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Review Manuscript

Reliability Improvement in the Traction System of Tanzania Standard Gauge Railway

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ABSTRACT

In recent years, many African governments have been developing Standard Gauge Railway (SGR) to replace the old after becoming absolute, inefficient Meter Gauge System (MGR) to carry more loads at high mileage and speed while combating the oil and environmental crises. With the increase of SGR, the amount of traction systems has grown sharply, the service life of the traction system has increased gradually, and the components of the vehicle traction system have become worn and aged as a result. While Tanzania is transitioning to SGR with its gradually increasing traction systems, reliability improvement becomes a key for the sustainability of its high-speed train services. This paper, therefore, aims to improve the reliability of traction motors used in Tanzania's SGR. Firstly, the factors affecting the reliability of the traction system of Tanzania's SGR and their significance are evaluated. Secondly, the computerized maintenance management system (CMMS) is designed to streamline and automate the maintenance management processes of the traction system of Tanzania's SGR. Finally, a regression model is established to forecast the uptime based on the established factors. The obtained uptime hours were predicted in order to compute the reliability of the traction motor and its criticality in operation. Critical factors for improving reliability have also been highlighted. These findings play vital roles in establishing the fundamentals of factors that affect reliability as well as strategies and countermeasures to extend the operational life of the traction motors cost-effectively.

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INTRODUCTION

In recent decades, standard gauge railways (SGR) have been established in many countries to revolutionize railway transport by relieving road networks from being congested with huge chunks of cargo which are transported via roads. Furthermore, SGR uses electricity to cut fuel costs as well as reduce emissions that could be released by the old, inefficient meter-gauge railway system (MGR). The SGR railway can transport passengers and cargo loads at high speed as opposed to the MGR. To date, the global SGR speedy trains can reach as high as 460 km/h for Shanghai Transrapid in China (The Eurasintimes, 2023), 350 km/h for High-Speed Rail in Hong Kong (High-Speed Rail, 2023),322 km/h for Shinkansen bullet trains in Japan (Japan Rail Pass, 2023), 320 km/h across European countries (The train line, 2023), and 160 km/h for Tanzania's SGR (Tanzania Invest, 2023). The traction motor is a critical component in maintaining the routine operation of the locomotives since it provides an efficient and reliable operation of SGRs. To prolong the routine operations of the locomotives, proper maintenance of the traction motor is crucial. The common strategy deployed globally is to adopt a maintenance management strategy in order to reduce unnecessary failures and costs during the operation of a traction motor (Sabitov, 2020).

Recent studies have explored various design and maintenance approaches that can contribute to improving the reliability of traction motors. Some of them analyze different design features, such as insulation systems, cooling mechanisms, and bearing materials, which can enhance motor performance and prevent failures. Additionally, maintenance strategies, including predictive and preventive maintenance, are discussed about their effectiveness in minimizing motor downtime and increasing its reliability. Smith & Johnson (2015) focuses on design optimization techniques for improving the reliability of traction motors. Their study discussed various design parameters and their impact on motor performance and reliability. The findings presented a comprehensive analysis of different design optimization methods and their effectiveness in enhancing motor reliability. Brown & Davis (2017) explore the application of predictive maintenance strategies to enhance the reliability of traction motors. It discusses various techniques such as condition monitoring, fault diagnosis, and prognostics to detect potential failures in advance. The study also evaluates the effectiveness of different maintenance strategies in minimizing downtime and improving motor reliability. Gupta, S., & Patel, R. (2018) presented a reliability analysis of traction motors in high-speed rail systems. They examined the failure patterns and causes of motor breakdowns in real-world scenarios. The study utilizes statistical methods and reliability models to assess the reliability performance of traction motors and identify potential improvement areas. Lee & Kim (2019) focused on advanced fault detection and diagnosis techniques for improving the reliability of traction motors. Various methods such as signal processing, machine learning, and data analytics to detect and diagnose motor faults accurately were studied. The study evaluates the effectiveness of these techniques in enhancing motor reliability and reducing maintenance costs. Even though the literature on improving the reliability of traction motors provides valuable insights into enhancing performance, efficiency, and durability, the integration of data-driven maintenance strategies can provide promising avenues to ensure the long-term reliability of traction motors. Besides, data-driven maintenance could be beneficial for developing countries transitioning to SGR.

