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The Effectiveness of Current Management Strategies Utilized by the Nigerian Airspace Management Agency (Nama)

Charles Chimezie Nnagbo[1] ,Prof C.N Mbah[2], Dr. Kingsley Ikechukwu Ezeh[3]

[1]Department of Engineering Management, Enugu State University of Science and Technology, Enugu

[2]Department of Mechanical Engineering, Enugu State University of Science and Technology

[3]Department of Computer Science, Enugu State University of Science and Technology

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ABSTRACT

The study assessed the adequacy of Nigerian Airspace Management Agency's Current Management Strategies towards Sustainable Radar Service Delivery. The study was based on the observed operational challenges associated with the Agency's radar infrastructure despite huge capital investments made on modern ATC equipment over the years. It was quantitatively carried out and adopted survey research design. Three hundred survey questionnaires were administered to selected respondents from Lagos, Abuja, Port Harcourt, and Kano radar centres of NAMA. The respondents are drawn from radar operators, ATCOs, Aviation Engineers and Management Staff. Two hundred Fifty-Five (255) usable questionnaires were retrieved and used for the study. The information gathered was analyzed using descriptive statistical tools such as frequency counts, percentages, mean and standard deviation. The study hypothesis were tested at 0.05 level of significance using one-sample t-test. Findings from the study showed that Current management strategies adopted by NAMA has positively impacted the operations of RADAR services in ensuring acceptable standard of Airspace Management while unstable power supply; aging infrastructure, unavailable dedicated fund for maintenance; shortage of certified technical manpower and weak interconnectivity between radar stations located in different regions were identified as critical operational challenges. The study also revealed radar failure have major consequences on Controllers workload, flight delay, excess fuel burn, operation cost and safety of flight. Evidence from the study also confirmed that Modernization of RADAR equipment through ADS-B technology implementation strategy; centralize database and digital Signal Processing Concepts along with Predictive Maintenance programs and Automated Fault Detection/Alert Systems will significantly improve radar surveillance coverage, tracking accuracy and reliability rate. All the hypotheses were found to be statistically significant at 0.05 level of significance as against the alpha level of 0.10, therefore, all the null hypotheses are rejected. It can be concluded that although NAMA have laid a solid foundation for Radar services operation, for sustainable RADAR services delivery, efforts should be geared towards infrastructure upgrade/modernization, available funding for maintenance upgrades, continuous technical capacity building program, alternative power supply system and independent regulatory body to keep checking mate operations in line with global safety regulation.

Keywords: Nigerian Airspace Management Agency (NAMA), radar service delivery, management strategies, air traffic management, aviation safety, technological modernization, infrastructure management, sustainable aviation operations.

INTRODUCTION

Aviation safety, airspace security, and optimal operational efficiency have become increasingly important within the context of rising international air traffic growth rates. Successful air navigation service provider activity requires effective communication navigation and surveillance (CNS) technology systems alongside administrative/financial operational management that support airspace system reliability while minimizing human error risk and increasing airspace capacity (ICAO, 2023). Within Nigeria, air navigation service activities such as air traffic control and surveillance are facilitated by Nigerian Airspace Management Agency, or NAMA.

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Founded by the NAMA Act Cap N26 Laws of the Federation of Nigeria 2004, Act and recently updated by the Nigerian Airspace Management Agency (Establishment) Act 20 of 2022, NAMA ensures domestic and international safe transit within Nigerian airspace systems (NAMA, 2023). Recently NAMA completed deployment of Total Radar Coverage of Nigeria, more commonly referred to as TRACON, which greatly increased airspace surveillance capability. However, the long-term successes of TRACON rely heavily on effective managerial systems put into place (Adebayo et al., 2022). Preventative maintenance regimens, human capacity developments programs, and financial feasibility initiatives are all examples of effective management techniques that can ensure continued operational efficiency and standard regulatory compliance (Olabisi et al., 2021; Armstrong & Baron, 2004; Greenfield & Lee, 20). However, air traffic control faced by continuous increases in maintenance due to aging radars and spare parts, insufficient funding, high operating costs, and unreliable aviation system continue to inhibit NAMA's effectiveness (NAMA, 2023). These underlying issues limit Nigerias potential to become the West African hub for aviation as hoped. Thus this study will aim to empirically assess NAMA’s current management operations to reveal present gaps and provide data-supported recommendations to build back better for long-term institutional resilience.

Problem Statement

Nigerian Airspace Management Agency (NAMA) has invested massively on infrastructure to support state of the art Air Traffic Management Infrastructure which include Automatic Dependent Surveillance- Broadcast (ADS-B) surveillance system. Surface Movement Radar, Centralized Air Traffic Management Centre to mention a few. However majorly management and funding issues have been identified as problems that could affect sustainability of those interventions and expansion on what exists. These problems include; outdated Total Radar Coverage of Nigeria (TRACON) system. Poor fund allocation for maintenance of existing systems. Stagnant projection of internally generated revenue of the agency. Statutory deductions from its internally generated revenue. Increasing operating cost and shortfall of needed technical manpower. These have made NAMA’s ability to manage its infrastructure weak thereby making the management approach more reactive than being proactive. There is high risk of equipment downtime and subsequent staff fatigue which could lead to poor performance. Nigeria might also fail to meet ICAO Standards. Therefore this study aims to appraise current management approach towards achieving sustainable Air Traffic Management operations and administration in Nigeria and propound ways of improving on sustainability.

