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Evaluation of Operational Readiness and Functional Effectiveness of Aircraft Rescue and Firefighting (ARFF) Apparatus at Murtala Muhammed International Airport, Lagos, Nigeria

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ABSTRACT

This study evaluated the operational readiness and functional effectiveness of Aircraft Rescue and Firefighting (ARFF) apparatus at Murtala Muhammed International Airport (MMIA), Lagos. Guided by the Resource-Based View, Systems Theory and Reliability-Centred Maintenance principles, the study assessed readiness levels, functional effectiveness, the effect of maintenance practices, and major operational challenges. A descriptive survey design with correlational elements was adopted. From a target population of approximately 150 ARFF-related personnel, a stratified random sample of 130 respondents yielded 120 usable questionnaires (response rate 92.3%). Data were analysed using descriptive statistics, Pearson Correlation and simple linear regression in SPSS Version 26 at the 0.05 significance level. Results indicated high operational readiness (composite mean = 4.13, SD = 0.52) and high functional effectiveness (composite mean = 4.17, SD = 0.49). Maintenance practices significantly predicted operational readiness ($\beta = 0.731$, $R^2 = 0.534$, $p < 0.001$). The most salient challenges were inadequate spare-parts availability (M = 4.25), insufficient funding (M = 4.18), maintenance delays (M = 4.12) and procurement bottlenecks (M = 4.08). All four null hypotheses were rejected. The study concludes that while ARFF apparatus at MMIA currently exhibit high readiness and effectiveness attributable largely to the 2023 fleet modernisation, sustained performance depends on robust recurrent investment in maintenance systems, spare-parts buffer stocks, technical capacity and continuous performance monitoring.

Keywords: Aircraft Rescue and Firefighting; Operational Readiness; Functional Effectiveness; Maintenance Practices; ARFF Apparatus; Airport Safety.

1. INTRODUCTION

Aircraft Rescue and Firefighting (ARFF) services constitute a critical component of airport safety management systems worldwide. The primary objective of ARFF is to save lives in the event of an

aircraft accident or incident by extinguishing fires, creating survivable conditions, and facilitating the safe evacuation of passengers and crew (International Civil Aviation Organization [ICAO], 2015).
The effectiveness of these services depends substantially on the operational readiness and functional capability of specialised ARFF apparatus, including major firefighting vehicles, rapid intervention vehicles, water tankers, and associated rescue equipment. International standards for ARFF are primarily established by ICAO Annex 14 – Aerodromes, Volume I, Chapter 9, which prescribes the level of protection required based on the aerodrome category. Complementary guidance is provided in the ICAO Airport Services Manual, Part 1 – Rescue and Fire Fighting (Doc 9137). Nigeria, as a Contracting State of ICAO, implements these standards through the Nigeria Civil Aviation Authority (NCAA) regulations and the operational oversight of the Federal Airports Authority of Nigeria (FAAN).

Murtala Muhammed International Airport (MMIA) in Lagos is Nigeria's busiest international gateway, handling a significant proportion of the country's air traffic and serving as a major hub for West and Central Africa. In 2023, FAAN invested substantially in modernising ARFF fleets by deploying ten high-capacity Lion Volkan 6×6 Major Aerodrome Rescue and Fire Fighting Vehicles, each carrying 14,000 litres of water, 1,700 litres of foam concentrate, and 250 kg of dry chemical powder (Federal Airports Authority of Nigeria [FAAN], 2023). These vehicles feature advanced capabilities such as pump-and-roll operations and under-chassis nozzles for tackling running fuel fires. Despite these investments, questions persist regarding the sustained operational readiness and functional effectiveness of ARFF apparatus.

The mere presence of sophisticated firefighting vehicles does not automatically translate into effective emergency response capability. Critical factors such as the frequency and quality of preventive and corrective maintenance, the availability of trained technical personnel, the adequacy of extinguishing agent stocks, and the consistency of readiness drills determine whether apparatus can meet ICAO-mandated performance standards when required. Empirical evidence from related contexts suggests that airports in emerging economies often struggle with equipment downtime, delayed spare parts procurement, and suboptimal maintenance cultures (Ojo & Akinola, 2020; Munyendo & Kibutu, 2024).