The goal of this paper is to improve the reliability of the traction system in Tanzania's Standard Gauge Railway (SGR). The contributions are the following:

- The factors affecting the reliability of the traction system of Tanzania's SGR and their significance are assessed.
- The Computerized Maintenance Management System (CMMS) is designed to streamline and automate maintenance management processes of the traction system of Tanzania's SGR.
- The reliability of the traction system

of Tanzania's SGR is assessed in terms of mean time before failure (MTBF), mean time to repair (MTTR), and uptime.

METHODS AND MATERIALS

Tanzania's SGR network, electric traction and traction motors

This study involves the improvement of the reliability of traction motors used for propelling electric traction in Tanzania Standard Gauge Railway (SGR). The traction system of Tanzania's SGR has the capacity to transport passengers and cargo shipments at 160 km/h (TanzaniaInvest, 2023) (see in Figure 1a) and employs a 3 Phase 4 Pole Squirrel-Cage Induction motor for its propulsion (see in Figures 1b-c). Tanzania's SGR is expected to link the port of Dar es Salaam from the Indian Ocean to the port of Mwanza on the shore of Lake Victoria and to the nearby countries including Burundi, Rwanda, and DRC (see Figure 1d). Tanzania's SGR network consists of a network of about 2000 km (TanzaniaInvest, 2023) implemented in 6 phases as shown in Table 1.