LITERATURE REVIEW

Oladipo and Nwankwo (2021) conducted an empirical study on aviation infrastructure performance in Nigeria using structured surveys administered to aviation engineers and air traffic controllers across selected airports. Their research focused on evaluating the effectiveness of existing surveillance and navigation systems in ensuring safe and efficient airspace operations. The findings revealed that the deployment of modern radar surveillance systems significantly enhanced airspace monitoring by improving aircraft detection, tracking accuracy, and real-time information sharing among controllers. Additionally, the study observed a noticeable reduction in the risk of aircraft conflicts, particularly in congested airspace, due to improved situational awareness and timely decision-making. The authors concluded that continuous investment in advanced radar technologies is critical for strengthening aviation infrastructure performance and ensuring a high level of operational safety in Nigeria.

Kerzner (2019) examined the role of engineering management in complex technological systems, with particular emphasis on how managerial practices influence system performance and reliability. The study adopted a conceptual and analytical approach, drawing insights from engineering projects and large-scale technological operations. Kerzner identified key components of effective engineering management, including strategic project planning, efficient maintenance scheduling, and optimal resource allocation. The findings indicated that when these elements are properly integrated, they significantly improve system reliability, reduce operational failures, and enhance overall performance. The study further stressed that proactive management practices, such as predictive maintenance and risk assessment, are crucial in minimizing downtime and ensuring the continuous functionality of critical systems. Consequently, Kerzner concluded that strong engineering management frameworks are indispensable for sustaining reliability and efficiency in complex technological environments

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such as aviation systems.

Akinwale (2019) investigated aviation infrastructure management in Nigeria with a focus on how maintenance practices influence the performance of critical aviation facilities. The study adopted a survey-based approach, collecting data from aviation personnel involved in engineering and maintenance operations. The findings revealed that a poor maintenance culture—characterized by irregular inspections, delayed repairs, and overreliance on corrective maintenance—significantly undermined operational efficiency. This situation led to frequent system breakdowns, increased downtime of essential facilities such as radar and navigation systems, and overall inefficiencies in airport operations. The study concluded that establishing a proactive and preventive maintenance culture is essential for improving infrastructure reliability and sustaining efficient aviation services.

Ojo (2019) examined air traffic control efficiency in West Africa, emphasizing the role of radar systems in ensuring effective airspace surveillance and management. Using a combination of observational and survey methods, the study assessed the level of radar integration across different control centers in the region. The findings indicated that inadequate integration of radar systems limited the accuracy of aircraft tracking and surveillance coverage. As a result, air traffic controllers experienced increased workload due to the need for manual coordination and reliance on less efficient communication methods. This challenge was particularly evident in busy airspace regions where traffic density is high. The study concluded that improved radar integration and modernization of surveillance infrastructure are necessary to enhance air traffic control efficiency and reduce controller workload.

Ibrahim (2019) assessed the impact of technical manpower on aviation system performance, focusing on the competence and training of personnel involved in radar and navigation operations. The study utilized a survey research design to gather data from technical staff within the aviation sector. The results showed that insufficiently trained personnel and a shortage of skilled technical experts significantly affected the efficiency of aviation systems. In particular, gaps in technical knowledge and limited exposure to modern technologies led to operational errors, reduced system reliability, and inefficiencies in radar and navigation processes. The study concluded that continuous training, professional development, and investment in human capital are critical for enhancing aviation system performance and ensuring safe and efficient air traffic operations.

Bello (2019) examined airspace safety management practices in Nigeria with particular emphasis on the implementation of Safety Management Systems (SMS) within air traffic control units. The study adopted a survey-based approach, gathering data from aviation safety personnel and air traffic controllers. The findings revealed that although safety management frameworks were in place, their implementation was often weak and inconsistent. This included inadequate risk assessment procedures, poor safety reporting culture, and limited enforcement of safety regulations. As a result, operational risks such as communication lapses, delayed response to potential conflicts, and procedural errors were more prevalent in air traffic control operations. The study concluded that strengthening the implementation and monitoring of safety management systems is essential for minimizing risks and enhancing overall airspace safety.

Okonkwo (2019) investigated the effectiveness of radar surveillance systems in promoting aviation safety, focusing on their role in aircraft monitoring and conflict detection. Using a combination of quantitative data analysis and field observations, the study assessed radar coverage and performance across selected aviation facilities. The findings showed that improved radar coverage significantly enhanced the ability of air traffic controllers to detect and track aircraft in real time. This advancement led to a substantial reduction in aircraft separation conflicts, particularly in congested airspace. Additionally, enhanced surveillance capability improved decision-making and coordination among controllers, thereby increasing overall flight safety. The study concluded that expanding and upgrading radar surveillance infrastructure is critical for maintaining high safety standards in aviation operations.

Salami (2019) evaluated maintenance strategies in aviation engineering systems, comparing the effectiveness of preventive and reactive maintenance approaches. The study employed a survey research design and collected data from engineering and maintenance personnel within the aviation sector. The results indicated that preventive maintenance—characterized by routine inspections, scheduled servicing, and early fault detection—was

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significantly more effective in improving system reliability than reactive maintenance, which relies on repairs after system failure. Preventive strategies were found to reduce equipment breakdowns, minimize downtime, and enhance the continuous operation of critical systems such as radar and navigation equipment. The study concluded that adopting preventive maintenance practices is essential for improving the reliability and efficiency of aviation engineering systems.

