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Failure Mode and Effects Analysis to Improve Locomotive Subsystem Reliability

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Abstract

The rail operator in South Africa is currently facing a challenge related to motor alternator failures in electric locomotives that operate between Durban and Johannesburg. A study was conducted to identify the causes of motor alternator failures in a locomotive between Johannesburg and Durban using Failure Mode and Effects Analysis (FMEA). A focus group of 13 participants was used to gather the necessary data. The study found 35 root causes, with the top 20% responsible for 80% of failures. The major causes identified included overhead sparks, inconsistency in overhead voltage, insulation failure, slow speed, bearing quality, humidity, defective rivets, and deterioration of windings. Sparks in overhead railway catenaries are mainly caused by impulsive noise, whereas voltage inconsistency can be caused by dynamic stiffness, wind-induced vibrations, high winds, geometric parameters, faults, and environmental influences. Insulation failure in electrical systems can be caused by factors such as space-charge accumulation, partial discharge, thermal loading conditions, high-temperature exposure, moisture, material degradation, and electrical treeing. Based on this study, it is recommended to develop a maintenance strategy to detect challenges in advance and to implement an overhaul program to address system deterioration.

Keywords

Electric locomotives, Failures, FMEA, Motor Alternator, and South Africa

1. Introduction

The South African rail operator faces the challenge of motor alternator failures on electric locomotives that run between Durban and Johannesburg. When failures occur, the locomotive is withdrawn from the service and the train is cancelled, leading to lost opportunities, customer frustration, and revenue loss. While maintenance strategies are in place, such as inspections every 45 days and inspections before train departure, existing strategies do not seem adequate to prevent motor alternator failures. The fleet in question has been in operation since the 1980s and underwent a major upgrade in 2001 to upgrade the control system and reduce maintenance costs by replacing the old components with new parts. However, this initiative did not address motor alternator failures or improve fleet reliability. Motor alternator failures can be caused by various factors such as damage to the bearing, stator, and rotor. According to Lee and Cheng (2020), most motor failures occur because of the damage to these components. Furthermore, Zhang et al. (2009) highlighted that thermal overload can cause the deterioration of key motor components such as stator winding insulation, bearings, motor conductors, and core. Therefore, the causes of motor alternator failures in locomotives can be attributed to various factors, such as damage to the bearing, stator, rotor, and thermal overload. Thus far, extensive research has not been conducted to gain a deeper understanding of the causes of motor alternator failure in locomotives that operate between Durban and Johannesburg. This study aimed to help rail operators enhance the availability and reliability of their fleets. Therefore, the results of this study can aid rail operators in enhancing the reliability of their fleets.

1.1 Objectives

The primary goal of this research was to use FMEA to determine the root cause of motor alternator failure in electric locomotives operating between Durban and Johannesburg. To collect data and meet the study objectives, the study relied on a focus group of a local expert.

2. Literature Review

Failure Mode and Effects Analysis (FMEA) is a crucial technique for ensuring the reliability and safety of electric systems. This involves identifying potential failure modes, their causes, and their effects on system performance and safety(Cickaric et al., Katic and Milic 2018). FMEA has been widely applied in various fields, including renewable energy systems such as photovoltaic (PV) systems (Colli 2015), wind power systems (Negnevitsky, Nguyen, and Piekutowski 2015), and electric-gas integrated energy systems (Liu et al. 2020). This versatile technique is essential for investigating and assessing the effects of possible failure modes, such as electrical failure modes involving shorts and open circuits, on the overall system.

FMEA is used to understand the specific failure modes that can occur in electrical components, such as IGBT modules, and to develop strategies to mitigate these failure modes(Uder, Stone and Tumer 2004; Wu, Yao and Wang 2016). It is instrumental in the reliability analysis of complex electrical systems, such as three-state electrical redundant systems, where it contributes to the optimization of the system design and the establishment of mathematical models for reliable system operation (Wu et al. 2016). Moreover, FMEA can be applied to assess the reliability of an entire system, such as electric power communication networks(Xing, 2014). This broader application allows the development of strategies for managing the reliability of electric power communication networks throughout their life cycle stages. In the field of renewable energy, FMEA has been used to conduct risk assessments for power system operational planning with high wind power penetration, highlighting its role in addressing the unique challenges posed by integrating renewable energy sources into electric systems (Negnevitsky et al. 2015).