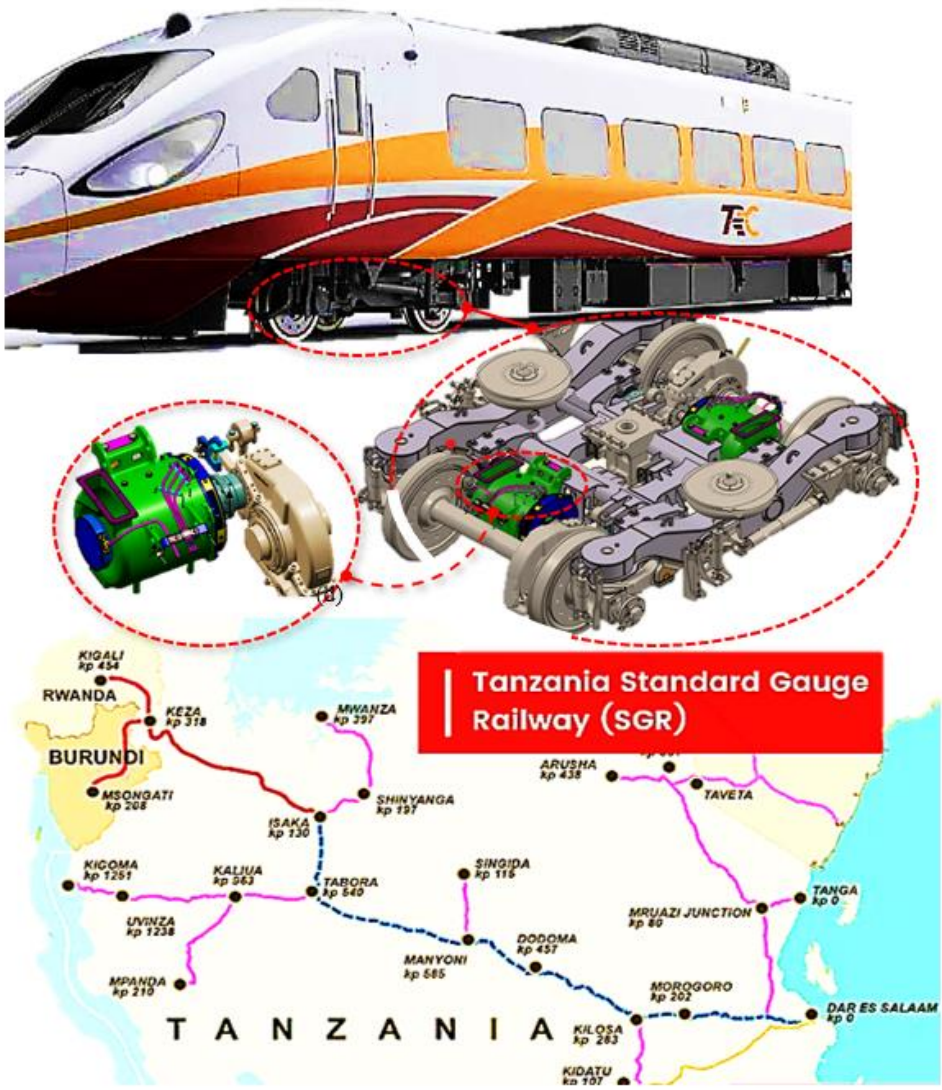

Figure 1: The electric train in Tanzania (a) electric traction (b) traction bogie (c) traction motor and (d) Tanzania Standard Railway (SGR) network for electric trains in Tanzania (TanzaniaInvest, 2023).

Table 1: Implementation phases of Tanzania's SGR network (TanzaniaInvest, 2023)

Phase description	Implementation details	Status
Phase 1: Dar -Morogoro (300 km)	Started in April 2017 by Yapı Merkezi from Turkey and Mota Engil Africa from Portugal	Completed
Phase 2: Morogoro-Makutupora (422 km)	Launched in 2018 and is done by Yapi Merkez	91.79%
Phase 3: Makutupora-Tabora (294 km)	Launched in 2018 and is done by Yapi Merkez	97.77%
Phase 4: Tabora-Isaka (130 km)	In July 2022, TRC signed with Yapi Merkez	3.95%
Phase 5: Isaka-Mwanza (249 km)	In January 2021, TRC signed with CCECC	22.71%
Phase 6: Tabora-Kigoma (506 km)	In December 2022, TRC signed with CCECC	Not updated

Table 2: Technical specification of traction motor used in Tanzania's SGR network.

	Implementation details			
Type	3 Phase 4 Pole Squirrel-Cage Induction motor			
Class	Class 220			
Ventilation	Self- Ventilation			
Dielectric test voltage	4600 Vac (eq. 2×Udc+1000 = 2×1800+1000)			
Maximum service speed	4816 rpm (at 160km/h with ⌀ 820mm wheel)			
Overspeed test	5779 rpm			
Noise value	Below 115 dBA (at maximum service speed 4515 rpm)			
Mass	Approx. 720 kg			
	Continuous Rating	**One Hour Rating**	**Nominal Point**	**Max. service Point**
Output power (kW)	250	280	478.6	240
Voltage (V)	1350	1350	1350	1350
Current (A)	135	151	245	126
Frequency (Hz)	100	100	72	162
Rotating per min. (rpm)	2970	2960	2125	4816
Slip (%)	1	1.33	1.62	0.91
Speed (km/h)	98.7	98.4	70.5	160

Tanzania's SGR mileage would consequently cause the components of the traction system to become worn and aged. The wear and ageing, if not properly maintained, would cause the failure of traction motors, and affect the operation of the vehicles. Hence, improving the reliability of traction motors would sustain the vehicle operation. Table 2 shows the technical specifications of the traction motor employed by Tanzania Railway Corporation (TRC) to propel the electric traction.

Research Methodology

The current study is based on the Tanzania Railway Corporation (TRC) which operat es Tanzania's SGR. TRC owns 5 worksho ps which are used to repair and maintain M GR. However, to a large extent, the same workshops and technical personnel will be used to repair and maintain the electric trac tions. Since, the majority of technical pers onnel are located at Dar es Salaam, the TR C's headquarters, the study will focus on t his city.

Study Setting

The TRC's headquarters has more than 2000 staff members who are engaged in the operations and maintenance of rolling stock and infrastructure. The first focal point of the reliability study is to understand the factors affecting the reliability of traction motors. However, not all the staff members will be able to participate in this research. Instead, a sample size will be selected based on the Eqn. (1) (Kotrlik & Higgins, 2001).

$$n = \frac{z^2 \times p \times q}{e^2(N-1) + z^2 \times p \times q} \qquad (1)$$

where n is the sample size, z is the confidence level (95%), p is the sample proportion, q is given as p - 1, e is the acceptable error (0.02), and N is the population (300).