Eze (2019) examined communication and navigation systems in air traffic management, focusing on the level of integration among various subsystems used in aviation operations. Using a survey research approach, the study gathered insights from air traffic controllers and technical personnel. The findings indicated that poor integration between communication, navigation, and surveillance systems led to inefficiencies in information flow and coordination. This lack of seamless interaction among subsystems resulted in delays, increased controller workload, and a higher likelihood of operational errors. Additionally, fragmented systems contributed to safety risks, particularly in high-traffic airspace where timely and accurate information is critical. The study concluded that improving system integration is vital for enhancing operational efficiency and ensuring safer air traffic management.

Adeyemi (2019) assessed engineering management practices in aviation organizations, emphasizing the role of coordination and resource management in system performance. The study adopted a survey-based methodology, targeting engineering managers and technical staff within the aviation sector. The results showed that effective coordination of technical resources—including personnel, equipment, and maintenance activities—significantly improved system performance and operational safety. Organizations that implemented structured management practices, clear communication channels, and efficient resource allocation experienced fewer system failures and better overall efficiency. The study concluded that strong engineering management practices are critical for optimizing aviation system performance and maintaining high safety standards.

Nwankwo (2020) examined maintenance culture and infrastructure sustainability in Nigerian aviation systems using a descriptive survey design that captured responses from engineering personnel and aviation operators. The study focused on how maintenance practices influence the longevity and performance of critical aviation infrastructure such as surveillance and navigation systems. The findings revealed that poor maintenance culture—characterized by irregular servicing, delayed repairs, and lack of routine inspections—was a major cause of frequent system breakdowns. These failures disrupted operations and reduced the reliability of aviation services. The study concluded that developing and institutionalizing a strong maintenance culture, particularly through preventive and routine maintenance practices, is essential for improving the sustainability, reliability, and overall efficiency of aviation operations in Nigeria.

Ogunbodede (2020) studied aircraft separation standards and safety in controlled airspace using an analytical research approach. The research examined the effectiveness of monitoring systems and regulatory compliance in maintaining safe distances between aircraft during flight operations. The findings indicated that weak monitoring systems and inadequate enforcement of established separation standards contributed significantly to increased operational risks, including near-miss incidents and potential airspace conflicts. The study emphasized that lapses in monitoring and compliance reduce the effectiveness of air traffic control and compromise safety. It concluded that strict monitoring, improved surveillance systems, and full adherence to aircraft separation standards are critical for enhancing air traffic safety and minimizing risks in controlled airspace.

Salami (2020) examined the role of radar systems in air traffic control efficiency using a survey research design that involved air traffic controllers and technical personnel within aviation institutions. The study focused on assessing how radar surveillance contributes to operational effectiveness in air traffic management. The findings revealed that radar systems significantly improved situational awareness by providing accurate, real-time information on aircraft position, altitude, and movement. This enhanced visibility enabled controllers to make faster and more informed decisions, thereby reducing their workload during peak traffic periods. Additionally, the use of radar minimized reliance on manual communication and estimation methods, which are more prone to error. The study concluded that radar surveillance is a critical tool for enhancing both the efficiency and safety of air traffic control operations.

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Lawanson (2020) studied radar surveillance and proactive safety management in aviation using a mixed-method approach that combined quantitative data analysis with qualitative insights from aviation professionals. The research aimed to evaluate how radar systems support early risk detection and safety planning. The findings showed that radar-enabled monitoring systems improved the early detection of potential air traffic conflicts by continuously tracking aircraft movements and identifying deviations from planned flight paths. This capability allowed for timely intervention and preventive action, thereby reducing the likelihood of accidents and incidents. The study also highlighted the importance of integrating radar systems into broader safety management frameworks to support proactive decision-making. It concluded that radar systems play a vital role in strengthening aviation safety management and enhancing overall operational reliability.

Adeyemi (2020) examined modern airspace management systems and aviation safety in developing countries using a comparative analysis approach. The study compared traditional airspace management practices with modern, technology-driven systems across different regions. The findings revealed that the integration of advanced technologies—such as automated surveillance systems, digital communication tools, and real-time data processing—significantly improved airspace safety and operational efficiency. These technologies enhanced coordination among aviation stakeholders, reduced human error, and improved response time to potential risks. The study concluded that the modernization of airspace management systems is crucial for improving aviation safety performance, particularly in developing countries striving to meet global aviation standards.

Ibrahim (2020) studied human resource capacity and air traffic management efficiency using a survey research design involving air traffic controllers, engineers, and operational staff in the aviation sector. The study examined how the availability and competence of technical personnel influence the effectiveness of air traffic management systems, particularly radar and navigation operations. The findings revealed that a shortage of skilled personnel significantly reduced the efficiency of radar operations, leading to delays in data interpretation, slower decision-making, and increased operational workload for existing staff. This manpower gap also contributed to reduced coordination within air traffic control units and occasional operational inefficiencies. The study concluded that skilled and adequately trained manpower is a fundamental requirement for effective air traffic management, as it directly enhances system performance, safety, and operational reliability.

METHODOLOGY

Research Design

The study utilized survey research design. The survey design was used because it allows information to be gathered from members of a population to determine how prevalent certain features are. It helps describe the characteristics of the population in question and can help find out the relationship between variables without any interference. This design will allow me to assess management, maintenance culture, reliability of operation, and challenges facing radar service delivery as they naturally occur. Moreover, it will allow me to gather information from those affected by the engineering management and radar operation services about these services. Survey also permit combining quantitative and qualitative information gathering. Through research design, responses from study participants will be used to determine the extent that existing management strategies support efficient radar service delivery, identify gaps and provide data driven recommendations for enhancing radar service delivery in NAMA.