Furthermore, there is a paucity of focused empirical studies that specifically examine the relationship between maintenance practices and the operational readiness of ARFF apparatus, as well as the extent to which readiness translates into functional effectiveness during simulated or actual aircraft emergency scenarios at MMIA. Without systematic evaluation, airport management and regulatory authorities lack robust evidence upon which to base targeted interventions, resource allocation decisions, and continuous improvement programmes. The aim of this study is therefore to evaluate the operational readiness and functional effectiveness of ARFF apparatus at MMIA, Lagos. Specifically, the study seeks to: (a) assess the operational readiness of ARFF apparatus; (b) evaluate their functional effectiveness in supporting aircraft emergency rescue and firefighting operations; (c) examine the effect of maintenance practices on operational readiness; and (d) identify the major challenges affecting readiness and effectiveness.

2. LITERATURE REVIEW

2.1 Conceptual Foundations

Aircraft Rescue and Firefighting (ARFF), also referred to as Rescue and Fire Fighting Services (RFFS) in ICAO terminology, is a specialised emergency response capability provided at aerodromes to protect aircraft, passengers, crew, and airport infrastructure in the event of an aircraft accident or incident involving fire or the risk of fire (ICAO, 2015). Unlike structural firefighting, ARFF operations are characterised by the need for extremely rapid response, high agent application rates, the ability to operate in a dynamic and hazardous aircraft environment, and a primary focus on creating a survivable path for occupant evacuation. Operational readiness is a multidimensional construct that encompasses availability, serviceability, agent capacity, and response capability. According to FAA regulations (14 CFR §139.319), each required ARFF vehicle must be maintained so as to be operationally capable of performing the functions required during all air carrier operations. Key indicators include vehicle availability rates, compliance with inspection schedules, maintenance of extinguishing agent quantities at or above Index requirements, demonstrated ability to meet response time standards (typically three minutes to the midpoint of the farthest runway), and functional integrity of critical systems (NFPA, 2024; ICAO, 2015).

Functional effectiveness refers to the extent to which ARFF apparatus achieves its intended operational outcomes when deployed. Effectiveness is evaluated not merely by the physical presence of equipment but by performance against mission-critical criteria: rapid agent application, sustained discharge rates, ability to create and maintain a foam blanket, support for forcible entry and rescue, and interoperability with other emergency response elements (IFSTA, 2024).

2.2 Theoretical Framework

This study is anchored primarily on the Resource-Based View (RBV) of the firm (Barney, 1991; Wernerfelt, 1984) and the Systems Theory of organisational performance (von Bertalanffy, 1968), supplemented by principles drawn from Reliability-Centred Maintenance (RCM) (Nowlan & Heap, 1978). The RBV posits that sustained operational performance derives from the possession and effective deployment of valuable, rare, inimitable, and non-substitutable resources. In the ARFF context, specialised apparatus, trained personnel, and institutional knowledge constitute strategic resources. Systems Theory views ARFF operations as a complex socio-technical system in which apparatus, personnel, procedures, maintenance regimes, and external regulatory environments interact; a deficiency in one subsystem can cascade to impair overall system performance. RCM provides a structured framework for determining optimal maintenance strategies based on the consequences of functional failure, encouraging a shift from purely calendar-based or reactive maintenance toward condition-based and risk-informed approaches.

2.3 Empirical Review and Research Gap

Empirical studies specifically focused on ARFF apparatus readiness in African airports remain limited. Faiyegbajeje et al. (2025) conducted an assessment of fire and rescue emergency preparedness at MMIA and reported generally high mean scores for equipment adequacy, personnel training, and regulatory compliance, while identifying challenges related to fire alarm maintenance and training frequency consistency. In the Kenyan context, Munyendo and Kibutu (2024) found that inadequate maintenance schedules significantly reduced equipment reliability at Jomo Kenyatta International Airport.

Similar patterns have been documented in broader Nigerian fire service research, where resource scarcity, outdated equipment, and training gaps were identified as major operational constraints (Adeyemi & Okeke, 2025). Collectively, the empirical literature indicates that equipment acquisition alone is insufficient; sustained readiness depends on robust maintenance systems, competent personnel, and continuous performance monitoring. Gaps remain in quantitative examinations of the statistical relationships among maintenance practices, readiness metrics, and functional effectiveness outcomes at major Nigerian airports following the significant 2023 fleet upgrade—precisely the gap this study seeks to address.

3. METHODOLOGY

3.1 Research Design and Population

The study adopted a descriptive survey research design with correlational elements. The descriptive component enabled systematic assessment of current levels of operational readiness and functional effectiveness, while the correlational component facilitated testing of hypothesised relationships among availability, readiness, maintenance practices, operational challenges, and functional effectiveness (Creswell & Creswell, 2018). The target population comprised approximately 150 personnel involved in the operation, maintenance, and supervisory oversight of ARFF apparatus at MMIA, including operational firefighters and drivers, technical maintenance staff, and supervisory/managerial officers.