Additionally, FMEA has been employed in the reliability analysis of electric power systems for nonconventional nuclear facilities during shutdown modes (Borsoi et al. 2022). These applications demonstrate FMEA's adaptability of FMEA to diverse and critical applications, playing a pivotal role in ensuring the reliability and safety of electric systems, encompassing a wide range of applications from individual electrical components to complex renewable energy systems and nuclear facilities.

2.1 FMEA process

The Failure Mode and Effect Analysis (FMEA) is a proactive method that identifies potential failures in complex processes and provides a basis for continuous improvement(Thornton et al. 2011). It is widely recognized as a valid program for risk management and error prevention in various fields including medicine, computer science, and engineering(Molavi-Taleghani et al., Ebrahimpour and Sheikhbardsiri 2020). FMEA comprises seven steps: team establishment, analysis of the current work process, latent failure and impact analysis, detectability of fault assessment, risk priority number (RPN) calculation and result assessment, corrective action implementation, countermeasure tracking, and outcome measurement (Uder et al. 2004; Colli 2015; Li, He and Wang 2017). Colli (2015) and Carbone and Tippett (2004) defined FMEA as a semiquantitative tool because it involves the collection of both qualitative and quantitative data.

Table 1 displays the standard FMEA template, which involves breaking down a system or process into subsystems, as shown in the first column. In the second column, the team outlines the various ways in which a subsystem fails. In the third column, the team evaluated the impact of failure on the system's operation and safety. Other authors (Carbone and Tippett 2004) assessed the impact in terms of cost, project schedule delays, and project scope on a scale of 1 to 10, with 1 indicating low impact and 10 indicating high impact. The fourth column records the potential cause of system failure, which is typically based on previous experience, simulation, or test results of the system. The probability of occurrence is based on the experience of individuals working with the system, with a scale of 1 indicating a rare occurrence of 1 in 1.5 million trials and 10 indicating an occurrence of 1 in two or three trials. The "detection" column assesses the system's ability to detect failure in advance, with a scale of 1 indicating that design control will detect the potential cause or mechanism and subsequent failure mode, while a scale of 10 indicates that the design control is incapable of detecting the potential cause or mechanism and subsequent failure mode. The risk priority number (RPN) column is a product of the severity score, probability of occurrence, and detection score, which serves as a prioritization matrix to improve the system's performance.

Table 1. Standard FMEA form (Carbone and Tippet 2004)

Subsystem or process	**Potential Failure**	**Severity**	**Potential Cause(s) or Mechanism(s) of Failure**	**Probability of occurrence**	**Detection**	**RPN**	**Recommendation**
System part or process	How the subsystem can experience failure	Scale 1 to 10	The cause of each failure based on their experience	Scale 1 to 10	Scale 1 to 10	RPN= Severity *Occurrence *Detectability	Suggestion to mitigate failure

FMEA is a systematic technique that is often used to prevent failure and for quality and reliability planning, event and failure mode analysis, and prioritizing actions to mitigate the effects of failures in products and processes(Bradley and Guerrero 2011). FMEA is also used in healthcare to assess the safety of patients and has been successfully applied to evaluate the safety of existing procedures, process changes, and the introduction of new processes (Micheletta et al. 2022). Moreover, it is useful for identifying potential faults or errors in systems and preventing them from occurring. The FMEA is a commonly used method for risk assessment in various organizations and industries (Uder et al. 2004; Liu et al. 2020; Rehman et al. 2020).

FMEA is a commonly used proactive engineering management method that aims to prevent a complex process or product from failing. This method can be applied in various fields, such as engineering, healthcare, manufacturing, aviation, and reliability enhancement. The FMEA process involves seven steps: team formation, identification of the product or process, identification of potential failures, impact analysis, detectability, and calculation of the risk priority number. The risk priority number was used to prioritize the impact of each failure. The primary objective of a systematic FMEA process is to reduce the risk of system failure. Therefore, it is considered the best tool for conducting this study.