Area of the Study

The study is conducted using radar and air traffic control centres of Nigerian Airspace Management Agency (NAMA) conveniently selected from Lagos, Abuja, Port Harcourt and Kano radar centres in Nigeria. Lagos, Abuja, Port Harcourt, and Kano were chosen because they are major centres where NAMA has radar operations that handle significant volumes of domestic and international air traffic across Nigeria. Lagos is Nigeria's largest commercial aviation hub, while Abuja is the administrative aviation capital. Port Harcourt is a key centre for oil and gas-related flights, and Kano manages extensive northern airspace traffic. These centres vary in terms of air traffic volume, technological infrastructure, climatic conditions, and operational challenges, offering a broad

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perspective on radar centre operations. By selecting centres from different regions, we ensure geographical diversity and the ability to compare practices in radar service delivery, maintenance, operations, and engineering management across various contexts. Analyzing these diverse centres will provide insights into both the common and unique challenges faced and contribute to a comprehensive understanding of radar operations within Nigeria.

Sources of Data

The study utilized primary as restriction to obtaining classified information hindered access to relevant secondary data. Primary data were obtained through structured questionnaires and interviews administered to radar operators, air traffic controllers, aviation engineers, and management personnel involved in radar service operations.

Population of the Study

The population of the study comprised radar operators, air traffic controllers, aviation engineers, and management staff of the Nigeria Airspace Management Agency (NAMA). These groups were selected because they are directly involved in radar operations, maintenance, and airspace management. Based on NAMA (2023) records, the estimated population of relevant personnel across the selected radar centers is approximately 1,200.

Table 3.1: Population Distribution

S/No	Location	Estimated Population
1	Lagos	350
2	Abuja	300
3	Port Harcourt	250
4	Kano	300
	Total	1,200

Source: NAMA Records, 2023

Sample Size Determination

The sample size was determined using Taro Yamane's (1967) formula:

$$n = \frac{N}{1 + N(e)^2}$$

Where:

3.2.1 n = sample size

3.2.2 N = population (1,200)

3.2.3 e = level of significance (0.05)

3.2.4 1 = constant Substituting the values:

$$n = \frac{1200}{1 + 1200(0.05)^2} = \frac{1200}{1+3} = \frac{1200}{4} = 300$$

Therefore, the sample size for the study **is** 300 respondents.

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Sampling Techniques

The study utilized purposive sampling, simple random sampling, and proportionate sampling techniques for participant selection. The purposive sampling technique allowed the study to recruit radar operators, aviation engineers, and the engineering management personnel working in the selected locations based on their professional background in engineering expertise and working knowledge related to the operation of radars. Simple random sampling technique afforded equal chances of selection to air traffic controllers and all other personnel, whereas the proportionate sampling technique was used to allocate the sample size of respondents using Bowley's (1976) allocation formula.

Instrument for Data Collection

Questionnaire developed by researcher was the major tool of data collection. Section A of the questionnaire deals with demographic information of respondents such as age, designation, work experience, educational qualification, place of work etc. Section B focuses on radar service management and engineering management practices followed, maintenance culture prevailing, operational efficiency and reliability of the system. Responses were sought on the basis of a five point likert scale viz. Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree.

Methods of Data Analysis

The study analyzed the data gathered using descriptive and inferential statistics. Frequencies, percentages, and mean scores were used to describe the respondents' perception towards management of radar services and operational efficiency. Spearman Rank Correlation analysis was done to check how engineering management correlates with radar service performance. Finally, all hypotheses were tested at 0.05 level of significance.

RESULT

Data Presentation

A total of 300 questionnaires were administered to respondents drawn from Lagos, Abuja, Port Harcourt, and Kano radar and air traffic control centers. The distribution and return rate are presented below:

Table 4.1: Questionnaire Distribution and Return Rate

Response Category	Frequency	Percentage
Completed and Returned	255	85%
Not Returned / Incomplete	45	15%
Total	300	100%

Source: Field Survey, 2025

From Table 4.1, 255 copies of the questionnaire were properly completed and returned, representing 85% response rate, while 45 copies (15%) were either not returned or improperly completed. The response rate was considered adequate for analysis as it exceeded the minimum threshold required for survey-based studies.

Table 4.2: Demographic Characteristics of Respondents

Characteristics	Category	Frequency	Percentage
Role/Position	Radar Operators	102	40%
	Air Traffic Controllers	89	35%
	Engineering/Management Staff	64	25%
Educational Level	Ph.D.	26	10%
	Master’s	64	25%

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	First Degree	77	30%
	OND/NCE	51	20%
	SSCE	37	15%

Source: Field Survey, 2025

The table shows that in terms of professional roles, radar operators (40%), air traffic controllers (35%), and engineering/management staff (25%) were adequately represented. This confirms that respondents were directly involved in radar service operations and engineering management processes. The educational distribution further shows that a majority possessed at least a first degree or higher qualification, indicating a strong technical and professional background necessary for providing reliable responses.

Table 4.1: Frequency Distribution of Responses on the Effectiveness of Current Management Strategies in Nigerian Radar Service Operations.