The study used the 95% confidence level to calculate sample size and to calculate the acceptable. Therefore, with a 95% confidence level, the sample size and acceptable error in the current research are 98 and ± 2.006%, respectively. The research used two types of data sources which were questionnaires and operational data to collect the information required by this study. The questionnaires were drawn up from the literature reviewed and validated using three experts and two statisticians from the Dar es Salaam Institute of Technology. Experts were involved to check the relevance, wording, length of questions, and whether the questions addressed the concept of interest. The questionnaire was sent to 98 technical personnel at TRC headquarters who were involved in maintenance and had access to the Internet. The questionnaires were distributed using Google Forms. Part I of the questionnaire requested the participants to decide whether they agreed to participate in the study using yes and no. Most participants chose yes and were allowed to proceed with the questions, except those who chose no. The data was collected over one month from 12 January 2023 to 13 March 2023. Table 3 provide the characteristic of the sample which was involved in this study. The majority (58.2%) had a college/diploma education followed by members (56.1%) who had working experience ranging from 1 to 4 years. The results revealed that the majority (41.8%) of the participants had the age between 31 to 40 years. Both the level of education and years of experience demonstrated that the participants had sufficient knowledge to participate in this study.

Table 3: Demographic information of TRC's staff members involved in the study.

Item	Response	Frequency	Percentage (%)	Cumulative frequency

Age	Between 20-30	35	35.7	35.7
	Between 31-40	41	41.8	76.9
	Between 41-50	11	11.2	88.1
	Between 51-60	11	11.9	100
	Total	98	100	
Level of education	Secondary school	3	3.1	3.1
	College /Diploma	57	58.2	61.3
	Graduated degree	35	35.7	97
	Postgraduate	3	3.0	100
	Total	98	100	
Year of experience	Between 1- 4 years	55	56.1	56.1
	Between 5 - 10 years	21	21.4	77.5
	Between 11- 20 years	11	11.2	88.7
	Above 21 years	11	11.3	100
	Total	98	100	

Factors Affecting the Reliability of Traction Motors.

In this section, questionnaires were prepared based on the key factors that could have influenced the reliability of traction motors. The explanation of each factor is given below.

- *Spare parts and tools delivery* – the focus is to investigate the impact of time to supply the spare parts on maintenance operations. The intention is to know the effect of delays in acquiring the spare parts and their implication on maintenance activities. The respondents were asked to evaluate the duration it took to receive necessary spare parts.
- *Communication between departments within the organization* – here the effective communication between departments within the organization is assessed. The respondents were asked to indicate if there exists an effective communication between departments.
- *Data recording, storage, and traction motor age* - the respondents were asked to indicate if data recording, storage and traction motor age have an impact on reliability.
- *Planning and scheduling for maintenance* - the respondents were asked to indicate if proper maintenance strategy for traction motors is highly practised in the workshop.
- *Availability of reliable maintenance tools and equipment* - the respondents were asked to indicate if maintenance activities are conducted in a good environment and suitable working tools and equipment are available.
- *Usage of Reliability, Availability, Maintainability and Safety Analysis (RAMS) tool* - the respondents were asked to indicate if the usage of the RAMS tool could have a great contribution to ensuring the reliable performance of the traction motors in the locomotives.
- *Maintenance strategy and policy* - the respondents were asked to indicate if the maintenance of traction motors is implemented as per plan and schedule.
- *Training and capacity building* - the respondents were asked to indicate if they get technical training for their specialization.
- *Maintenance budget* - the respondents were asked to indicate if the budget is satisfactory for executing the maintenance.

The key factors are shown in Table 4. The questionnaires were given to participants and requested them to select their level of agreement on a five-point Likert scale. Then, relative importance index (RII) was computed using Eqn. (2) to determine the relative importance or priority of different factors in the study. According to Soesatijono & Darsin (2021), a degree of significance (DS) of RII of 0.76 and above is regarded as the most significant, between 0.67 and 0.75 as significant, 0.45 to 0.66 as less significant, and below 0.45 as not significant. The results are presented in Table 4.

