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**In loving Memory of Late Professor Oliver E. Osuagwu
(D.Sc, FNCS, FBCS, MIEEE)**

Sensitivity Model Analysis of a Lassa Fever Treatment Control

Achugamonu, Pius Chukwuma¹; Awah, Uchenna Chinyelugo²; Uwakwe, Joy³; Anyanwu, Eric Onyebuchi⁴; Chinaka, Augustina Ifeoma⁵.

¹Department of Mathematics / Alvan Ikoku Federal University of Education Owerri, Imo State.

Abstract:

Background: Lassa virus, the causative agent of Lassa fever, is listed among potential bio-weapons agents. In recent years, cases have been imported into Germany, the Netherlands, the United Kingdom, and the United States due to the rapid expansion of international travel. Understanding its transmission dynamics is therefore of global importance. In this study, a treatment model consisting of seven mutually exclusive compartments related to Lassa fever infection was developed and analyzed. The basic reproduction number was derived, and four major research objectives were achieved. Published articles in standard journals, clinical data, and medical interviews formed the foundation of the study. The disease dynamics were fully determined by the effective reproduction number, obtained using the next-generation matrix approach.

Materials and Methods: A deterministic compartmental model with seven epidemiological classes was formulated to describe Lassa fever transmission under treatment intervention. The effective reproduction number was computed using the next-generation approach. Sensitivity analysis was performed to determine the relative importance of model parameters on disease transmission. Stability and sensitivity assessments employed mathematical tools such as Lyapunov functionals and the Comparison Theorem. Numerical simulations were conducted using MATLAB and MAPLE to validate and support the theoretical findings.

Results: Sensitivity analysis revealed that the effective reproduction number is strongly influenced by specific model parameters. The treatment rate emerged as the most sensitive parameter, indicating that improvements in treatment effectiveness significantly reduce disease transmission. This was followed by the human recovery rate and then person-to-person contact rate. The results suggest that treatment interventions and improved recovery mechanisms have the greatest potential impact on reducing Lassa fever spread. Numerical simulations aligned with the analytical results, confirming the robustness of the model.

Conclusion: This study demonstrates that treatment plays a critical role in controlling Lassa fever transmission. The sensitivity analysis shows that the treatment rate is the most influential parameter, followed by human recovery rate and person-to-person contact. These findings indicate that control strategies should prioritize effective therapeutic interventions and public health education aimed at reducing direct human-to-human transmission. The model provides a useful framework for designing cost-effective intervention strategies and guiding national Lassa fever control programs.

Key Word: Lassa fever; Lassa virus; treatment model; effective reproduction number; sensitivity analysis; mathematical epidemiology; stability analysis; disease transmission dynamics.

1.0 Introduction

There is no US approved vaccine for Lassa fever but it can be treated using Ribavirin which is effective during early stage of infection (McCormick et al, 1987). Lassa fever can be prevented by using: rodent-proof containers for food storage. Rodents control measures such as traps and insecticides are to be used in and around human homes. Avoid eating rodent (rats) and avoid attracting rodents to house by cleanliness and healthy waste disposal practices. Also isolation of patients till recovery is well advised, use of gown, gloves mask and cap, careful segregation of biologically hazardous waste and sterilizing all equipment used for the patients are seriously recommended.

The main aim of this study is to determine the relative importance of the model parameters to the disease transmission based on treatment model of Lassa fever.

Lassa fever is an acute viral Hemorrhagic fever (VHF) first isolated in a town called Lassa in the Yedseram River Valley in the present Borno State of Northern Nigeria in 1969 (Tara, 2004). Lassa fever is endemic in Nigeria, Liberia, Sierra Leone, Guinea, and other West African countries, affecting about 2 – 3 million persons with 5000 - 10,000 fatalities annually (McCormick, et al 1987). Since its initial discovery in Lassa-Nigeria, rural and nosocomial outbreaks of Lassa fever have occurred repeatedly in other parts of Nigeria: Jos, Onitsha, Zonkwa, Ekpoma (Tomori, et al, 1988). Promed (2006) reported outbreaks in some cities of West African countries of Sierra Leone, Liberia, Guinea. In Côte d'Ivoire, Ghana, Togo and Benin, no outbreak has ever been recorded, though isolated cases show evidence of viral circulation (Gunther et al, 2001). Lassa fever therefore appears to have 2 geographically separate endemic areas: the Mano River region (Guinea, Sierra Leone, and Liberia) in the West, and Nigeria in the East. However, Some Lassa fever cases have been "imported" into the U.S. and U.K. through travelers who acquired the disease elsewhere (Tara, 2004).

Lassa fever is a zoonotic disease, i.e. it can be transmitted from infected animal to a human. The natural Reservoir of the Lassa virus is the Multimammate Rat species known as *Mastomys natalensis* (Fisher-Hoch et al, 1995). Because certain varieties of *Mastomys* often live in human homes, the virus is easily transmitted to humans. Transmission occurs via direct contact with rat urine, feces, and saliva; via contact with excretion- or secretion-infected materials; or via ingestion of excretion-contaminated food. Victims can also become infected via skin breaks, and via mucous membranes from aerosol transmission from dust-borne particles. In some areas, the rodents are used as a food source, thus providing additional exposure to the infected rat blood, as well as allowing ingestion of potentially contaminated meat. Eze et al (2010) stated that Health workers become infected usually from contact with rodent saliva or contamination of needles. Unlike other arena viruses, Lassa virus can be fairly easily transmitted from human to human (WHO, 2004). Richmond (2000) stated that humans can come in contact with the disease from other humans via aerosol transmission (coughing), or from direct contact with infected human blood, urine, or semen. Lassa virus has been isolated from semen 6 weeks after acute illness; thus the virus can be transmitted to sexual partners by convalescent men (Tara, 2004). The symptoms of Lassa fever develop about 21 days after the infection with acute illness involving multiple organs. Specific symptoms include fever, facial swelling, muscle fatigue, vomiting, cough, meningitis, and hypertension. In some patients neurological problems, including hearing loss which may be transient or permanent, tremors, and encephalitis, have been described (Omalibu et al, 2005)

2.0 Specific Objectives

The specific objectives of this study are to:

1. Present the mathematical treatment model of the Lassa fever epidemic.
2. Predict the future course of the epidemic using threshold analysis.
3. Determine the dynamic properties of the model.
4. Assess the relative importance of model parameters in disease transmission.