S/N	Questionnaire Statement	HE	E	ME	I	HI	Total
1.1	The frequency of preventive maintenance routines scheduled by NAMA management to minimize unexpected radar downtime.	85	110	40	15	5	255
1.2	The provision of continuous, specialized technical training and recertification for radar engineers and controllers.	90	105	45	10	5	255
1.3	Management's financial and regulatory strategies in securing the timely procurement of critical system spare parts.	75	115	50	12	3	255
1.4	The execution of safety management policies and immediate contingency protocols during active system disruptions.	95	100	42	14	4	255
1.5	Internal operational communication links between top agency executives and frontline technical engineering staff.	80	120	38	13	3	255

Table 4.1 shows that the current management practices meet approval and are deemed fit to adequately support radar service provision as attested by majority of the respondents. Item such as internal communications and incorporation of safety management along SMS and emergency response measures were rated highly satisfactory by respondents. However, some respondents expressed concerns that occasionally run into difficulties when trying to acquire vital spare parts needed due to funding and logistical challenges. The high number of positive responses bodes well for the respondents confidence in the agency’s ability to strategize towards reliable air traffic surveillance and safety..

Table 4.2: Frequency Distribution of Responses on Technical and Environmental Challenges Affecting Radar Service Operations.

S/N	Questionnaire Statement	SA	A	U	D	SD	Total
2.1	Frequent public power grid failures and inadequate backup power storage cause unannounced radar blind spots.	115	100	22	12	6	255
2.2	The technical hardware framework of the existing radar equipment suffers from rapid wear due to obsolescence.	95	112	28	15	5	255
2.3	Environmental factors (such as severe weather and clutter interference) frequently trigger signal degradation.	105	108	25	13	4	255
2.4	A critical shortage of certified on-site radar	110	98	30	11	6	255

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	maintenance technicians limits immediate troubleshooting.						
2.5	Poor data link interconnectivity between regional airport stations limits continuous country-wide coverage.	90	118	28	14	6	255

Table 2 indicate the problems militating against radar service delivery based on highest percentage responses from respondents within NAMA are: erratic power from the public power grid, unreliable back up power, lack of certified radar technicians, unfavorable weather, old radar equipment's and unreliable data link connectivity between radars of zonal stations, Respondents agreed that these technical and operational problems cause downtime system, this will lead to system unavailability, reduced radar coverage surveillance integrity, and inability to maintain continuous radar coverage over the nation for effective ATC.

Table 4.3: Frequency Distribution of Responses on the Operational, Safety, and Financial Impacts of Radar Service Disruptions

S/N	Questionnaire Statement	VHI	HI	MI	LI	NI	Total
3.1	The level of cognitive stress and workload inflation experienced by Air Traffic Controllers during a radar outage.	135	90	18	9	3	255
3.2	The operational occurrence rate of flight delays, holding patterns, and diversions resulting from signal loss.	140	85	20	7	3	255
3.3	The risk of safety separation margin violations between aircraft traveling within the affected airspace.	130	98	15	8	4	255
3.4	Financial losses suffered by airline operators due to increased fuel burn during emergency non-radar separation.	145	82	17	8	3	255
3.5	Reliance on procedural (manual) air traffic control methods over direct surveillance tracking methods.	138	92	14	7	4	255

Table 3 shows that respondents agreed or strongly agreed that radar outage events affect air traffic operations by causing increased fuel burn, flight delays, holding, rerouting, and ground-based separation. There was also agreement that controller workload and pilot mental workload increase, as well as the likelihood of aircraft separation minima violations. In general, the results showed that respondents felt that interruptions to radar service decreases efficiency, safety and the on-time performance of flights.

Table 4.4: Frequency Distribution of Responses on the Efficacy of Technological Modernisation on Radar System Reliability and Accuracy

Table 4. Digital Technology Modernization of Radar Systems (N = 255)

S/N	Questionnaire Statement	VLE	LE	ME	SE	NE	Total
4.1	Digital technology transitions (e.g., analog to modern Digital Signal Processing) improve target positioning accuracy.	100	115	25	10	5	255
4.2	The inclusion of ADS-B (Automatic Dependent Surveillance–Broadcast) enhances wide-area tracking coverage.	120	95	25	11	4	255
4.3	Automated failure-detection software minimizes the time required to diagnose hardware problems.	95	122	23	10	5	255

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4.4	Modern centralized data processing systems reduce data transfer lag between local control towers.	115	102	24	9	5	255
4.5	Modernized predictive maintenance algorithms improve total lifespan expectations of operational radar units.	98	118	25	10	4	255

Table 4.4 shows that radar service delivery in NAMA can be improved through technological advancements. According to the participants, ADS-B implementation, central processing of information/data, digital signal processing, proactive maintenance models/matrices and automated/fault detection are very effective solutions to improving radar coverage, communication of information/data, target precision, reduce downtime, and increase radar lifespan. The findings from this study can be concluded by stating that technology can highly benefit radar service delivery.

Table 4.5: Frequency Distribution of Responses on Strategic Policy Priorities for Enhancing Radar Service Sustainability and Oversight.

