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Assessment of Bird and Wildlife Control Measures for Enhancing Aviation Safety at Murtala Muhammed Airport Terminal 2 (MM2), Lagos, Nigeria.

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ABSTRACT

This project assessed the effectiveness of bird and wildlife control measures in enhancing aviation safety at Murtala Muhammed Airport Terminal 2 (MM2), Lagos, Nigeria. Despite the existence of a dedicated Wildlife Control Department under the Federal Airports Authority of Nigeria (FAAN) and a formal regulatory framework administered by the Nigerian Civil Aviation Authority (NCAA), bird and wildlife strike incidents at Nigerian airports have continued to rise. A descriptive survey research design with a quantitative orientation, supplemented by qualitative insights, was adopted. The target population comprised approximately 185 relevant FAAN and aviation personnel at MM2. Using the Taro Yamane formula, a sample size of 126 was determined and adjusted upward to 145. Data from 132 usable questionnaires (91.0% effective response rate) were analysed using descriptive statistics, Pearson's correlation, and multiple regression analysis in SPSS Version 26. Key findings revealed that the effectiveness of bird and wildlife control measures was perceived as high (composite mean = 3.41), with active deterrence methods rated most favourably. Staff training and awareness recorded a moderate composite mean of 3.28, with the frequency of refresher training emerging as the weakest element (mean = 2.78). Regulatory compliance also registered a moderate composite mean of 3.15. All three null hypotheses were rejected. An integrated multiple regression model showed that the three constructs jointly explained 37.5% of the variance in aviation safety outcomes, with staff training and awareness emerging as the strongest unique predictor. The study concludes that aviation safety with respect to wildlife hazards at MM2 is jointly produced by interacting layers of defence—control measures, human competence, and regulatory oversight—consistent with Reason's Organisational Accident (Swiss Cheese) Model and Regulatory Compliance Theory. Recommendations are directed at FAAN, the NCAA, airline operators and future researchers.

Keywords: Bird strike; Wildlife hazard management; Aviation safety; Murtala Muhammed Airport; Staff training; Regulatory compliance; Swiss Cheese Model

Keywords: Network Intrusion Detection, Lightweight Deep Learning, Edge Computing, Traffic, Data Ensemble Knowledge Distillation, , *Knowledge Distillation, Adversarial Robustness.*

1. INTRODUCTION

Aviation safety continues to be threatened globally by the presence of birds and other wildlife within and around airport environments, a hazard that has persisted despite decades of technological and procedural advancement in air transport (Dolbeer, 2013). Wildlife strikes, commonly referred to as bird strikes, occur when an aircraft collides with an animal, mostly a bird, during taxiing, take-off, climb, approach, or landing, and such collisions can damage engines, airframes, and other critical aircraft components (Cleary & Dolbeer, 2005). The Federal Aviation Administration (2024) reported that although the average reported damage rate from wildlife strikes in the United States declined from about six percent in 1996 to roughly 3.7 percent in 2023, the absolute number of reported strikes has continued to rise as air traffic volumes grow. Globally, wildlife strikes have been linked to hundreds of human fatalities and hundreds of destroyed aircraft since the late 1980s (Ogwo, 2024).

The economic burden associated with wildlife strikes is equally significant. In the United States alone, the cost of wildlife strikes to civil aviation was estimated at approximately 461 million dollars in 2023, excluding downstream costs of delays (Ogwo, 2024). International bodies such as the International Civil Aviation Organization (ICAO) have therefore continued to strengthen the regulatory architecture around wildlife hazard management, most notably through Annex 14 to the Convention on International Civil Aviation, which requires aerodrome operators to take action to decrease the risk to aircraft operations by adopting measures that minimise the likelihood of collisions between wildlife and aircraft (International Civil Aviation Organization, 2024).

In Nigeria, the wildlife hazard problem has become a recurring and worsening operational challenge. The Federal Airports Authority of Nigeria (FAAN) recorded over 93 bird strike incidents in the first half of 2022 alone, with the Murtala Muhammed Airport complex in Lagos consistently identified as one of the highest-risk locations in the country (Tribune Online, 2025). Between 2015 and 2020, FAAN documented 134 bird strike incidents nationwide, and individual carriers have suffered disproportionately; for instance, Air Peace alone recorded 14 bird strikes affecting its aircraft engines in 2021 (Tribune Online, 2025). The Airline Operators of Nigeria have further estimated that Nigerian carriers lose over 20 billion naira annually to bird-strike-related damage and disruption (Tribune Online, 2025).