3. Methods

This is exploratory research that uses a focus group as a data collection method. As a data collection method, focus groups are a qualitative research technique used to gather insights and perceptions from diverse groups of participants on a specific topic (Marques et al. 2021). This method involves a structured, facilitated discussion among a small group of individuals, typically ranging from six to twelve participants, led by a moderator or facilitator (Matthews et al. 2018). The participants were selected based on specific criteria relevant to the research topic, and discussions were guided by a set of predetermined open-ended questions or topics. One of the key advantages of using focus groups as a data-collection method is the opportunity to explore complex topics in depth, allowing for the generation of rich, detailed data. The interactive nature of focus group discussions also enabled participants to build on each other's responses, leading to a more comprehensive understanding of the topic under investigation. Additionally, focus groups can be particularly useful for exploring participants' attitudes, beliefs, and experiences, providing valuable insights that may not be easily captured through quantitative methods alone (Flynn, Albrecht and Scott 2018).

However, it is important to note that the focus groups also have limitations. The dynamics of group interaction can sometimes lead to certain individuals dominating the discussion, potentially silencing others from different perspectives. Additionally, the findings from focus groups may not be generalizable to a larger population, as the sample size is typically small and non-random. Therefore, it is essential to carefully consider the strengths and limitations of focus groups when choosing this method for data collection. This research recognized the disadvantages associated with the focus group and ensured that all members of the group had equal opportunities to contribute to the research.

4. Data Collection

Thirteen people attended the focus group: two engineers, a principal engineer who developed the product, a fleet owner, a quality manager, a senior quality engineer, a coach from the school of engineering, a quality manager, a senior engineer, and a senior fleet manager. The participants were specifically chosen based on their roles and responsibilities and were responsible for improving the rolling stock's reliability and product design. The meetings were conducted face-to-face and by a Microsoft team. The first meeting was a brainstorming session to gain members' agreement to attend, and they were asked to identify other people who could positively contribute to developing a solution to prevent motor alternator failure. The initial session was also used to identify documents and tools that could be used as inputs for the FMEA process. The team was given a month to develop the solution and two meetings, the first and last of which were face-to-face, while the other four were conducted using Microsoft Team.

The breakdown structure of the product was developed using various configuration documents, such as design drawings and maintenance documents. This structure was then implemented to map the motor alternator subsystems using a Failure Mode and Effects Analysis (FMEA) template. During the meetings, the system was divided into six subsystems: armature (high-voltage side), armature (lower voltage side), bearing (ball bearing), brush arm (high voltage side), fan motor end-slip rings (lower voltage coil), and voltage regulator. The members were encouraged to brainstorm the various ways in which a subsystem could fail and to consider the effects of these failures on waste, defects, or negative outcomes for the customer. Participants were also asked to rate the severity of each failure using the ratings in Table 2, with 1 indicating that the failure would have no impact, and 10 indicating that the severity of the failure would have an impact on safety without any warning signs.

Table 2. Severity of Effect

Effect	**Severity of effect**	**Ranking**
Hazardous without warning	Extremely high ranking for severity when a potential failure mode affects the safe operation of the system with no prior warning.	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects the safe operation of the system and there is a warning.	9
Very High	System inoperable due to destructive failure without jeopardizing the safety	8
High	The system is inoperable due to equipment damage.	7
Moderate	The system is inoperable due to minor damage.	6
Low	The system inoperable without damage	5
Very Low	System operable with significant degradation of performance	4
Minor	System operable with some degradation of performance	3
Very Minor	System operable with minimal interference	2
None	No effect	1

After rating each failure mode, the participants were asked to indicate the cause of each failure based on their experience. Inaccurate specifications, improper alignment, operator errors, missing items, fatigue, faulty components, maintenance requirements, and environmental effects are all possible causes. Table 3 shows how participants rated the likelihood of failure based on their prior experiences.

Table 3. Probability of Failure

Probability Of Failure	**Failure Probability**	**Ranking**
Very High: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Repeated failures	1 in 8	8

	1 in 20	7
Moderate: Occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: Relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	<1 in 1,500,000	1

After determining the likelihood of failure, participants were asked to evaluate the processes and design elements set up to detect failures and rate how likely those elements were to detect the failure before it occurred. Participants were asked to rate the effectiveness of the design control in identifying failures using the ratings in Table 4. A rating of 1 indicates that the process and design control would be able to detect the failure mode, whereas a rating of 10 indicates that the design control would not be able to detect failures before they occur.