3.0 Mode of Transmission

The **multimammate rat (*Mastomys natalensis*)** is the primary vector responsible for transmitting Lassa fever (Yun & Walker, 2012). This rodent species does not die when infected; instead, it remains a persistent carrier, shedding the virus continuously through its urine, feces, and saliva. Food items contaminated by these secretions become infectious. When the rat consumes food, viral particles from its saliva may also contaminate the item, placing humans at risk upon ingestion.

Human-to-human transmission occurs when an infected individual comes into close contact with an uninfected person. Infectious body fluids include saliva, blood, semen, sweat, urine, and feces. Health workers are particularly vulnerable during sample collection and drug administration. Inhalation of aerosolized particles containing viral material is also considered a significant route of exposure (WHO, 2019).

4.0 Clinical Symptoms

Following an incubation period of **6 to 21 days**, Lassa fever typically presents as an acute illness with **multi-organ involvement** (Fehling et al., 2012). Early symptoms are often nonspecific and may include fever, facial

swelling, muscle fatigue, conjunctivitis, and mucosal bleeding. Additional symptoms vary depending on the organ systems affected (Bowen et al., 2000; Mahanty et al., 2003; Baize et al., 2004):

Gastrointestinal Tract

1. Nausea
2. Vomiting (may be bloody)
3. Diarrhea (may be bloody)
4. Abdominal pain
5. Constipation
6. Dysphagia (difficulty swallowing)
7. Hepatitis

Cardiovascular System

1. Pericarditis
2. Hypertension
3. Hypotension

4. Tachycardia (abnormally high heart rate)

Respiratory Tract

1. Cough
2. Chest pain
3. Dyspnoea (difficulty breathing)
4. Pharyngitis (sore throat)
5. Pleuritis

Nervous System

1. Encephalitis
2. Meningitis
3. Unilateral or bilateral hearing loss
4. Seizures

Clinically, Lassa fever is difficult to distinguish from other viral hemorrhagic fevers such as **Ebola** and **Marburg**, as well as from common febrile illnesses like malaria. The virus may be excreted in urine for **3–9 weeks** and in semen for up to **3 months** after infection (WHO, 2018). Consequently, recovered patients are advised to abstain from sexual activity for three months and should still be handled with caution, as they may continue to transmit the virus during convalescence.

5.0 Laboratory Investigation

A range of laboratory investigations is required to diagnose Lassa fever and monitor its progression and complications. The **ELISA test** for detecting viral antigen and IgM antibodies provides approximately **88% sensitivity** and **90% specificity** for confirming infection (Ogabi et al., 2012). Virus isolation can also be performed, although this requires specialized high-containment laboratories such as the facility in **Eruwa, Edo State, Nigeria**.

Additional laboratory abnormalities commonly observed in Lassa fever include **lymphopenia** (reduced white blood cell count), **thrombocytopenia** (low platelet count), and elevated **aspartate aminotransferase (AST)** levels, which may indicate liver involvement (NCDC, 2016).

5.1 Treatments, Prevention and Prognosis

Patients diagnosed with Lassa fever are typically managed in **isolation wards** with strict waste-disposal protocols to prevent further transmission. The only antiviral medication with proven efficacy is **Ribavirin** (McCormick et al., 1987; Carrillo-Bustamante et al., 2017). When administered during the **first week of illness**, Ribavirin significantly reduces mortality and shortens hospital stay (WHO, 2019).

Because many fatalities result from **shock due to excessive bleeding**, supportive care is essential. This includes maintaining adequate **intravenous fluid** levels and administering **whole blood transfusions** when necessary.

Lassa fever poses a particularly high risk to **pregnant women in their third trimester**. Due to the virus's affinity for the placenta and other highly vascular tissues, early **induction of labor** is often required to improve maternal survival (Fisher-Hoch et al., 2007). Fetal survival is extremely low—approximately **10%**, regardless of intervention (Baize et al., 2004; CIA, 2015). Consequently, clinical management prioritizes saving the mother's life. After delivery, affected women receive the same treatment regimen as other Lassa fever patients (NCDC, 2016).

5.2 Prevention

Community-level prevention focuses on promoting **good hygiene practices** to reduce rodent–human contact. Effective measures include:

1. Storing food in **rodent-proof containers**
2. Disposing of garbage far from residential areas
3. Maintaining clean households
4. Keeping domestic cats (WHO, 2018)

Because **Mastomys** rodents are abundant in endemic regions, complete eradication is not feasible. Family members and healthcare workers must avoid contact with blood and bodily fluids of infected individuals. Routine **barrier nursing precautions** provide substantial protection. For suspected cases, stricter **isolation precautions** are

recommended, including the use of masks, gloves, gowns, face shields, and systematic sterilization of contaminated equipment (WHO, 2019; CDCP, 2019).

5.3 Prognosis

Approximately **15–20%** of hospitalized Lassa fever patients die from the illness (WHO, 2018). The overall mortality rate is estimated at **1%**, but during epidemics it may rise to **50%** (Yun & Walker, 2012). Mortality exceeds **80%** among pregnant women in their third trimester, with fetal death occurring in nearly all cases (Fisher-Hoch et al., 2007). Termination of pregnancy significantly improves maternal survival.

The availability of Ribavirin has contributed to declining fatality rates. Research toward a **Lassa fever vaccine** is ongoing, with several promising approaches demonstrating positive results in animal studies (Mylnea et al., 2015).