Factors	SD	D	N	A	SA	ΣW	RII	DS	Ranking
Spare parts and tools delivery	0	4	12	20	4	120	0.76	MS	1
Communication within departments	0	3	15	16	6	120	0.76	MS	2
Data recording, storage, and motor age	0	6	10	15	9	120	0.71	S	3
Planning and scheduling for maintenance	0	7	11	21	1	120	0.61	LS	6
Availability of reliable maintenance tools and equipment	4	8	11	14	3	120	0.49	LS	9
Usage of RAMS tool	1	2	6	14	17	120	0.67	S	4
Maintenance strategy and policy	0	15	7	14	4	120	0.67	S	5
Training and capacity building	2	11	7	18	2	120	0.54	LS	7
Maintenance budget	0	2	5	6	12	120	0.54	LS	8

Table 4 Demographic information of TRC's staff members involved in the study

SD : Strongly disagree
N : Neutral
A : Agree
SA : Strongly agree
DS : Degree of significant, D : Disagree
S : Significant
LS : Less significant
MS : Most significant

$$RII = \frac{\sum W}{A \times N} \tag{2}$$

where *RII* is the relative importance index, *W* is the weighting given to each factor ranging from 1 to 5, *A* is the maximum importance rating, and *N* is the total number of respondents in this study (98). TRC has a relatively promising delivery time of spare parts and tools as well as good communication within the departments. However, the factor of the availability of reliable maintenance tools and equipment seemed to be the critical issue at TRC which could have a strong impact on the reliability. Overall, practicing the scheduled maintenance activities as per plan and usage of RAMS tools to analyze the reliability needs some improvement.

Development of a computerized maintenance management system

This section describes the development of a computerized maintenance management system (CMMS) for assessing the reliability of traction motors

The conceptual framework of the proposed CMMS is shown in Fig. 2 and is developed using a Statistical Package for the Social

Science (SPSS) software. The above-assessed factors are represented as X_1, X_2, … X_n and are used as the input parameters to the developed CMMS. The developed CMMS can calculate the performance metrics such as the mean time before failure (MTBF), mean time to repair (MTTR), and uptime. The proposed system is a web-based application solution that addresses the limitations of the existing system. The CMMS was developed for TRC to enforce all personnel responsible for maintenance while centralizing all maintenance reports.

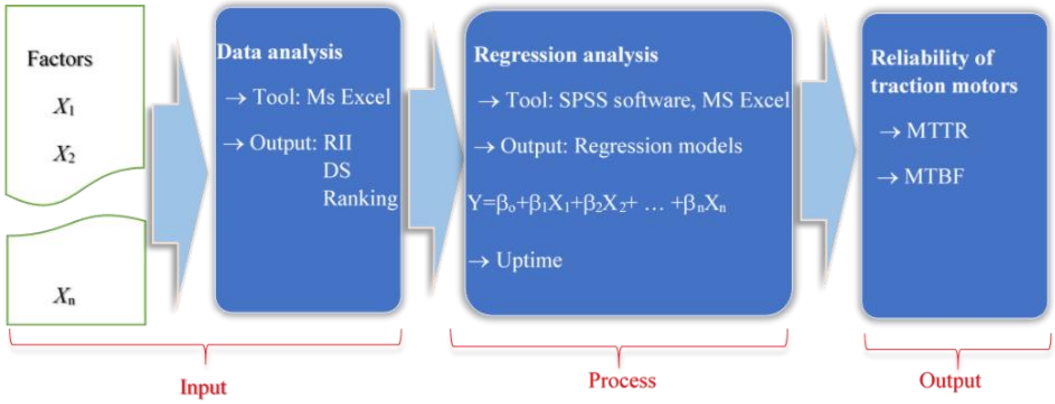

Figure 2: Proposed CMMS model for traction motors.

RESULTS AND DISCUSSION

Table 5 shows the strength of the relationship i.e., the significance of the variable in the model and the magnitude with which it impacts the dependent variable. This analysis helps in performing the hypothesis testing for a study. As seen in the "Sig." column, all independent variable coefficients are statistically different from 0 (zero). Although the intercept, β_o, is tested for statistical significance, this is rarely an important or interesting finding. Therefore, the regression model is given in Eqn. (3) where Y is the uptime (h).