Table 4. Likelihood of detection by design control

Detection	**Likelihood of detection by design control**	**Ranking**
Absolute Uncertainty	Design control is incapable of detecting the potential cause/mechanism and subsequent failure mode.	10
Very Remote	Very remote chance the design control will detect potential causes/mechanisms and subsequent failure mode	9
Remote	Remote chance the design control will detect potential cause/mechanism and subsequent failure mode	8
Very Low	Very low chance the design control will detect potential causes/mechanisms and subsequent failure mode	7
Low	Low chance the design control will detect potential causes/mechanisms and subsequent failure mode	6
Moderate	Moderate chance the design control will detect potential causes/mechanisms and subsequent failure mode	5
Moderately High	Moderately High chance the design control will detect potential cause/mechanism and subsequent failure mode	4
High	High chance the design control will detect potential causes/mechanisms and subsequent failure mode	3
Very High	Very high chance the design control will detect potential causes/mechanisms and subsequent failure mode	2
Almost Certain	Design control will detect potential cause/mechanism and subsequent failure mode	1

The calculation of the risk priority number (RPN) involved the multiplication of the severity rating, probability of occurrence, and detectability rating. In the last stage of the process, participants were asked to suggest potential strategies for organizing each cause of failure or to indicate actions that could be taken to reduce the associated risk. In conclusion, focus groups are a valuable data collection method for qualitative research, providing a platform for the in-depth exploration of participants' perspectives and experiences. When conducted rigorously and systematically, focus group discussions can provide rich and nuanced data that contribute to a comprehensive understanding of the research topic. However, researchers must be aware of the limitations of the method and consider them when interpreting the results.

5. Results and Discussion

5.1 Numerical Results

The FMEA template consisted of 8 columns (Table 5). The first column provided a breakdown of the system components, which were, in this case, the armature (high-voltage side), armature (lower-voltage side), bearing (ball bearing), brush arm (high-voltage side), fan motor end-slip rings (lower-voltage coil), and voltage regulator. This is followed by an analysis of the potential failure modes of the system. The severity of each failure mode was assessed using a scale ranging from 1 to 10 (Table 5). The fourth column evaluates the underlying reasons for each failure, whereas the fifth column records the probability of occurrence. This probability was rated on a scale of 1–10. The sixth column represents the detectability of each root cause, followed by the risk priority number and the recommended approach to address the root cause. It is important to note that only RPNs greater than 100 are included in Table 5 owing to the table length.

Table 5. Failure Mode and Effects Analysis

Item or Function	**Potential Effect(s) of Failure**	**Sev**	**Potential Cause(s)**	**Prob**	**Det**	**RPN**	**Recommended Action(s)**
Armature (LT)	No output	5	Deterioration of windings	7	10	350	• Motor Alternator (MA) sets that are three years or older should be sent in for heavy repairs (including rewinding)
		5	Burnt winding	6	10	300	• The depot will perform Meggaring on all C sheds (once a year)
		5	Lose connection	6	10	300	• Brushes must be bedded to prevent overcurrent in the Rotating Machine department and the Depots.
	Low to no output	5	Insulation failure	6	10	300	• Motor Alternator sets that are three years or older should be sent in for heavy repairs (including rewinding)
	Damaged voltage regulator	7	Insulation failure	8	10	560	• Depots must conduct megger (insulation tester) tests during the yearly maintenance cycle (C-shed) • Quality control to ensure that maintenance instructions are followed • MA sets three years old and older will be sent for heavy repairs (including rewinding)
		7	Inconsistency overhead voltage	9	9	567	• Technology management to ensure that old locomotives are compatible with the energy regenerated by new locomotives. • Management of technology to confirm the effects of regenerated energy on old locomotives
		7	Down to earth	8	10	560	• Depots must perform megger (insulation tester) tests during the yearly maintenance cycle (C-shed). • Quality to ensure adherence to maintenance instructions.
		7	Overhead spark	9	10	630	• The fleet management and quality management teams must confirm that the KM11 is done during the shedding process. • Infrastructure to confirm voltage consistency and provide recommendations for dealing with voltage fluctuations.
	High current	7	Slow speed	9	8	504	• Infrastructure to confirm voltage consistency and provide recommendations for dealing with voltage fluctuations. • Infrastructure to eliminate speed limits
	Rheostatic trip	4	The set's output does not fall within the range that the invert accepts.	6	6	144	• Perform an annual resistance test on the armature coil (immediate action). • Install the alarm/sensor to direct us to the location of the fault.