6.0 Model Assumptions

1. The population is sufficiently large such that each compartment can be treated as a continuous variable.
2. Uniform mixing of the population is assumed.
3. Vital dynamics (recruitment and deaths) occur through immigration.
4. The virus does not kill rodents; rodent mortality is assumed to be natural or accidental.
5. “Control” refers to reducing the number of infectious Lassa fever cases.
6. Rodents acquire the virus from the environment or from other rodents.
7. The probability of rodents becoming infected through contact with infectious humans is assumed negligible.

6.1 Model Formulation

There is currently **no vaccine** available for Lassa fever in humans, and the only effective treatment—**Ribavirin**—is beneficial primarily when administered early in the infection (McCormick et al., 1986). Carrillo-Bustamante et al. (2017) reported that Ribavirin’s modeled viral kinetics suggest its main mechanism is **protecting infected cells from dying**, thereby reducing inflammatory responses, rather than inhibiting viral replication or transmission.

Several mathematical models have examined Lassa fever transmission (Onuorah et al., 2016; Akinpelu & Akinwande, 2018; Obasi & Mbah, 2019; Onah & Obiora, 2020; Erinle-Ibrahim et al., 2022), but few have focused on the **impact of treatment**.

The goal of this study is to use a mathematical modeling approach to analyze the **sensitivity of a treatment-based Lassa fever model**. To evaluate the effect of treatment as a control strategy, we incorporate **early-stage** and **late-stage treatment compartments** into the basic Lassa fever transmission model developed by Obasi and Mbah (2019). The resulting system, as extended by Obasi et al. (2022), is expressed in the following equations:

$$\left\{ \begin{array}{l}
 \frac{dS_h}{dt} = \Lambda_h + \phi(1 - \nu)I_h + \psi R_h - \beta_1 \sigma I_r S_h - \beta_2 \varepsilon I_h S_h - \eta(1 - e^{-rt})S_h - \mu_h S_h \\
 \frac{dE_h}{dt} = \beta_1 \sigma I_r S_h + \beta_2 \varepsilon I_h S_h + \eta(1 - e^{-rt})S_h - (\kappa + \mu_h)E_h \\
 \frac{dI_h}{dt} = \kappa E_h - (\phi + \theta + \delta + \mu_h)I_h \\
 \frac{dT_{h1}}{dt} = \alpha \theta I_h - \mu_h T_{h1} \\
 \frac{dT_{h2}}{dt} = (1 - \alpha)\theta I_h - (\delta + \mu_h)T_{h2} \\
 \frac{dR_h}{dt} = \phi \nu I_h + \varpi T_{h1} - (\psi + \mu_h)R_h \\
 \frac{dS_r}{dt} = \Lambda_r - \beta_3 \vartheta I_r S_r + \varphi R_r - \mu_r S_r \\
 \frac{dI_r}{dt} = \beta_3 \vartheta I_r S_r - (\omega + \mu_r)I_r \\
 \frac{dR_r}{dt} = \omega I_r - (\varphi + \mu_r)R_r
 \end{array} \right. \quad (1)$$

The definitions of above model variables and parameters are listed in Table 1 and 2.

Table No 1: Description of the state variables of the model

| Variable | Description |
|----------|-------------------------------|
| S_h | Number of Susceptible humans |
| E_h | Number of Exposed humans |
| I_h | Number of Infectious humans |
| T_{h1} | Early stage treatment group |
| T_{h2} | Late stage treatment group |
| R_h | Number of Recovered humans |
| S_r | Number of Susceptible rodents |
| I_r | Number of Exposed rodents |
| R_r | Number of Infectious rodents |

Table No 2: Description of the parameters of the Lassa fever model

| Parameters | Description | Values | Source |
|---------------|---|---------|--------------|
| Λ_h | Recruitment level of humans | 20 | Assumed |
| Λ_r | Recruitment level of rodents | 200 | Assumed |
| δ | Per capita Lassa-induced death rate | 0.2 | WHO |
| ψ | Recovered human loss of immunity | 0.9 | NCDC |
| ϕ | Spontaneous individual recovery | 0.001 | WHO |
| β_1 | Transmission rate per contact by an infectious rodent | 0.00002 | Yun & Walker |
| β_2 | Transmission rate per contact by an infective through sexual activity | 0.002 | Yun & Walker |
| β_3 | Transmission rate per contact by an infected human | 0.08 | Yun & Walker |
| η | Relative infectiousness of individuals with aerosol | 0.03 | Tara |
| μ_h | Natural mortality rate for humans | 0.02041 | NCDC |
| μ_r | Natural mortality rate for rodents | 0.06 | WHO |
| κ | Progression rate of human from exposed to infected | 0.05 | Obasi et al |
| α | Progression rate of rodents from exposed to infected | 0.42 | Estimated |
| σ | Contact rate of rodent per human per unit time | 0.005 | Obasi et al |
| ϱ | Relative human-to-rodent transmissibility of infected humans | 0.6 | Obasi et al |
| ε | Relative human-to-human transmissibility of infected humans | 0.5 | Obasi et al |
| r | Rate of exposure to aerosol | 0.02 | Obasi et al |
| ω | Recovery rate of rodents | 0.00001 | Obasi et al |
| φ | Recovered rodent loss of immunity | 0.001 | Estimated |
| ϖ | Rate of early stage treated group who recovers | 0.2 | Estimated |
| α | Fraction of early stage treatment group | (0,1) | Assumed |
| θ | Treatment rate of humans | 0.8 | Estimated |

Source: Obasi et al, 2022

6.2 Mathematical Analysis of the Model

The analysis of the model presented previously is carried out in this section. We perform key mathematical investigations on both the **basic** and **control models**, including derivation of the **basic reproduction number**, **stability analysis**, **threshold conditions**, **sensitivity analysis**, and **numerical simulations**.

6.3 Qualitative Properties of the Model

Since the model (1) monitors the human population, all associated parameters and state variables are assumed to be **non-negative** for all $t \geq 0$. Before proceeding with further analysis, it is important to establish that the state variables remain non-negative for all non-negative initial conditions.

