branch have the consequences of runaway TM, overheating TM, coil failure and burning collector blades.

Recommendations for Improving Locomotive Operational Availability

The recommendations are made to overcome the problems found when using Ishikawa and OFS, they are :

- Track maintenance and record locomotive fault history data on a regular basis ;
- Strictly respect the supply and compliance deadlines for spare parts ;
- Reinvigorating the diesel block (db) triplet, the technical organization office (too) and the depots;
- Comply with maintenance plans provided by locomotive manufacturers ;

Article DOI: https://doi.org/10.37284/eaje.5.1.749

- Comply with the requirements of the functional locomotive operating specifications ;
- Increase the capacity of the receiving tracks and increase the number of trains, in order to avoid axle overload ;
- Establish and implement a plan for the decommissioning or renewal of locomotives, especially those that are more than thirty years old.

CONCLUSION

An inventory was made of the operation and maintenance of the locomotives by the International African Transport Company buy RAIL technical teams. It appears that the recurring failures recorded on the TM led to a decrease in the company's OA of twelve out of twenty locomotives. International African Transport Company buy RAIL suffers from an organizational problem related to the operation and maintenance of locomotives.

Concepts have been proposed to improve locomotive OA, however difficulties remain. Thus, failure to comply with the rules laid down for the operation of said locomotives is detrimental to their proper functioning. It is therefore imperative to analyse their operating methods in depth using the functional analysis method in order to identify possible solutions. Beyond this analysis, predictive maintenance also remains a possibility for better monitoring of locomotive operation today. Scrupulous adherence to maintenance plans with the implementation of the proposed recommendations may contribute to improving locomotive OA.

REFERENCES

[1] A.K. Samanta, A. Nah., D. Basu, A. Routray, & A. K. Deb, "Online Condition Monitoring of Traction Motor", Handbook of Research on Emerging Innovations in Rail Transportation Engineering, pp. 489-523, 2016.

[2] A. P. De Souza, F. M. Tavares, R.T.R. Bonikowski, & V. H. M. Pereira, "Reduction of number of Railroad Accidents with Locomotive as the main cause", p.68, 2019.

[3] G. Marc, R. Daniel, and C. Norberto, "Implementation a sectoral benchmarking to improve the organization of SME maintenance"; *1st International Industrial Engineering Congress; Montreal*, 1995.

[4] I. I. Ozigis, J. I. O. Oche, and N. M. Lawal, "Locomotive engines and the future of railway automotive power in Africa: A review," *Nigerian Journal of Technology*, vol.40, no.4, 2021, 2467-8821.

[5] I. W. Suweca, Y. B. Pratiknyo, and R. Setiawan, The Improvement of Maintenance Program to Increase Locomotive Reliability through Component Class Grouping, Bandung, 2007, p. 131-138.

[6] M. Szkoda, & M. Satora, "The application of failure mode and effects analysis (FMEA) for the risk assessment of changes in the maintenance system of railway vehicles. Technical transactions ", 8(9), pp.159-172, 2019.

[7] J.C. Ligeron, "Le Management des grands contrats, prise en compte des aspects qualité et sûreté de fonctionnement. Edition, Paris: Techniques et documentation", pp. 1497, 1998.

[8] K.A. ASRI, Ir. R. Muryamto, & M. Eng.Sc, "Visualisasi Perjalanan Kereta Api Berdasarkan Grafik Perjalanan Kereta Api (GAPEKA) dengan Peta Online (Studi Kasus : Kereta Api Rute Semarang –Jakarta) ", Universitas Gadjah Mada, 2021, p. 55, 2021.

[9] K. C. Kapur and L. R. Lamberson, Reliability in Engineering Design. Nashville, TN: John Wiley & Sons, 1977.

Article DOI: https://doi.org/10.37284/eaje.5.1.749

[10] L. P. Lingaitis, S. Mjamlin, D. M. Baranovsky, and V. Jastremskas, "Prediction Methodology of Durability of Locomotives Die sel Engines," Metodologia Prognozowania Tr wałości Silników Dieslaw Lokomotywach, Vol. 14, No. 2, pp. 154–159, 2012.

[11] M. Rausand and J. Vatn, "Reliability Centred Maintenance," in *Complex System Maintenance Handbook*, K. A. H. Kobbacy and D. N. P. Murthy, Ed. London: Springer, 2008, p. 79-108.

[12] O. B. Ochkasov, O. M. Shvets, & L.Čern iauskait, "Usage of Intelligent Technologies in Choosing the Strategy of Technical Maintenance of Locomotives, " (ISSN: 2310-7758), pp. 68-71, 2017.

[13] P. A. V. Schuina, "Study on the quality of ballast maintenance on the railroad Vitória a Minas," Monograph (Production Engineering) - Federal Institute of Education, Science and Technology of Minas Gerais, p.62, 2014.

[14] R. Nehete, P. P. Patil, and S. T. Jangam, "Root cause analysis of failure of suspension spring used in fiat bogie of Indian railways," *Industrial Engineering Journal (ISSN- 0970- 2555)*, *14*(06), 37-42, 2021.

[15] Kauschke, S, "Improving Cargo Train Availability with Predictive Maintenance : An Overview and Prototype Implementation", European Transport Conference 2016, Association for European Transport (AET), p.15, 2016.

[16] T. K. Bopape, "Factors that can improve the reliability of the traction motor for the Locomotives," University of Johannesburg (South Africa), 2018.

[17] T. Kiendrebeogo, "Improving the operational availability of traction engines: the case of the SITARAIL locomotive. Professional Master in Industrial Engineering from the Higher Institute of Technology", 2018.

[18] T. M. Oliveira, "Reliability analysis of permanent track equipment: Regulators and Ballast Cutters of MRS Logística S.A", p.88, 2012.

[19] V. M. Sh, & H. K. Kosimov, "Schedule maintenance and repair system of Locomotive", icecrs, vol. 8, 2020.

[20] W. Hong, "Application of the risk analysis method to the derailment study, 2011. (Master's degree University of São Paulo).

[21] W. Hong, "Application of the risk analysis method to the derailment study, 2011. (Master's degree University of São Paulo).