Murtala Muhammed Airport, comprising the international terminal (MM1) and the domestic terminal (MM2), sits within an urbanising coastal ecology characterised by wetlands, refuse dumps, and open drainage systems that attract large concentrations of birds such as kites, egrets and vultures (Olowonawu et al., 2026). A recent ecological and machine-learning based risk assessment of the airport recorded 27 bird species within the aerodrome environment and established a statistically significant upward trend in annual strike frequency using historical FAAN data spanning 2012 to 2022 (Olowonawu et al., 2026).

In response, FAAN operates a dedicated Wildlife Control Department mandated to implement bird and wildlife dispersal measures, including bio-acoustic and pyrotechnic bird-scaring devices, habitat and grass management, falconry, netting, and airside patrols, while the Nigerian Civil Aviation Authority (NCAA) has issued Advisory Circular AC-12 on Wildlife Strike Hazard Management (Nigerian Civil Aviation Authority, 2023). Despite these interventions, aviation stakeholders continue to report that a wide gap exists between stated policy and operational reality (Ogwo, 2024). It is against this background that this study assesses the effectiveness of bird and wildlife control measures at Murtala Muhammed Airport Terminal 2 (MM2), Lagos.

2. LITERATURE REVIEW

2.1 Conceptual Review

2.1.1 Aviation Safety

Aviation safety is generally conceived as the state in which risks associated with aviation activities are reduced and controlled to an acceptable level through a continuing process of hazard identification and risk management (ICAO, 2020). Within this framework, safety management systems (SMS) have become the dominant regulatory instrument through which civil aviation authorities compel airport and airline operators to institutionalise hazard identification, risk assessment and safety assurance processes (Federal Aviation Administration, 2023). For an airport terminal such as MM2 Lagos, aviation safety is therefore best understood as a composite outcome shaped by wildlife hazard management practice, the competence of personnel who implement that practice, and the rigour with which regulators enforce compliance.

2.1.2 Bird and Wildlife Strike

A bird or wildlife strike refers to a collision between an aircraft and a bird, bat, or other animal, most commonly occurring during the take-off, climb, approach or landing phases of flight (Dolbeer & Begier, 2025). Globally, bird and wildlife strikes are estimated to cost the aviation industry hundreds of millions of dollars annually in aircraft damage, flight delays, cancellations and, in the most severe cases, loss of life (DeVault et al., 2018). In the Nigerian context, empirical evidence shows that kites and hawks account for well over half of all reported strikes within the country (Usman et al., 2012). At MM2 Lagos specifically, historical strike data revealed a recorded pattern of strikes dominated by species such as the Cattle Egret (Oduntan et al., 2012).

2.1.3 Bird and Wildlife Control Measures

Bird and wildlife control measures denote the range of habitat management, active dispersal, technological and procedural interventions that airports deploy to reduce the presence of hazardous wildlife on and around the aerodrome (ICAO, 2020). These measures are typically classified into habitat modification techniques, active harassment techniques (including pyrotechnics, distress calls and trained falconry), and technological measures such as avian radar and remote sensing (Altringer et al., 2024). Evidence from the United States indicates that the systematic, sustained deployment of such a programme measurably reduces realised wildlife strike risk and generates economic benefits that considerably outweigh the cost of implementation, with one large-scale evaluation reporting a benefit-cost ratio of approximately seven to one (Altringer et al., 2024).

2.1.4 Staff Training, Refresher Programmes and Awareness

Staff training in the context of wildlife hazard management refers to the structured process by which airport personnel acquire the knowledge, skills and procedural competence required to identify hazardous wildlife, apply approved control techniques and communicate effectively with air traffic control during hazard events (Cleary & Dolbeer, 2005, as cited in ICAO, 2020). International guidance stipulates that a training programme conducted by a qualified wildlife damage management professional should form part of any credible wildlife hazard management plan, alongside a defined schedule for recurrent or refresher training (ICAO, 2020). Empirical evidence from a quasi-experimental study demonstrated that a structured educational intervention produced a statistically significant improvement in participants' wildlife hazard knowledge and decision-making scores (Dolbeer & Begier, 2025).