We therefore state the following result:

Theorem 1:

Let the initial data be non-negative. Then, the solutions of model (1) remain **positive and bounded** for all $t \geq 0$, whenever they exist.

Proof:

Suppose $S_h(0) \geq 0$. The first equation (1) of the system can be written as:

$$\begin{aligned} \frac{dS_h}{dt} + [\lambda(S_h) + \mu_h] S_h &= \Lambda_h + \phi(1 - \nu) I_h + \psi R_h \\ \frac{d}{dt} [S_h(t) \eta(t)] &= (\Lambda_h + \phi(1 - \nu) I_h + \psi R_h) \eta(t), \end{aligned}$$

where $\eta(t) = \exp\left(\int_0^t [\lambda(S_h) + \mu_h] t dt\right) > 0$ is the integrating factor. Hence, integrating this last relation from 0

to t_1 , we have

$$\begin{aligned} [S_h(t_1) \eta(t_1)] - S_h(0) \eta(0) &= \int_0^{t_1} (\Lambda_h + \phi(1 - \nu) I_h + \psi R_h) \exp[(\lambda(S_h) + \mu_h) p] dp, \\ \eta(0) &= 1, \\ [S_h(t_1) \eta(t_1)] - S_h(0) &= \int_0^{t_1} (\Lambda_h + \phi(1 - \nu) I_h + \psi R_h) \exp[(\lambda(S_h) + \mu_h) p] dp \\ S_h(t_1) \eta(t_1) &= S_h(0) + \int_0^{t_1} (\Lambda_h + \phi(1 - \nu) I_h + \psi R_h) \exp[(\lambda(S_h) + \mu_h) p] dp \end{aligned}$$

so that the division of both side by $\eta(t)$ yields

$$S_h(t_1) = \left[S_h(0) + \int_0^{t_1} (\Lambda_h + \phi(1 - \nu) I_h + \psi R_h) \exp[(\lambda(S_h) + \mu_h) p] dp \right] \times \eta^{-1}(t_1) > 0.$$

The same arguments can be used to prove that $E_h(t), I_h(t), R_h(t), S_r(t), I_r(t), R_r(t) \geq 0$ for all $t > 0$

Furthermore, let $N = S_h + E_h + I_h + T_{h1} + T_{h2} + R_h$. Then,

$$\begin{aligned} \dot{N}(t) &= \dot{S}_h + \dot{E}_h + \dot{I}_h + \dot{T}_{h1} + \dot{T}_{h2} + \dot{R}_h \\ &= \Lambda_h + \phi(1 - \nu) I_h + \psi R_h - \lambda_h S_h - \mu_h S_h + \lambda_h S_h - (\kappa + \mu_h) E_h + \kappa E_h - (\phi + \theta + \delta + \mu_h) I_h \\ &\quad + \alpha \theta I_h - \mu_h T_{h1} + (1 - \alpha) \theta I_h - (\delta + \mu_h) T_{h2} + \phi \nu I_h + \varpi T_{h1} - (\psi + \mu_h) R_h \\ &\leq \Lambda_h - \mu_h N_h - \delta I_h, \quad \delta = 0 \end{aligned}$$

This implies that as $t \rightarrow \infty, \sup N_h \leq \frac{\Lambda_h}{\mu_h}$. Also from (1), we have that as: $t \rightarrow \infty, \sup S_r(t) \leq \frac{\Lambda_r}{\mu_r}$.

This completes the proof.

Combining Theorem 1 with the trivial existence and uniqueness of a local solution for the model (1), we have established the following theorem which ensures the mathematical and biological well-posedness of system (1).

Theorem 2: The dynamics of model (1) is a dynamical system in the biological feasible compact set

$$\Gamma := \left\{ (S_h, E_h, I_h, T_{h1}, T_{h2}, R_h, S_r, I_r, R_r) \in \mathbb{R}_+^9 : 0 \leq S_h \leq \frac{\Lambda_h}{\eta(1-e^{-rt}) + \mu_h}; N_h \leq \frac{\Lambda_h}{\eta(1-e^{-rt}) + \mu_h}, N_r \leq \frac{\Lambda_r}{\mu_r} \right\} \quad (2)$$

Stability Analysis

The model (1) has a disease-free equilibrium (DFE), obtained by setting the right hand sides of the equations in the model to zero, given by

$$\xi_0 = (S_h^0, E_h^0, I_h^0, T_{h1}^0, T_{h2}^0, R_h^0, S_r^0, I_r^0, R_r^0) = \left(\frac{\Lambda_h}{\eta(1-e^{-rt}) + \mu_h}, 0, 0, 0, 0, 0, \frac{\Lambda_r}{\mu_r}, 0, 0 \right) \quad (3)$$

The stability of ξ_0 can be established using the next generation operator method on the system (1). Using the notations in van den Driessche and Watmough (Obasi & Mbah, 2019), the matrices F and V , for the new infection terms and the remaining transfer terms respectively, are given by

$$F = \begin{pmatrix} 0 & \beta_2 \varepsilon S_h^0 & 0 & 0 & \beta_1 \sigma S_h^0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \beta_3 \vartheta S_r^0 \end{pmatrix}$$

$$V = \begin{pmatrix} (\mu_h + \kappa) & 0 & 0 & 0 & 0 \\ -\kappa & (\phi + \mu_h + \delta + \theta) & 0 & 0 & 0 \\ 0 & \alpha \theta & \mu_h & 0 & 0 \\ 0 & -\alpha(1-\theta) & 0 & (\delta + \mu_h) & 0 \\ 0 & 0 & 0 & 0 & (\omega + \mu_r) \end{pmatrix}$$