3.2 Sample and Sampling Technique

A sample size of 130 respondents was targeted, guided by the Yamane (1967) formula for finite populations. A stratified random sampling technique was employed. The population was stratified into three primary cadres: (1) operational ARFF personnel (firefighters/drivers), (2) technical/maintenance personnel, and (3) supervisory/managerial staff. Proportional allocation was applied to ensure representation across strata. Of the 130 questionnaires distributed, 124 were returned and 120 were found usable, yielding an effective response rate of 92.3%.

3.3 Research Instrument and Psychometric Properties

Primary data were collected using a structured questionnaire organised into sections corresponding to the study variables: demographic characteristics, operational readiness (12 items), functional effectiveness (12 items), maintenance practices (12 items), and challenges (12 items). Most items utilised a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Content validity was established through expert review by specialists in aviation/safety management, ARFFS practice, and measurement/evaluation. A pilot study with 18 ARFF-related personnel yielded Cronbach's alpha coefficients ranging from 0.84 to 0.91 for individual scales and an overall reliability coefficient of 0.92, indicating excellent internal consistency (Nunnally & Bernstein, 1994).

3.4 Data Analysis

Data were coded and analysed using SPSS Version 26. Descriptive statistics (means, standard deviations) were used to summarise demographic characteristics and to answer the research questions. Pearson Product-Moment Correlation assessed relationships among variables, while simple linear regression examined the effect of maintenance practices on operational readiness. The level of significance was set at $\alpha = 0.05$. Qualitative responses from open-ended items were subjected to thematic content analysis to enrich interpretation of quantitative findings. Ethical clearance and formal permission from FAAN/ARFFS management were obtained prior to data collection; informed consent, anonymity, and confidentiality were assured.

4. RESULTS

4.1 Demographic Profile of Respondents

The sample comprised 81.7% male and 18.3% female respondents. The largest age cohort was 35–44 years (35.0%), followed by 25–34 years (28.3%). Forty percent held HND or Bachelor's degrees, while 31.7% possessed OND/NCE qualifications. ARFF Firefighters constituted 43.3% of respondents, Maintenance/Engineering personnel 23.3%, and ARFF/Fire Officers 16.7%. Cumulatively, 60.0% possessed at least 10 years of airport or ARFF-related experience, and 85.0% had participated in aircraft emergency drills at MMIA. These characteristics confirm that respondents possessed relevant experiential knowledge, enhancing the credibility of the self-reported assessments.

4.2 Operational Readiness of ARFF Apparatus

The composite mean for operational readiness was 4.13 (SD = 0.52), falling within the "High" category on the five-point Likert scale (decision rule: 3.41–4.20 = High). The highest-rated items were vehicle positioning for prompt response (M = 4.42) and availability of required ARFF vehicles and major apparatus (M = 4.38), reflecting the positive impact of the 2023 deployment of Lion Volkan 6×6 vehicles. Access to appropriate personal protective equipment (M = 4.25) and adequacy of firefighting agents (M = 4.21) were also rated very high. The lowest-rated item within the high band concerned the prompt reporting and addressing of defects (M = 3.85), suggesting residual challenges in the maintenance feedback loop. Overall, ARFF apparatus at MMIA are generally available, serviceable and positioned for rapid deployment in accordance with ICAO and NCAA expectations.

4.3 Functional Effectiveness of ARFF Apparatus

Functional effectiveness recorded a composite mean of 4.17 (SD = 0.49), indicating a High level of perceived performance. The strongest ratings were obtained for the ability of apparatus to be used effectively during drills and simulated exercises (M = 4.35), adequate firefighting capability for aircraft-related emergencies (M = 4.32), and the capacity of vehicles to reach emergency locations quickly (M = 4.28). Support for rapid suppression and prevention of fire escalation (M = 4.22) further reinforced the positive assessment. These findings suggest that the modern ARFF fleet, characterised by pump-and-roll capability, high agent capacity and under-chassis nozzles, is regarded as capable of performing its core mission functions when activated.

4.4 Maintenance Practices

Maintenance practices yielded a composite mean of 3.89 (SD = 0.58), placing overall maintenance quality in the High category. The strongest agreement was recorded for the statement that effective maintenance reduces downtime and improves readiness (M = 4.28) and for the inspection and maintenance of firefighting agents and tanks (M = 4.11). Relatively lower means were observed for spare-parts availability (M = 3.48) and timely repair of defective apparatus (M = 3.65), highlighting areas requiring managerial attention even though they remain within the High band.