2.1.5 Regulatory Compliance and Policy Enforcement

Regulatory compliance refers to the extent to which an airport operator conforms to the standards, recommended practices and national regulations governing wildlife hazard management, while policy enforcement denotes the actions taken by a civil aviation authority to monitor, audit and sanction non-conformity with those standards (Federal Aviation Administration, 2023). At the international level, Annex 14 to the Chicago Convention obliges contracting states to assess wildlife strike hazards and to take action to minimise the risk of collision between aircraft and wildlife (ICAO, 2020). Evidence from the wider East African aviation industry indicates that regulatory compliance functions as a strategic amplifier, strengthening the relationship between an organisation's safety management practices and its overall safety outcomes (Roba et al., 2026).

2.2 Theoretical Framework

This study is anchored on two complementary theoretical perspectives: Reason's Organisational Accident Theory (Swiss Cheese Model) and the Regulatory Compliance (Deterrence) Theory.

2.2.1 Reason's Organisational Accident Theory (Swiss Cheese Model)

Reason (1990, 1997) proposed that accidents in complex socio-technical systems, including aviation, rarely result from a single failure but instead occur when weaknesses across multiple layers of organisational defence align to allow a hazard to pass through the entire system. In this model, each layer of defence—such as habitat management, active bird dispersal, staff training and regulatory oversight—is likened to a slice of Swiss cheese containing randomly distributed holes representing latent weaknesses. An aviation safety incident occurs only when the holes in successive layers momentarily align. Applied to the present study, a bird strike incident at MM2 Lagos can be understood not as the failure of a single control measure but as the outcome of simultaneous weaknesses in habitat and wildlife control, inadequate staff training or refresher provision, and lapses in regulatory compliance and enforcement.

2.2.2 Regulatory Compliance (Deterrence) Theory

Regulatory compliance theory holds that organisations conform to safety standards principally in response to the credible threat of external monitoring, audit and sanction, alongside the internalisation of the legitimacy of the regulatory regime itself (Federal Aviation Administration, 2023). Within this framework, compliance is theorised as a function of the certainty, consistency and severity of enforcement action. This perspective predicts that variation in the intensity of NCAA oversight and enforcement of the Nigerian Civil Aviation Regulations should be systematically associated with variation in the extent to which wildlife hazard management plans are implemented on the ground.

2.3 Empirical Review and Research Gap

A growing body of empirical evidence has examined the effectiveness of bird and wildlife control measures at airports internationally. Altringer et al. (2024) found that the presence of structured wildlife hazard management was associated with improved strike reporting and a measurable reduction in economically damaging strike events. DeVault et al. (2018) developed a probabilistic risk metric for prioritising wildlife control effort by species. In the Nigerian context, Oduntan et al. (2012) documented a rich diversity of bird species at MM2 Lagos alongside a recorded history of strike occurrences, while more recent modelling by Olowonawu et al. (2026) confirmed that a small number of highly abundant species continue to drive the bulk of aviation safety risk at the airport.

Empirical findings on the human dimension of wildlife hazard management similarly point to training and awareness as significant determinants of aviation safety outcomes. In the Nigerian aviation industry, inadequate staff training has been explicitly identified, alongside shortage of funds and lack of public awareness, as one of the principal factors militating against effective bird and wildlife control (Usman et al., 2012). Roba et al. (2026), in a mixed-methods study of licensed aviation companies in Kenya, found that regulatory compliance significantly moderated the relationship between strategic safety management system components and organisational outcomes.

Notwithstanding this substantial body of literature, a clear gap remains. Much of the rigorous empirical evidence on the effectiveness of wildlife hazard management programmes has been generated in the context of North American, European and East African airports, while the Nigerian evidence base remains dominated by ecological survey and descriptive incident-reporting studies. No identified study has empirically examined, within a single integrated framework at MM2 Lagos, the joint relationship between the effectiveness of bird and wildlife control measures, the level and frequency of staff training and refresher programmes, and the strength of regulatory compliance and policy enforcement in shaping aviation safety outcomes. It is this gap that the present study seeks to address.