In the calculation of matrices F and V , we took the infection variables to be E_h, I_h, T_{h1}, T_{h2} and I_r as explained in (Obasi & Mbah, 2019). Thus

$$R_T = R_h + R_r = \frac{\beta_2 \kappa \varepsilon \Lambda_h}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1-e^{-rt}) + \mu_h)} + \frac{\beta_3 \vartheta \Lambda_r}{\mu_r(\omega + \mu_r)}$$

where R_T is obtained from $\rho(FV^{-1})$ with ρ being the spectral radius of the matrix FV^{-1} . Computing the partial derivatives of R_T with respect to the parameters under investigation (θ, ϖ) further reveals the effect of these parameters on Lassa fever control in the community. This gives

$$\frac{\partial R_T}{\partial \theta} = -\frac{\beta_2 \varepsilon \kappa}{(\mu_h + \kappa)(\phi + \mu_h + \delta + \theta)^2} \left[\frac{\Lambda_h}{\eta(1 - e^{-rt}) + \mu_h} \right] < 0 \quad (4)$$

Clearly, it follows from (4) that the partial derivative is less than zero, unconditionally. Hence, treatment rate of humans will have a positive impact in reducing the burden of LF in the population, irrespective of the values of the other parameters in the expressions on the right-hand sides of (4). Furthermore, if the combined effect of preventive measures reduces R_0 by a factor q , then effective reproduction number $R_T = (1 - q)R_0$ (Obasi et al, 2022). This

implies that no outbreak if $R_T \leq 1$, i.e, if $q \geq 1 - \frac{1}{R_0}$. Assuming treatment control can reduce the basic reproduction

number R_0 by a factor q , i.e. $R_T = (1 - q)R_0$, we obtain that

$$\frac{R_T}{R_0} = \frac{\phi + \mu_h + \delta}{\phi + \mu_h + \delta + \theta} = 0.88 \Rightarrow R_T = (1 - q)R_0$$

$$\therefore 1 - q = 0.88 \Rightarrow q = 0.12$$

Thus, introduction of treatment control significantly reduces the transmission of LF required for successful eradication of the disease (requirement of at least 12% effectiveness). This means that the treatment reproduction number R_T is 12% smaller than the basic reproduction number R_0 , indicating that the use of treatment as a control strategy is 12% effective on reducing LF transmission. This implies that early detection is of paramount importance in the control of Lassa fever in a population. However, this is an indication that the early stage group treatment program alone at this rate is not enough to eliminate the disease. So, multiple control strategy requires urgent assessment.

Lemma 1: The DFE of the model (1), ξ_0 , is locally asymptotically stable if $R_T < 1$ and unstable if $R_T > 1$. The threshold quantity R_T is the effective reproduction number under treatment control for the Lassa fever model. Biologically speaking, Lemma (1) implies that Lassa fever can be eliminated from the community (when $R_T < 1$) if the initial sizes of the subpopulation of the model are in the basin of attraction of ξ_0 in the presence of treatment.

Global Asymptotic Stability: Special Case $\sigma = \eta = 0$.

Consider the model (1) with $\sigma = \eta = 0$. We claim the following:

Theorem 2: The DFE of the model (1) with $\sigma = \eta = 0$ is globally-asymptotically stable (GAS) whenever $R_T < 1$.

Proof

Consider the model (1) with $\sigma = \eta = 0$. Further, consider the following linear Lyapunov function

$$F = \kappa E_h + (\kappa + \mu_h) I_h$$

with Lyapunov derivative (where a dot represents differentiation with respect to t)

$$\begin{aligned}
\dot{F} &= \kappa \dot{E}_h(t) + (\kappa + \mu_h) \dot{I}_h(t) \\
&= \kappa (\lambda_h S_h - (\kappa + \mu_h) E_h) + (\kappa + \mu_h) (\kappa E_h - (\phi + \theta + \delta + \mu_h) I_h) \\
&= (\kappa + \mu_h) (\phi + \theta + \delta + \mu) \left[\frac{\beta_2 \varepsilon \kappa S_h}{(\kappa + \mu_h) (\phi + \theta + \delta + \mu)} - 1 \right] I_h \\
\dot{F} &\leq (\kappa + \mu_h) (\phi + \theta + \delta + \mu_h) [R_T - 1] I_h
\end{aligned}$$

Hence, $\dot{F} \leq 0$ if $R_T \leq 1$ with $\dot{F} = 0$ if and only $I_h = 0$. Therefore F is a Lyapunov function in Γ and it follows Salle's Invariance Principle (Obasi et al, 2022), that every solution to the equations in (1) (with $\sigma = \eta = 0$) with initial conditions in Γ converges to ξ_0 as $t \rightarrow \infty$. i.e.,

Theorem 3: If $R_T > 1$, then endemic equilibrium point of the model (1) is globally asymptotically stable if

$$S_h = S_h^*, E_h = E_h^*, I_h = I_h^*, T_{h1} = T_{h1}^*, T_{h2} = T_{h2}^* \text{ and unstable if } R_T < 1.$$

Proof

Consider the following Lyapunov function,

$$Q(S_h, E_h, I_h, T_{h1}, T_{h2}) = \frac{1}{2} (S_h - S_h^*)^2 + \frac{1}{2} (E_h - E_h^*)^2 + \frac{1}{2} (I_h - I_h^*)^2$$

Differentiating wrt t ,

$$\begin{aligned}
\frac{dQ}{dt} &= (S_h - S_h^* + E_h - E_h^* + I_h - I_h^*) (S_h'(t) + E_h'(t) + I_h'(t)) \\
&= (S_h - S_h^* + E_h - E_h^* + I_h - I_h^*) (\Lambda_h - \mu_h S_h + \lambda S_h - (\kappa + \mu_h) E_h + \kappa E_h - (\phi + \theta + \delta + \mu_h) I_h) \\
&= - (S_h - S_h^* + E_h - E_h^* + I_h - I_h^*) (H - W)
\end{aligned}$$