4.5 Major Challenges

The most strongly endorsed challenges were inadequate availability of spare parts (M = 4.25), insufficient funding for procurement, maintenance and readiness (M = 4.18), delays in maintenance and repair (M = 4.12), and procurement/administrative bottlenecks (M = 4.08). Ageing or obsolete equipment (M = 3.42) and limited modern ARFF technology (M = 3.38) ranked lowest, consistent with the relatively recent modernisation of the MMIA ARFF fleet. The composite challenges mean was 3.84 (SD = 0.61).

4.6 Hypothesis Testing

All four null hypotheses were rejected at the 0.05 significance level. Availability showed a strong positive relationship with operational readiness ($r = 0.784$, $p < 0.001$). Operational readiness was strongly associated with functional effectiveness ($r = 0.812$, $p < 0.001$).

Maintenance practices significantly and positively predicted operational readiness ($\beta = 0.731$, $R^2 = 0.534$, $F(1,118) = 135.28$, $p < 0.001$), explaining 53.4% of the variance. Operational challenges were significantly and negatively related to functional effectiveness ($r = -0.612$, $p < 0.001$). These results provide empirical support for the centrality of robust maintenance regimes and the adverse impact of logistical and administrative constraints on ARFF performance.

4.7 Qualitative Findings

Thematic analysis of open-ended responses triangulated the quantitative results. Respondents consistently identified genuine spare-parts availability (cited by approximately 68%), consistency of funding (61%), and competence of technical personnel (54%) as the most important factors affecting operational readiness. Priority maintenance measures recommended included establishing a dedicated ARFF spare-parts buffer stock, institutionalising condition-based and predictive maintenance, strengthening digital maintenance management systems, and expanding local technical capacity through manufacturer-supported training. Suggestions for enhancing functional effectiveness centred on increasing the frequency and realism of full-scale drills (including night and low-visibility scenarios) and improving inter-agency coordination protocols.

5. CONCLUSION AND RECOMMENDATIONS

This study concludes that the operational readiness of ARFF apparatus at Murtala Muhammed International Airport is currently high (composite mean = 4.13), largely attributable to the 2023 investment in modern Lion Volkan major firefighting vehicles. Vehicles are generally maintained in a serviceable condition and are capable of meeting prescribed response-time standards under normal circumstances. ARFF apparatus are also functionally effective (composite mean = 4.17) in supporting aircraft emergency rescue and firefighting operations, demonstrating strong capability in rapid agent application, fire suppression, and support for rescue activities. Maintenance practices exert a strong, statistically significant positive effect on operational readiness, explaining 53.4% of the variance. This finding provides robust empirical support for Reliability-Centred Maintenance principles and underscores that capital acquisition without commensurate investment in preventive, predictive and corrective maintenance systems will not deliver sustained readiness. The principal challenges constraining ARFF performance are logistical and administrative rather than technological: inadequate spare-parts availability, insufficient and inconsistent funding, maintenance delays, and procurement bottlenecks. These challenges are significantly and negatively associated with functional effectiveness.

In theoretical terms, the findings affirm the Resource-Based View: specialised ARFF apparatus constitute strategic resources whose value is realised only when they are maintained in a deployable state. Systems Theory is equally validated; deficiencies in one subsystem cascade to impair overall system performance. Reliability-Centred Maintenance emerges as a practical framework particularly relevant in resource-constrained environments.

Based on the findings, the following recommendations are offered:

1. Establish a dedicated ARFF spare-parts buffer stock for critical high-failure-rate components specific to the Lion Volkan platform to reduce prolonged downtime arising from import delays.
2. Institutionalise Reliability-Centred and condition-based maintenance using vibration analysis, oil analysis and onboard diagnostic data, supported by digital maintenance management systems.
3. Ensure consistent and adequate recurrent funding for maintenance, agent stocks, consumables and technical training, with budget release processes aligned to scheduled maintenance cycles.
4. Expand local technical capacity through structured manufacturer training programmes and the development of in-house specialists for the current generation of apparatus.
5. Increase the frequency and realism of full-scale aircraft emergency drills, including night and low-visibility scenarios, to maintain crew proficiency and test inter-agency coordination.
6. Streamline procurement and administrative procedures for critical ARFF components through pre-approved vendor lists, framework contracts or emergency procurement windows.
7. Strengthen regulatory oversight by incorporating specific readiness and maintenance indicators into NCAA aerodrome certification and surveillance programmes.

While this study provides a focused empirical evaluation of ARFF apparatus at MMIA, further research is recommended through comparative multi-airport studies, longitudinal designs tracking readiness metrics over time, incorporation of objective performance data alongside perceptual measures, cost-benefit analyses of alternative maintenance strategies and human-factors investigations of organisational safety culture.

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