3. METHODOLOGY

3.1 Research Design

The study adopted a descriptive survey research design with a quantitative orientation, supplemented by qualitative insights. A descriptive survey design is appropriate for assessing the current status of bird and wildlife control measures, staff training and awareness levels, and regulatory compliance practices at a specific operational environment such as MM2 (Creswell & Creswell, 2023). The quantitative approach facilitates the measurement of variables related to the effectiveness of control measures, training frequency and awareness, regulatory compliance, and perceived impacts on aviation safety outcomes through structured questionnaire items measured primarily on Likert-type scales.

3.2 Population and Sample

The target population comprised all staff of the Federal Airports Authority of Nigeria (FAAN) and other relevant aviation personnel working at Murtala Muhammed Airport Terminal 2 (MM2), Lagos, who are involved in, or have knowledge of bird and wildlife hazard management, airside operations, aerodrome safety, and regulatory compliance. Based on available organisational information, the estimated accessible population was approximately 185 staff members. The sample size was determined using the Taro Yamane formula for finite populations:

$$n = N / [1 + N(e)^2] \dots\dots\dots (1)$$

where n is the sample size, N is the population size (185), and e is the level of precision (0.05). Applying the formula yielded a minimum sample size of approximately 126 respondents. To account for possible non-response, the sample size was adjusted upward by 15%, resulting in a target of 145 questionnaires distributed. A stratified random sampling technique was employed, with the population stratified according to functional categories (airside operations, wildlife control personnel, managers/supervisors, and SMS/quality staff).

3.3 Research Instrument

The principal research instrument was a structured questionnaire divided into five sections: demographic and occupational information; effectiveness of bird and wildlife control measures; staff training, refresher programmes and awareness; regulatory compliance, policy enforcement and implementation; and perceived aviation safety outcomes. The majority of items were measured on a five-point Likert scale. Content validity was established through expert review by three subject-matter experts. Face validity was enhanced by a pilot administration to 12 staff members. Reliability analysis using Cronbach's alpha yielded an overall coefficient of 0.91 for the main sample, with all individual scales exceeding the 0.70 threshold.

3.4 Data Collection and Analysis

Data collection was conducted over approximately six weeks following formal approval from FAAN management authorities at MM2. Distribution combined physical hard-copy administration and electronic distribution. Of 145 questionnaires distributed, 140 were retrieved (96.6%), and after screening, 132 usable responses were retained (effective response rate of 91.0%). Data were analysed using SPSS Version 26. Descriptive statistics (frequencies, percentages, means, and standard deviations) summarised demographic characteristics and perceptions. Pearson's correlation and multiple regression analysis tested the hypotheses at the 0.05 level of significance. Qualitative responses from open-ended items were subjected to thematic content analysis.

4. RESULTS

4.1 Demographic Profile of Respondents

Of the 132 respondents, 63.6% were male and 34.8% female. The modal age group was 36–45 years (36.4%), followed by 26–35 years (31.1%). Over half (53.8%) held an HND or Bachelor's degree, while 18.2% possessed a Master's degree. Wildlife/Bird Control personnel formed the largest single group (26.5%), followed by Airside Operations (21.2%) and Safety/Compliance (16.7%). Approximately two-thirds of respondents (67.4%) reported direct involvement in bird or wildlife control activities at MM2. Senior staff and supervisors/officers together accounted for 60.6% of respondents, while 43.9% had seven or more years of relevant experience.

4.2 Effectiveness of Bird and Wildlife Control Measures

The composite mean for effectiveness of control measures was 3.41 (SD = 0.72), falling within the "High" category on the interpretive scale (1.00–1.80 Very Low; 1.81–2.60 Low; 2.61–3.40 Moderate; 3.41–4.20 High; 4.21–5.00 Very High). Active deterrence methods received the highest rating (M = 3.62), followed by monitoring and reporting systems (M = 3.55) and the overall contribution of the control programme to safety (M = 3.52). Habitat management (M = 3.35), passive control measures (M = 3.21) and the perceived reduction in strike frequency (M = 3.18) scored in the moderate range. When asked to identify the most effective measures, respondents most frequently cited regular patrols/harassment (59.1%) and pyrotechnics/acoustic deterrents (53.8%).