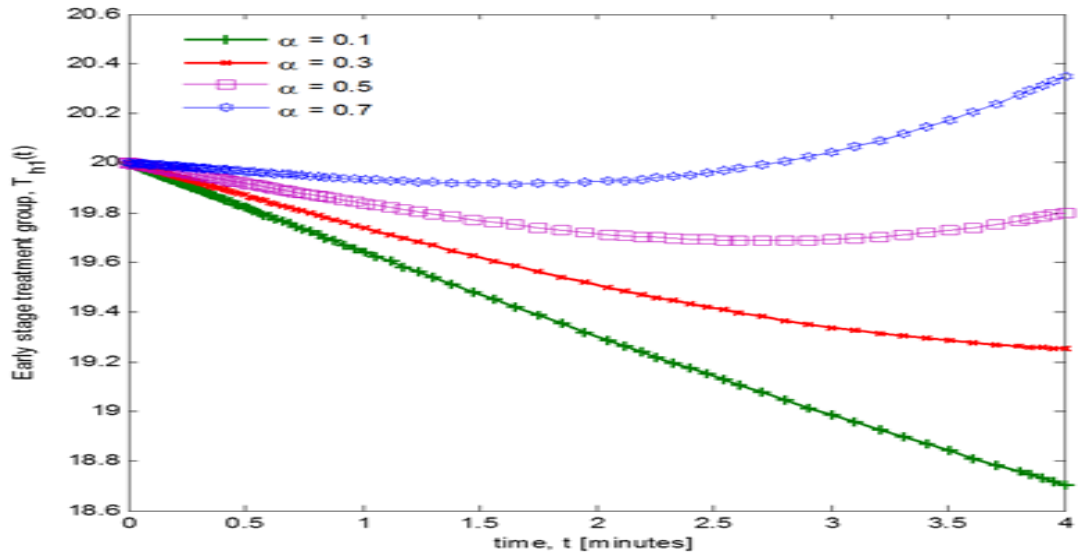
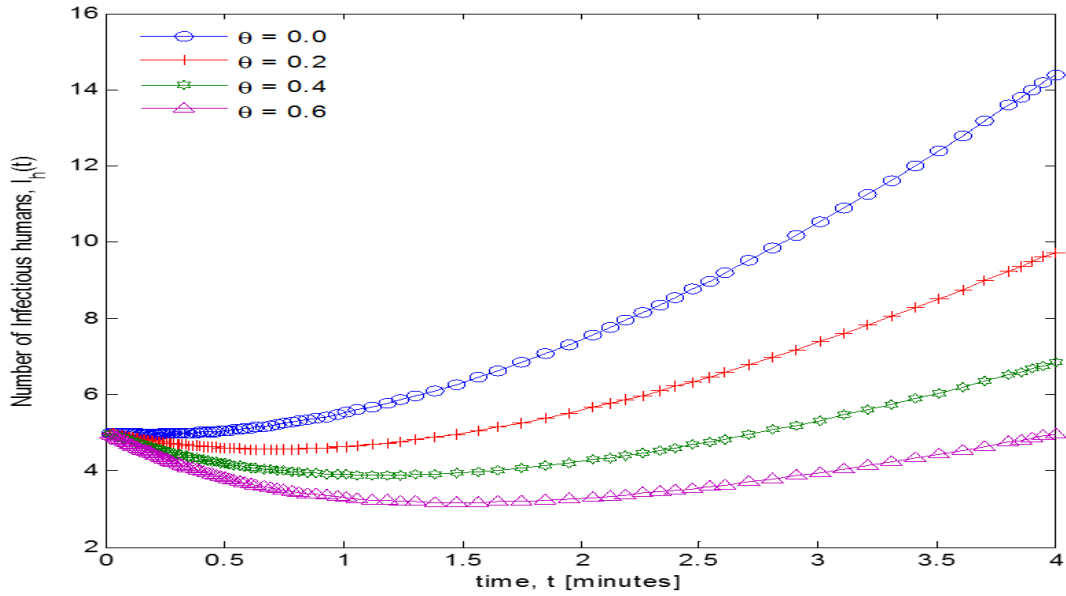
where

$$H = \mu_h S_h + (\kappa + \mu_h) E_h + (\phi + \theta + \delta + \mu_h) I_h; W = \Lambda_h + \kappa E_h$$

Hence we have $\frac{dQ}{dt} = 0$ if $S_h = S_h^*, E_h = E_h^*, I_h = I_h^*, T_{h1} = T_{h1}^*, T_{h2} = T_{h2}^*$, also $\frac{dQ}{dt} < 0$ if $H > W$. Thus, it is clear that the endemic equilibrium point of the model (1) is globally asymptotically stable. So the proof is completed.

7.0 Effect of the effective treatment rate

In order to investigate the impact of the effective treatment rate on the spread of LF, we carry out some numerical simulations to show the contribution of effective treatment rate during the whole infection. From Figure 2, we can observe that infected individuals reach a lower point level as θ increases. This Figure 2 illustrates the great influence of the effective treatment rate as shown in the threshold analysis.