Item or Function	**Potential Effect(s) of Failure**	**Sev**	**Potential Cause(s)**	**Prob**	**Det**	**RPN**	**Recommended Action(s)**
							• Product Development will investigate the possibility of installing the sensor to aid in fault detection (Long-term)
	inverter trips	6	Secondary insulation failure	6	6	216	• MA sets that are three years or older should be sent in for heavy repairs (including rewinding)
	CBR strip	6	Contamination	5	6	180	• The quality management team will confirm that the depots are performing the necessary inspections.
		6	Insulation failure	6	10	360	• The depots to perform megger (insulation tester) during the yearly maintenance cycle (C-shed) • Quality to confirm compliance with maintenance instructions. • The MA sets which are three years and older are to be sent for heavy repairs (including rewinding)
Brush arm (HT)	comm damage (burn marks), T4 and T5 will not read the current and the MPU will shat the loco down	10	Low segments and high segments	7	7	490	• Quality management team to audit the supplier torquing processes or comm repair process
		10	Comm out of round	7	7	490	• Quality management team to audit the supplier torquing processes or comm repair process
	Burn the comm and start flashing over	7	The brush piece is too small, or the brush itself is defective.	5	4	140	• Verify if the Rotating Machine (RM) department has a go/no-go gauge to check brush box compliance. • Depot to look at brush dimensions and brush box dimensions/eliminate incorrect ones. • Depot to get go/no-go gauges to verify incoming material
Armature (HT)	Loss of cooling of the T/M	7	Age	3	8	168	• Monitor the age at which the bearing change should be done.
		7	Quality of the bearing	6	10	420	• RM to only use approved suppliers. • Quality team to audit RM process from time to time. • The fleet to analyse the data related to bearing failures
		7	Contamination	2	10	140	• Visual inspection every 45 days. • Quality team to audit the process.
		7	Humidity	6	10	420	• The depot to perform megger. • Technology management to advise on the technology which can be used to control humidity. • Technology management to develop the solution to deal with the water coming inside the loco.
Fan-motor end	Once the fan becomes lost, it will damage the impellers	8	defective rivet	5	9	360	• Visual inspection and compliance with the specification. • Check the ages of the fan
Bearing (ball bearing)	The locomotive will shut	7	Damaged shaft and cage	4	10	280	• Product development to advise on the solution.
		4	Low voltage	4	7	112	• Quality management team to audit the supplier torquing processes or comm repair process
Slip rings (LT COIL)	No excitation and damage Voltage Regulator	7	Insulation failure	3	10	210	• We will have to deal with the main cause of insulation failure to put this issue to rest now we use the same recommendation for the insulation failure

Item or Function	**Potential Effect(s) of Failure**	**Sev**	**Potential Cause(s)**	**Prob**	**Det**	**RPN**	**Recommended Action(s)**
	No output from the MA set	7	Conductor failure (the wire connecting the LT ring to the coil o/c)	2	9	126	• RM to ensure that connections are tightened correctly, and test values will be the verification method
	No output from the MA set	7	Conductor failure (the wire connecting the rings)	5	9	315	• The MA has more than three years to be reminded. • RM to confirm the correct intervals for heavy repairs
	insulation failure or o/c on the slip ring	7	LT bolts loose	2	10	140	• The deport to perform inspections to see if the coil has moved. • The deport to send the component to RM for further diagnosis
		7	LT spring plates defective	2	10	140	• The depot to perform inspections to see if the coil has moved. • The deport to send the component to RM for further diagnosis
Voltage regulator	The MA set output will be too low or too high	7	Quality of the VR from power electronic	8	10	560	• The MA has more than three years to be reminded. • RM to confirm the correct intervals for heavy repairs

5.2 Graphical Results

A total of 35 root causes were identified as having an impact on the performance of motor alternators. These causes are ranked based on their Risk Priority Number (RPN), which ranges from 630 to eight, as shown in Figure 1. The leading cause of failure is overhead sparking with an RPN of 630, followed by inconsistency in overhead voltage with an RPN of 567, insulation failures with an RPN of 560, down-to-earth issues with an RPN of 560, and slow speed with an RPN of 504. Additionally, Low and high segments with RPN 490, humidity, and bearing quality are among the top 80% of root causes of motor alternator failures, with RPNs of 420. Defective revit (RPN=360), deterioration of windings (RPN=350), burnt windings (RPN=300), loose connections (RPN=300), and damaged shafts (RPN=280) are among the remaining 20% of the causes that contribute to 80% of motor alternator failures.