Table 1: Descriptive Statistics for Effectiveness of Control Measures

Item	Mean	SD	Interpretation
Control measures effective in reducing airside hazards	3.48	0.91	High
Habitat management adequately discourages wildlife	3.35	0.98	Moderate
Active deterrence methods regularly & effectively applied	3.62	0.89	High
Passive control measures well maintained & functional	3.21	1.02	Moderate
Frequency of strikes/near-misses has decreased	3.18	1.05	Moderate
Monitoring & reporting systems provide timely information	3.55	0.92	High
Control programme contributes significantly to safety	3.52	0.87	High
Composite Mean (Effectiveness)	3.41	0.72	High

Source: Field Survey, 2026.

4.3 Staff Training, Refresher Programmes and Awareness

The composite mean for staff training and awareness was 3.28 (SD = 0.81), indicating a moderate overall level. Awareness of hazard management protocols (M = 3.51) and the contribution of staff awareness to safety culture (M = 3.68) were rated relatively highly, whereas the frequency of refresher programmes recorded the lowest mean (M = 2.78). Only 28.0% of respondents reported participating in training annually or more frequently; nearly 40% had either never received such training or had received it only at induction.

4.4 Regulatory Compliance and Policy Enforcement

The composite mean for regulatory compliance and policy enforcement was 3.15 (SD = 0.78), indicating a moderate level overall. The existence of a documented Wildlife Hazard Management Plan (M = 3.48) and overall compliance with NCAA and ICAO standards (M = 3.42) were rated relatively favourably, while resource allocation (M = 2.71) and the addressing of non-compliance through sanctions (M = 2.89) scored lowest.

4.5 Perceived Aviation Safety Outcomes

Overall satisfaction with current control measures was moderate (M = 2.98). Respondents strongly agreed that bird and wildlife hazards remain a significant residual risk despite existing controls (M = 3.72). When asked to rank factors for improving control effectiveness, increased resources (budget, personnel, technology) ranked as most important, followed by improved staff training and awareness, and stronger regulatory compliance and enforcement.

4.6 Hypothesis Testing

All pairwise correlations among the four constructs were positive and statistically significant at the 0.01 level. The strongest association was between effectiveness of control measures and staff training and awareness ($r = .612$, $p < .01$).

4.6.1 Hypothesis One

Effectiveness of control measures significantly predicted aviation safety outcomes ($\beta = 0.489$, $t = 6.41$, $p < .001$), explaining 23.9% of the variance, $F(1, 130) = 41.09$, $p < .001$. H_{01} is rejected.

4.6.2 Hypothesis Two

Staff training and awareness significantly predicted aviation safety outcomes ($\beta = 0.521$, $t = 6.97$, $p < .001$), accounting for 27.1% of the variance, $F(1, 130) = 48.58$, $p < .001$. H_{02} is rejected.

4.6.3 Hypothesis Three

Regulatory compliance significantly predicted the effectiveness of control measure implementation ($\beta = 0.574$, $t = 8.02$, $p < .001$), explaining 33.0% of the variance, $F(1, 130) = 64.32$, $p < .001$. H_{03} is rejected.

4.6.4 Integrated Multiple Regression Model

The combined model explained 37.5% of the variance in aviation safety outcomes ($R = 0.612$; Adjusted $R^2 = 0.360$; $F(3, 128) = 25.61$, $p < .001$). All three predictors remained significant. Staff training and awareness emerged as the strongest unique predictor ($\beta = 0.298$), followed by effectiveness of control measures ($\beta = 0.241$) and regulatory compliance ($\beta = 0.187$). These results reinforce Reason's Organisational Accident Theory: aviation safety with respect to wildlife hazards is jointly produced by interacting layers of defence.