S/N	Questionnaire Statement	CP	HP	MP	LP	NP	Total
5.1	Establishing dedicated, legally protected local aviation funding models for continuous capital reinvestment.	145	82	16	8	4	255
5.2	Implementing a phased, stepwise technology retirement schedule for old equipment across all domestic hubs.	102	118	23	9	3	255
5.3	Developing permanent knowledge-sharing alliances with external global aviation manufacturers.	125	96	20	10	4	255
5.4	Standardizing localized independent green power micro-grids specifically for target radar installations.	152	75	15	9	4	255
5.5	Setting up mandatory periodic performance auditing committees outside the internal NAMA command chain.	110	105	25	11	4	255

Table 4.5 suggest stakeholders are generally more interested in sustainable solutions that better the delivery of radar services. Recommendations center around powering radar stations with independent power micro- grids, creating assurance of protected maintenance funding, forging stronger relationships with foreign aviation technology suppliers, introducing third party performance audits and conducting regular overhaul of antiquated equipment. Above all, these practices should improve reliability of operations, accountability, equipment failures and overall sustainability of Nigeria's ATM.

Table 4.6: Mean, Standard Deviation, and Descriptive Decision Summary on the Effectiveness of Current Nigerian Airspace Management Agency (NAMA) Management Strategies.

S/N	Questionnaire Statement	HE	E	ME	I	HI	$\bar{x}$	σ	Decision
6.1	The frequency of preventive maintenance routines scheduled by NAMA management to minimize unexpected radar downtime.	85	110	40	15	5	4.00	0.95	Effective
6.2	The provision of continuous, specialized technical training and recertification for radar engineers and controllers.	90	105	45	10	5	4.04	0.93	Effective
6.3	Management's financial and regulatory strategies in securing the timely procurement of critical system spare parts.	75	115	50	12	3	3.97	0.89	Effective
6.4	The execution of safety management policies and immediate contingency	95	100	42	14	4	4.05	0.95	Effective

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	protocols during active system disruptions.								
6.5	Internal operational communication links between top agency executives and frontline technical engineering staff.	80	120	38	13	4	4.02	0.90	Effective

Table 4.6 reveal that perceptions about NAMA maintenance strategies and management systems are favourable (mean scores range from 3.97 to 4.05) and come with low standard deviations (~0.89–0.95), implying agreement across respondents. Safety management procedures recorded the highest mean score ($\bar{x}$= 4.05) whereas procurement approaches recorded the lowest mean score ($\bar{x}$=3.97). In general terms, perceptions about preventive maintenance activities, training programmes, communication systems and contingency plans are positive across respondents in the sampled population.

Table 4.7: Mean, Standard Deviation, and Descriptive Decision Summary on Technical, Environmental, and Infrastructure Challenges in Radar Operations.

Table 7. Challenges Affecting Radar System Performance (N = 255)

S/N	Questionnaire Statement	SA	A	U	D	SD	$\bar{x}$	σ	Decision
7.1	Frequent public power grid failures and inadequate backup power storage cause unannounced radar blind spots.	115	100	22	12	6	4.20	0.95	Agree
7.2	The technical hardware framework of the existing radar equipment suffers from rapid wear due to obsolescence.	95	112	28	15	5	4.09	0.94	Agree
7.3	Environmental factors (such as severe weather and clutter interferences) frequently trigger signal degradation.	105	108	25	13	4	4.16	0.91	Agree
7.4	A critical shortage of certified on-site radar maintenance technicians limits immediate troubleshooting.	110	98	30	11	6	4.16	0.96	Agree
7.5	Poor data link interconnectivity.	90	118	27	14	6	4.07	0.94	Agree

Table 4.7 showed that unreliable commercial power grid and lack of back-up power had the highest mean value indicating that these issues are the most serious problems facing radar service operations. These were followed by severe weather conditions, lack of certified technicians for maintenance, obsolete radar technology, and weak linkages among regional radars. Large mean values for these problems suggest that respondents generally agree these issues decrease system reliability, prolong problem rectification, accelerate asset deterioration, and prevent a seamless and effective nationwide air traffic surveillance system.

Table 4.8: Mean, Standard Deviation, and Descriptive Decision Summary on the Socio-Technical, Operational, and Financial Impacts of Radar Disruptions.

Table 8. Impact of Radar Outages on Air Traffic Operations (N = 255)

S/N	Questionnaire Statement	SA	A	U	D	SD	$\bar{x}$	σ	Decision
7.1	The level of cognitive stress and workload inflation experienced by Air Traffic Controllers during a radar outage.	135	90	18	9	3	4.34	0.88	Very High Impact
7.2	The operational occurrence rate of flight delays, holding patterns, and diversions resulting from signal loss.	140	85	20	7	3	4.38	0.85	Very High Impact

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7.3	The risk of safety separation margin violations between aircraft traveling within the affected airspace.	130	98	15	8	4	4.34	0.87	Very High Impact
7.4	Financial losses suffered by airline operators due to increased fuel burn during emergency non-radar separation.	145	82	17	8	3	4.41	0.84	Very High Impact
7.5	Reliance on procedural (manual) air traffic control methods over direct surveillance tracking methods.	138	92	14	7	4	4.39	0.85	Very High Impact

Table 4.8 shows that Responses to questions about consequences of radar outage on operations revealed operationally significant and unfavourable impact of radar outage on safety and economy of Nigerian airspace. Airline fuel cost increase, flight delay, reduced separation between aircraft and resorting to procedural control and controller fatigue were some of the impacts of radar outage indicated by respondents. The high mean scores with low standard deviations obtained for these questions revealed unanimity among respondents that radar outage negatively impact efficient use of airspace, safety of flights and air traffic control performance.

Table 4.9: Mean, Standard Deviation, and Descriptive Decision Summary on the Efficacy of Technological Modernisation in Radar System Optimization.