5.3 Proposed Improvements

The sparks in overhead railway catenaries are mainly caused by the impulsive noise generated from the gap between the catenary and pantograph (Zhou et al. 2022). This gap can create electric sparks that can severely affect the current collection of the pantograph-catenary contact and cause arcing phenomena. Excessive contact force between the pantograph and the catenary can worsen the wear and fatigue of the contact wire and strip, whereas inadequate contact force can increase the possibility of contact loss between the pantograph and catenary (Song et al. 2021). It is crucial to maintain the railway catenaries in good condition to ensure the continuous availability of the train power supply and the safety of the traction power system. Therefore, the company should implement condition-based maintenance and regularly monitor the condition of catenaries and locomotive pantographs.

Voltage inconsistencies in overhead railway catenaries can be caused by several factors including dynamic stiffness, wind-induced vibrations, high winds, geometric parameters, faults, and environmental influences (Song et al. 2018). Understanding and addressing these issues is critical to maintaining a stable and consistent voltage in railway catenary systems

Insulation failure in electrical systems can be caused by a combination of factors including space charge accumulation, partial discharge, thermal loading conditions, high-temperature exposure, space charges under high-voltage direct current fields, moisture, material degradation, and electrical treeing (Zhou et al. 2016). Understanding these factors is crucial for developing effective strategies for mitigating insulation failure and enhancing the reliability of electrical systems.

The slow speed of a train can significantly impacts the performance of DC motors (Zhai et al. 2015). To ensure efficient and precise operation, it is essential to control and regulate the speed of DC motors, and various techniques and control methods have been employed to address the challenges associated with low-speed operation (Mehrzad and Ataei 2021). It is highly recommended that the company avoid operating motor alternators at slow speeds.