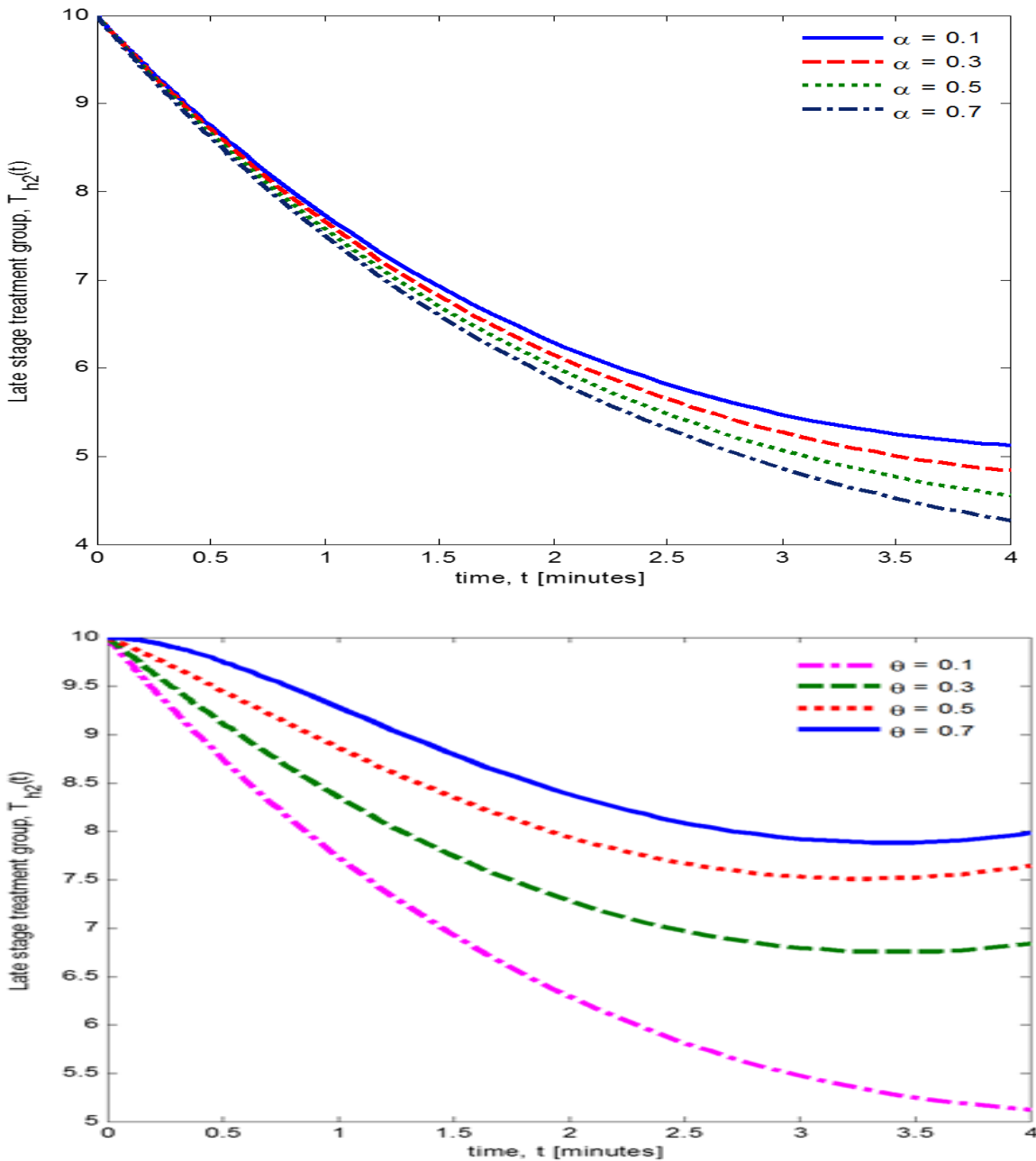


Figure 2. Impact of effective treatment rate on the spread of LF.

Sensitivity Analysis

Sensitivity indices allow us to measure the relative change in a variable when a parameter changes. If the model is simple, it may be possible to differentiate the outcome with respect to each parameter in turn. The derivatives are the rate of changes of predictions with respect to the parameters. This work adopts the normalized forward sensitivity index to conduct the sensitivity index of a variable with respect to a parameter is the ratio of the change in the parameter. When the variable is a differentiable function of the parameter, the sensitivity index may be alternatively defined using partial derivative (Obasi & Mbah, 2019). For instance, the normalized forward sensitivity index on R_T , which depends differentially on a parameter φ , is defined by

$$\Pi_{\varphi}^{R_T} = \frac{\partial R_T}{\partial \varphi} \times \frac{\varphi}{R_T} \quad (5)$$

The sensitivity index of parameters with respect to R_T is given as:

$$\Pi_{\Lambda_h}^{R_T} = \frac{\beta_2 \varepsilon \kappa}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)} \times \frac{\Lambda_h(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = 1 > 0$$

$$\Pi_{\beta_2}^{R_T} = \frac{\varepsilon \kappa \Lambda_h}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)} \times \frac{\beta_2(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = 1 > 0$$

$$\Pi_{\varepsilon}^{R_T} = \frac{(1 - u_1) \kappa \Lambda_h}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)} \times \frac{\varepsilon(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = 1 > 0$$

$$\Pi_{\kappa}^{R_T} = \frac{\beta_2 \varepsilon \Lambda_h \mu_h}{(\kappa + \mu_h)^2 \left[(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h) \right]} \times \frac{\kappa(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = 0.667 > 0$$

$$\Pi_{\theta}^{R_T} = -\frac{\beta_2 \varepsilon \kappa}{(\mu_h + \kappa)(\phi + \mu_h + \delta + \theta)^2} \left[\frac{\Lambda_h}{\eta(1 - e^{-rt}) + \mu_h} \right] \times \frac{\theta(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = -1.784 < 0$$

$$\Pi_{\delta}^{R_T} = \frac{-\beta_2 \varepsilon \kappa \Lambda_h}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)^2 (\eta(1 - e^{-rt}) + \mu_h)} \times \frac{\delta(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = -0.743 < 0$$

$$\Pi_{\eta}^{R_T} = \frac{-(1 - e^{-rt}) \beta_2 \varepsilon \kappa \Lambda_h}{(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)^2} \times \frac{\eta(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = -0.0012 < 0$$

$$\Pi_{\mu_h}^{R_T} = \frac{-\beta_2 \varepsilon \kappa \Lambda_h \left[3\mu_h + 2\mu_h \left((2\kappa(\phi + \delta + \theta) + \eta(1 - e^{-rt})) + \kappa(\phi + \delta + \theta) + 2\kappa(\phi + \delta + \theta)(\eta(1 - e^{-rt})) \right) \right]}{\left[(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h) \right]^2}$$

$$\times \frac{\mu_h(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = -1.603 < 0$$

$$\Pi_r^{R_T} = \frac{\beta_2 \eta \varepsilon \kappa \Lambda_h e^{-rt}}{t(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)^2} \times \frac{r(\kappa + \mu_h)(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = 0.0116 > 0$$

$$\Pi_{\phi}^{R_T} = -\frac{\beta_2 \varepsilon \kappa}{(\mu_h + \kappa)(\phi + \mu_h + \delta + \theta)^2} \left[\frac{\Lambda_h}{\eta(1 - e^{-rt}) + \mu_h} \right] \times \frac{\phi(\phi + \mu_h + \delta + \theta)(\eta(1 - e^{-rt}) + \mu_h)}{\beta_2 \varepsilon \kappa \Lambda_h} = -1.482 < 0$$