Table 2: Multiple Regression – Predictors of Aviation Safety Outcomes

Predictor	B	t	Sig.	VIF
Effectiveness of Control Measures	0.241	2.68	.008	1.89
Staff Training & Awareness	0.298	3.41	.001	1.76
Regulatory Compliance	0.187	2.19	.030	1.68
Constant	0.92	2.74	.007	—

Model Summary: $R = 0.612$; $R^2 = 0.375$; Adjusted $R^2 = 0.360$; $F(3, 128) = 25.61$; $p < .001$.

Source: Field Survey, 2026 (SPSS Output).

4.7 Qualitative Findings

Open-ended responses identified four dominant challenges limiting the effectiveness of control measures: (1) inadequate funding and resource constraints (shortages of pyrotechnic consumables, fuel for patrol vehicles, and modern detection equipment); (2) habitat and ecological attractants outside the aerodrome (wetlands, open drainage, refuse dumps); (3) inconsistent maintenance of passive measures (fencing, netting and drainage systems); and (4) limited inter-agency coordination. Respondents recommended institutionalisation of mandatory annual refresher training, practical scenario-based modules, extension of basic awareness training to ATC, pilots and ground handlers, and development of localised training materials reflecting MM2's high-risk species.

5. CONCLUSIONS

On the basis of the empirical evidence generated by this study, the following conclusions are drawn. First, the bird and wildlife control measures currently deployed at MM2 are perceived as moderately to highly effective, particularly in the domain of active deterrence and monitoring. Nevertheless, residual wildlife hazard risk remains significant. Second, staff training, refresher programmes and awareness constitute a critical but currently under-developed layer of defence. While general awareness of protocols is relatively strong, the low frequency of structured refresher training represents a clear vulnerability. Third, regulatory compliance and policy enforcement significantly shape the effectiveness with which control measures are implemented.

Formal structures exist, yet gaps in resource allocation, audit frequency and the application of sanctions limit the translation of regulatory requirements into consistent operational practice. Fourth, the joint explanatory power of the three constructs confirms that aviation safety with respect to wildlife hazards at MM2 is a systemic product of interacting organisational defences. Consequently, isolated interventions are unlikely to produce durable improvements; coordinated strengthening across all three domains is required.

6. RECOMMENDATIONS

6.1 For the Federal Airports Authority of Nigeria (FAAN)

- i. Strengthen resource allocation for wildlife hazard management by establishing a ring-fenced annual budget line covering pyrotechnic consumables, vehicle maintenance, modern detection equipment (including consideration of avian radar), and maintenance of passive barriers.
- ii. Institutionalise mandatory annual refresher training aligned with ICAO guidance for all wildlife control personnel and relevant airside and safety staff, incorporating practical scenario-based modules and localised content reflecting MM2's high-risk species.
- iii. Enhance habitat management and coordination on off-aerodrome attractants by intensifying drainage control, vegetation management and waste management within the aerodrome boundary, and actively engaging state environmental authorities and surrounding communities.
- iv. Improve maintenance of passive control measures through a scheduled inspection and maintenance regime for fencing, netting, drainage systems and other passive barriers.

6.2 For the Nigerian Civil Aviation Authority (NCAA)

- i. Intensify audit and inspection of wildlife hazard management implementation, moving beyond documentary compliance to verify the availability of resources, the currency of training, and the actual deployment of control measures.
- ii. Strengthen enforcement and sanctioning mechanisms so that non-compliance with Advisory Circular AC-12 or Nig.CARs Part 12 provisions attracts proportionate and predictable corrective actions.
- iii. Support standardisation of wildlife hazard training curricula by promoting or mandating a nationally standardised initial and recurrent training curriculum for airport wildlife control personnel.

6.3 For Airline Operators and Inter-Agency Coordination

- i. Airlines operating at MM2 should participate in regular joint review meetings with FAAN and the NCAA, share timely and accurate strike data, and ensure that flight crew and ground operations personnel receive periodic briefings on local wildlife hazard patterns.
- ii. A standing multi-stakeholder wildlife hazard coordination forum involving FAAN, the NCAA, airline operators, state environmental agencies and local government authorities should be established to coordinate the management of off-aerodrome attractants and align resource and enforcement priorities.

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