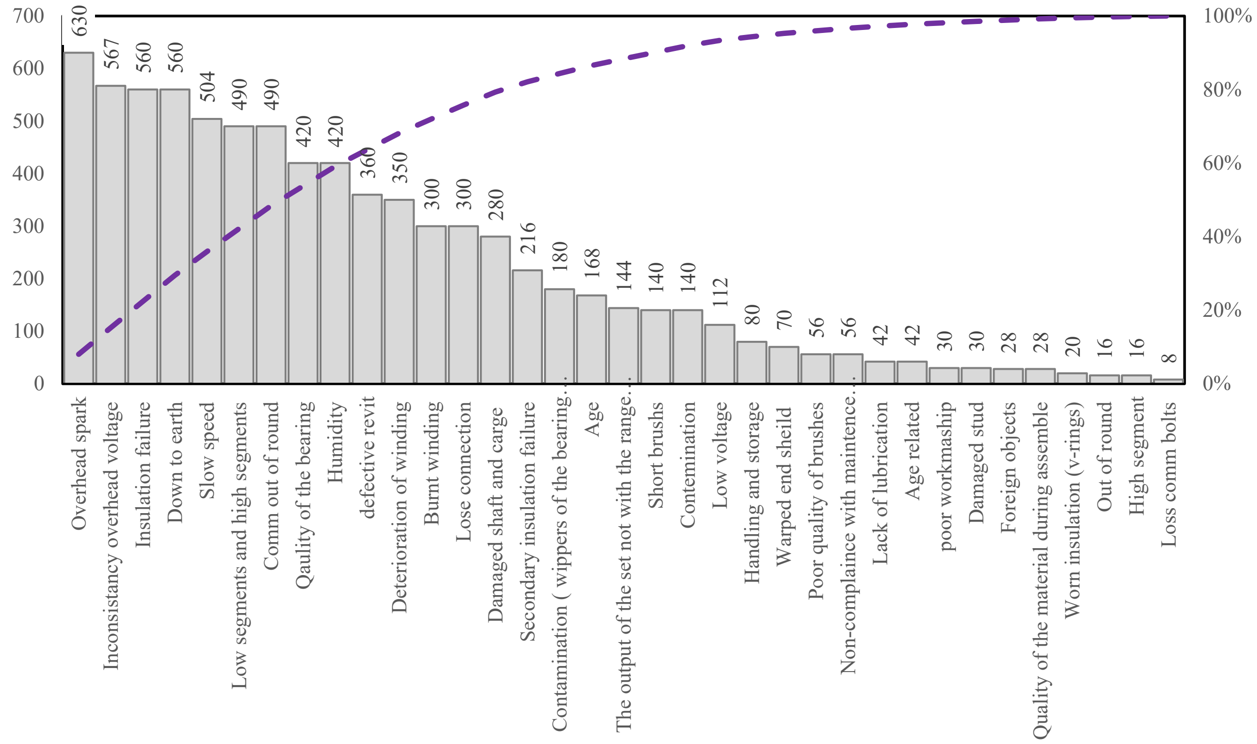

Figure 1. Risk Priority Numbers

Out-of-round commutators in DC motors can be caused by a variety of factors, including the commutation torque ripple, arc discharge erosion, and commutation arc (Türker and Khudhair 2017). Commutation torque ripple, which causes abrupt changes in the torque output, is a common problem in brushless DC motor drives. This phenomenon can result in mechanical wear of the commutator and brush, resulting in an out-of-round commutator. Furthermore, arc discharge erosion at the carbon contacts during the commutation process can contribute to commutator and brush wear. Furthermore, the current ripple generated during the commutation process in brushless DC motor drives can affect the mechanical integrity of the commutator. As a result, it is recommended that the company regularly checks the commutator and brush conditions to reduce the commutator's failure.

5.4 Validation

Creswell and Miller (2000) define research validity as the extent to which a study accurately measures or predicts what it is supposed to. Validity is established in qualitative research through various procedures, such as triangulation, which involves the use of multiple data sources, methods, or theories to ensure the credibility and authenticity of the findings (Whittemore et al., 2001). Furthermore, the distinction between "validity of measurement" and "validity of research" has been emphasized, emphasizing the importance of both aspects in ensuring the overall validity of a study (Truijens et al., 2010). Research validity refers to the extent to which a study accurately measures or predicts what is supposed to ensure that the results are credible and trustworthy. It involves establishing the plausibility and defensibility of the data as well as ensuring that the research methods and measures are sound and reliable. This is crucial for ensuring that the findings of a study can be applied to real-world situations, and that the conclusions drawn are meaningful and relevant. This study used an audit trail to ensure the trustworthiness and rigor of the research process. This process was implemented by recording in detail all step-by-step processes followed in the decision-making process of this study.

6. Conclusion

This study aimed to identify the causes of motor alternator failures in locomotive operations between Johannesburg and Durban. To achieve this, the study used Failure Mode and Effects Analysis (FMEA). The study relied on a focus group of 13 participants who were purposively selected because of their roles in improving the fleet's reliability and their knowledge of the challenges and products being investigated. The research team conducted several meetings to collect data, both face-to-face and online, using Microsoft Teams. The study identified 35 root causes of motor alternator failures, with the top 20% being responsible for 80% of failures. The major causes identified were overhead sparks, inconsistency in overhead voltage, insulation failure, slow speed, low and high segments, common out-of-round, bearing quality, humidity, defective rivets, and deterioration of windings. The sparks in the overhead railway catenaries are mainly caused by the impulsive noise generated from the gap between the catenary and the pantograph. Voltage inconsistencies in overhead railway catenaries can be caused by dynamic stiffness, wind-induced vibrations, high winds, geometric parameters, faults, or environmental influences. Insulation failure in electrical systems can be caused by a combination of factors including space charge accumulation, partial discharge, thermal loading conditions, high-temperature exposure, space charges under high-voltage direct current fields, moisture, material degradation, and electrical treeing. The study recommends that the company develop a maintenance strategy to detect any of the challenges in advance and implement an overhaul program to deal with system deterioration.

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Biography

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