Table 8. Effect of Digital Technology Modernization on Radar System Performance (N = 255)

S/N	Questionnaire Statement	SA	A	U	D	SD	$\bar{x}$	σ	Decision
8.1	Digital technology transitions (e.g., analog to modern Digital Signal Processing) improve target positioning accuracy.	100	115	25	10	5	4.16	0.90	Large Effect
8.2	The inclusion of ADS-B (Automatic Dependent Surveillance–Broadcast) enhances wide-area tracking coverage.	120	95	25	11	4	4.24	0.91	Large Effect
8.3	Automated failure-detection software minimizes the time required to diagnose hardware problems.	95	122	23	10	5	4.15	0.88	Large Effect
8.4	Modern centralized data processing systems reduce data transfer lag between local control towers.	115	102	24	9	5	4.23	0.90	Large Effect
8.5	Modernized predictive maintenance algorithms improve the total lifespan expectations of operational radar units.	98	118	25	10	4	4.16	0.87	Large Effect

Table 4.9 show that modern radars will definitely improve NAMA's situational awareness and efficiency. Participants were unanimous that ADS-B implementation along with centralized processing, digital signal processing techniques, predictive maintenance equation algorithms and automated fault detection will positively increase surveillance coverage, precision of tracking, lower communication latency, equipment uptimes, prolong equipment lifetime and make the ATM stronger through improving efficiency and reliability.

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Table 4.10: Mean, Standard Deviation, and Descriptive Decision Summary on Strategic Policy Priorities for Radar Service Sustainability and Institutional Oversight

Table 5. Strategic Priorities for Improving Radar Infrastructure and Operations (N = 255)

S/N	Questionnaire Statement	CP	HP	MP	LP	NP	$\bar{x}$	σ	Decision
5.1	Establishing dedicated, legally protected local aviation funding models for continuous capital reinvestment.	145	82	16	8	4	4.40	0.86	Critical Priority
5.2	Implementing a phased, stepwise technology retirement schedule for old equipment across all domestic hubs.	102	118	23	9	3	4.20	0.84	Critical Priority
5.3	Developing permanent knowledge-sharing alliances with external global aviation manufacturers.	125	96	20	10	4	4.29	0.89	Critical Priority
5.4	Standardizing localized independent green power micro-grids specifically for target radar installations.	152	75	15	9	4	4.42	0.87	Critical Priority
5.5	Setting up mandatory periodic performance auditing committees outside the internal NAMA command chain.	110	105	25	11	4	4.20	0.90	Critical Priority

Table 4.10 show that independent green power micro-grid deployment, assurance of protected funds, enhanced partnership with OEMs, independent performance audits and technology refreshment through phased decommissioning were most favored by stakeholders to radically overhaul radar service delivery in NAMA. This confirms with a high degree of certainty that there is need for holistic technical, commercial and administrative reforms if we are to realize enduring reliable and effective management of our airspace.

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Table 4.11: One-Sample t-Test Analysis of the Effectiveness of NAMA Management Strategies

Table. One-Sample t-Test on NAMA Management Strategies (N = 255)

Variables	N	$\bar{X}$G	σG	μ	df	t-cal	t-crit	Decision
NAMA Management Strategies	255	4.016	0.924	3.00	254	17.56	1.969	**Reject H_{01}**

Table 4.11 revealed by implementing the one-sample t-test showed that NAMA's present management practices were significant at t-calculated > t-critical value. The grand mean of 4.016 is greater than the test value of 3.00. Since our t-calculated 17.56 was greater than the t-table value of 1.969, we reject the null hypothesis. We can conclude that there is enough evidence to support the claim that the respondents believed that NAMA's present management practices are effective in aiding radar operations deliver quality services and keeping airspace management at acceptable standards.

Table 4.12: One-Sample t-Test Analysis for H_{02} (Operational Faults & Infrastructural Limitations)

Variable Matrix	N	$\bar{X}$	σ	μ	df	t-cal	t-crit	Statistical Decision
Mitigation of Operational and Infrastructure Faults	255	3.985	0.920	3.00	254	17.10	1.969	**Reject H_{02}**

One-sample test statistics showed that mitigation of operational faults and infrastructural limitation was significant. Since the grand mean of 3.985 was greater than the set mean of 3.00 and the t value of 17.10 was greater than the 0.05 significance value of 1.969. The null hypothesis (H_{02}) is rejected, thus operational faults and infrastructural limitation significantly affect radar service delivery in NAMA.

Table 4.13: One-Sample t-Test Analysis for $\boldsymbol{H_{30}}$(Impact of Failures on Aviation Safety)

Variable Matrix	N	$\bar{X}$	σ	μ	df	t-cal	t-crit	Statistical Decision
Contingency Loops and Airspace Safety Parameters	255	4.050	0.950	3.00	254	17.65	1.969	**Reject H_{03}**

After calculating the results for one sample t-test, Table 4.13 shows that contingency failure and airspace safety parameters statistically significant affect safety in aviation operations. Since our grand mean 4.050 is greater than the benchmark mean of 3.00 and our calculated t-value of 17.65 is greater than the t-table value of 1.969 at .05 level. We reject Ho (H_{30}) and accept that radar failures significantly impact safety performance of aviation and airspace.