Table 5 Coefficients of the developed regression model

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.770	.894		3.090	.003
	Maintenance budget allocation	.292	.078	.303	3.355	.001
	Availability of spare parts	.611	.072	.074	.756	.000
	Effective Communication	.720	.059	-.257	-2.954	.004
	Technical training	.810	.123	.229	2.441	.017
	Effective Communication	.580	.109	-.003	-.031	.001
	Planned Maintenance	.290	.067	-.292	-3.087	.003

$$Y = 0.77 + 0.29X_1 + 0.26X_2 + 0.61X_3 + 0.58X_4 + 0.81X_5 + 0.29X_6 \quad (3)$$

From Eqn. (3), the operation time of the TRC equipment is between 3 to 4 hours a day, so by considering a maximum of 4 hours for 26 working days in a month for 12 months in a year, it shows that the equipment operates for a total time of 1152 hours, and the MTBF of equipment is 1350.

From Eqn. (4), The reliability of the equipment is found to be 42.6%.

$$R = e^{\left(-\frac{1}{MTBF}\times t\right)} \quad (4)$$

$$R = e^{\left(-\frac{1}{1350}\times 1152\right)} = 42.5\%$$

Currently, at TRC, only 25 out of 57 traction motors, equivalent to 42.8% of the fleet, are consistently accessible for traffic. The availability of these traction motors in locomotives has been discovered to be 42.8%, which is a very low figure. Along with inadequate availability, there is a high rate of in-service mechanical and electrical problems, resulting in trains becoming trapped in the midst of block sections and holding down other traffic. As a result, the ability to move products is severely hampered, lowering the existing timetable speed. The current TRC system schedule speeds for freight and passenger locomotives are only 30 and 40 km/h, respectively, which corresponds to an annual freight hauling volume of little more than 285,000 tons. To improve the availability and performance of traction motors in locomotives used in the railway transportation business, TRC is advised to focus heavily on the two most critical criteria: spare parts and effective communication.

With the current conditions, TRC requires a significant amount of time to obtain replacement parts and complete traction motor repairs. To acquire locomotive spare parts currently takes more than three months, and it takes an engineer two months to repair a locomotive. A railroad driver reports a failed locomotive for hours, causing the workshop to delay assigning emergency technicians. This research highlighted the above seven maintenance parameters as being more relevant and playing a critical role in the availability of the locomotives through SPSS software version 26 and the analysis of model coefficients and the Relative Importance Index (RII). The installation of a computerized maintenance management system (CMMS) improved the evaluation of the locomotives' traction motors' performance and reliability subsequently. The planned CMMS is intended to raise the reliability of traction motors in locomotives at the TRC workshop from 43.8 to 84.7 %.

CONCLUSION

This work aims to improve the reliability of the traction system in Tanzania's Standard Gauge Railway (SGR) by designing a computerized maintenance management system (CMMS) to streamline and automate the maintenance management processes of the traction system of Tanzania's SGR. The reliability of the traction system of Tanzania's SGR is assessed in terms of mean time before failure (MTBF), and mean time to repair (MTTR). Currently, at TRC, only 25 out of 57 traction motors, equivalent to 42.8% of the fleet, are consistently accessible for traffic. The availability of these traction motors in locomotives has been discovered to be 42.8%. This is because TRC requires a large amount of time to get replacement parts and conduct traction motor repairs. Obtaining locomotive spare parts currently takes more than three months, and repairing a locomotive takes two months. A railroad driver reports a failed locomotive for hours, leading the workshop to delay deploying emergency technicians. With the proposed CMMS, the reliability of traction motors in locomotives at the TRC workshop is expected to rise from 43.8 to 76.38 %. The seven maintenance parameters studied in this research were found to be more relevant and played a critical role in the availability of the locomotives. The findings of this work are found to be crucial in understanding the factors affecting reliability as well as strategies as countermeasures to extend the operational life of the traction motors cost-effectively.

DECLARATION OF COMPETING INTEREST

The authors declared that there are no relations that appeared to the inspiration of this work.

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