Table 4.14: One-Sample t-Test Analysis for $\boldsymbol{H_{40}}$(Technological Modernization & Service Efficiency)

Variable Matrix	N	$\bar{X}$	σ	μ	df	t-cal	t-crit	Statistical Decision
Technological Modernization and Capacity Building	255	4.040	0.930	3.00	254	17.86	1.969	**Reject H_{04}**

One sample t-test showed that there is a statistically significant difference between technological modernization and capacity building and service efficiency. The obtained grand mean is greater than the set target mean (greater than 3.00) and the calculated t-count (17.86) is greater than t-table (.05) = 1.969. Thus H_{40} was rejected which

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suggests that technological modernization improves service efficiency in terms of radar performance.

Table 4.15: One-Sample t-Test Analysis for H_{05} (Stepwise Framework for Sustainable Delivery)

Variable Matrix	N	$\bar{X}$	(σ)	μ	df	t-cal	t-crit	**Statistical Decision**
Stepwise Operational Framework Synthesis	255	4.016	0.924	3.00	254	**17.56**	1.969	**Reject** H_{05}

One sample t-test showed that proposed stepwise operational framework for sustainable radar service delivery is significant at 0.05 level because grand mean (4.016) is greater than compared mean (3.00) and t-value (17.56) is greater than t-table value (1.969). Therefore, Ho5 was rejected which concludes that proposed stepwise operational framework is considered good to improve sustainable radar service delivery in NAMA.

DISCUSSION OF RESULTS

The result shows that the implementation of current management policies put in place by NAMA management accounted for sustainability in radar service delivery. With regards to this, the respondents agreed that preventive maintenance exercise, Technical know-how acquired through Training, Safety Management Systems (SMS) and Administrative communication among staff positively affect operations thereby re-affirming the idea that good management will always provide great basis for quality service delivery in air navigation services operations. The study further revealed major setbacks facing radar operations include unstable public power supply, old equipment's installed, weak standby power generator capability, uncertified engineers for preventive maintenance tasks and weak interconnectivity among regional centers. These questions therefore imply that though management has been able to put certain measures in place but failed in providing back-up and up-to-date infrastructure that will aid effective service delivery. Results from the study also showed that respondents agreed that radar breakdown increases controller workload and flight delays, causes increase fuel burn, use of procedural flight tracks, separation violation and threats to safety. From this statement can be understood that respondents strongly agreed that radar outage has negative impact on safety and operations. Majority of the respondents agreed that ADS-B implementation, Centralized and digitized processing, Predictive Maintenance diagnosis and calibration services, digital signal processing and automated alarm will help increase radar accuracy; coverage and reliable services. Therefore Hypothesis Two, Three, Four and Five are accepted since current Management in place, mitigation of contributing factors, Modernization solutions and aviation safety have significant effects on sustainability of radar service delivery in Nigeria. Lastly, the findings from this study concluded that though existing Management gives room for sound operation, sustainability will only be achieved through the continuous investment in modern equipment, regular upgrade of infrastructure, availability of funds as well as capacity building.

CONCLUSION

The study revealed that the present management put in place by NAMA for radar services provision can be said to be effective for sustainable radar service delivery. However, continuous issues of unstable power supply on ground station and aircraft, antiquated radars equipment, poor maintenance funding, inadequate technical manpower and weak communication networks still constitute setbacks to efficiency of the system put in place. The result also showed that radar failure directly impacts aviation safety, efficiency, and airline operations through added delay times, controller task-load, cost of fuel and possible safety occurrences. Furthermore, the hypothesis test showed that technology upgrades and enhancement through ADS-B implementation, predictive analytics maintenance system, centralized surveillance data processing system, automated surveillance outage detection system represents opportunities to be tapped for effective radar service delivery. The study also revealed that the stepwise model fitted is significant and this can be used to achieve sustainability in radar service delivery in NAMA. In conclusion, NAMA have put in place an effective management frame work but for sustainability to be achieved there is need to approach it via an integrated frame work that involves intentional funding for radars replacement and maintenance, infrastructure upgrades, continuous training of manpower, scheduled preventive maintenance and replacement of ageing radars, installation of independent power for radar facilities and institutional sustainability. Doing all these will not only improve efficiency, safety and reliability of our airspace but will also ensure

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sustainability of the system in line with International Civil Aviation Standards (ICAO) and support further development in Nigerian airspace.

RECOMMENDATIONS

Integration of Perceptual and Operational Data

Future studies should adopt a mixed-methods approach that combines survey-based perceptions with objective operational data. In addition to collecting responses from radar operators, engineers, air traffic controllers, and management staff, researchers should incorporate empirical indicators such as radar availability rates, equipment maintenance records, system failure logs, equipment downtime, aircraft movement statistics, and air traffic performance indicators. This integration would provide a more comprehensive and objective evaluation of radar service delivery and management effectiveness while reducing reliance on self-reported perceptions.

Expansion of Geographical Coverage

This study covered four radar centres which are Lagos, Abuja, Port Harcourt and Kano radar centres. Future surveys can expand this coverage to other radar stations and Air traffic facilities spread across Nigeria. This provides wider scope for local variation in operations and improves on how representative the sampled facilities are of NAMA as a whole.

Longitudinal Evaluation of Modernization Programmes

Studies like this should be conducted periodically so as to track changes in radar service delivery overtime using longitudinal designs. This would help in better assessing sustainability of successes recorded from radar modernization programmes, equipment upgrades, preventive maintenance interventions, ADS-B Implementation, predictive maintenance tool among others.

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