Table 3: Sensitivity indices of the effective reproduction number to model parameters

| Parameter | Estimated values | Sensitivity index |
|---------------|------------------|-------------------|
| μ_h | 0.02041 | -1.603 |
| θ | 0.8 | -1.784 |
| δ | 0.2 | -1.784 |
| ϕ | 0.001 | -1.482 |
| Λ_h | 20 | 1 |
| β_2 | 0.002 | 1 |
| ε | 0.5 | 1 |
| κ | 0.01 | -0.667 |
| r | 0.02 | 0.0116 |
| η | 0.03 | -0.0012 |

Source: Researcher's Computation

It is observed in Table 3 that these parameters have either positive or negative effects on the effective reproduction number. Positive index indicates that the value of R_T will increase with increase in the parameter and the one with negative index will decrease the value of R_T with increase in the parameter values.

8.0 Discussion

The present study developed and analyzed a deterministic treatment-based model for Lassa fever transmission, providing new insights into how therapeutic interventions influence disease dynamics. The model incorporated seven mutually exclusive epidemiological compartments, enabling a structured representation of infection progression under treatment. By deriving the effective reproduction number using the next-generation matrix approach, the study established a quantitative foundation for assessing the potential impact of treatment and recovery mechanisms on disease spread.

A key finding of this work is the dominant influence of the treatment rate on the effective reproduction number. Sensitivity analysis consistently identified treatment as the most critical parameter, indicating that even modest improvements in treatment effectiveness can substantially reduce transmission. This aligns with clinical evidence showing that early administration of antiviral therapy improves patient outcomes and reduces viral shedding, thereby lowering the likelihood of onward transmission. The model therefore reinforces the importance of strengthening treatment infrastructure, ensuring timely diagnosis, and improving access to effective therapeutics in endemic regions.

The human recovery rate emerged as the second most influential parameter. This result highlights the role of supportive care, early case detection, and improved clinical management in reducing infectious periods and limiting community spread. Enhancing recovery rates through better clinical protocols, improved hospital capacity, and targeted training for healthcare workers could therefore serve as a complementary strategy to treatment-focused interventions.

Person-to-person contact rate was identified as the third most sensitive parameter, underscoring the continued relevance of behavioral and public health measures. Although zoonotic spillover remains the primary source of Lassa fever infections, human-to-human transmission—particularly in healthcare settings—can sustain outbreaks. Public health education, infection-prevention practices, and community engagement remain essential components of any comprehensive control strategy. The model's findings support the integration of behavioral interventions with clinical and therapeutic measures to achieve optimal disease control.

The stability analysis further demonstrated that the disease-free equilibrium is locally and globally stable when the effective reproduction number is less than unity, confirming that reducing this threshold remains the central objective of intervention programs. Numerical simulations conducted using MATLAB and MAPLE validated the analytical results, demonstrating consistency between theoretical predictions and simulated epidemic trajectories. The agreement

between analytical and numerical findings strengthens the reliability of the model and its potential application in real-world decision-making.

Overall, this study contributes to the growing body of mathematical epidemiology literature by providing a treatment-focused framework for understanding Lassa fever transmission. The results emphasize that treatment interventions, improved recovery mechanisms, and reduced human contact rates collectively offer the most effective pathway for controlling the disease. These insights can guide national Lassa fever control programs in designing cost-effective strategies, optimizing resource allocation, and prioritizing interventions with the greatest epidemiological impact. Future work may extend this model by incorporating stochastic effects, spatial heterogeneity, or rodent population dynamics to further enhance predictive accuracy and policy relevance.

9.0 Conclusion

In this project, we have successfully carried out the sensitivity analysis of treatment model of Lassa fever transmission in human and rodent population. Mathematically, we have shown that it is possible to control Lassa fever disease in Nigeria by treatment measure. We therefore conclude that early treatment measures have some influence in reducing the burden of Lassa fever. Also, it was concluded that the most sensitive parameter is the treatment rate, followed by human recovery rate, Lassa fever induced-death then person to person contact.

10.0 Recommendations

The following recommendations are made:

1. We recommend possible public health interventions based on the result of this study. This result obtained in this work can be a useful guide for the local national control programme on Lassa fever, decide on the framework for planning and designing the cost-effective strategies for the best intervention packages in eliminating Lassa fever in Nigeria.
2. Finally, we recommend that relevant health agencies of government (such as NCDC) should bring about rapid control of Lassa fever through the results of this study as well as increasing capacity for early detection. More so, we recommend a research collaboration between mathematical epidemiologists and other medical researchers such as epidemiologists, virologists, microbiologists, etc.
3. The result of the sensitivity analysis shows that the most sensitive parameter is the treatment rate, followed by human recovery rate, then person to person contact. This suggests that control strategies should target effective drugs for treatment and education to reduce person to person contact.

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Safeguarding Digital Infrastructure for the Effective, Sustainable Development of Secondary Education in Orlu LGA

Cyprian Chiadi Enwerem¹

¹*Department of Educational Management / University of Agriculture and Environmental Sciences, Umuagwo, Imo State*

Abstract:

Background: *The integration of digital technologies into the educational sector offers significant potential for transforming learning delivery, administrative processes, and policy implementation, particularly in developing regions. This study investigated the extent to which digital infrastructures in secondary schools in Orlu Local Government Area (LGA) of Imo State are safe, secure, and adequately safeguarded for sustainable educational development. Anchored on the Technological Determinism Theory, the study adopted a descriptive survey design with a sample size of 156 respondents comprising principals and teachers. Data were collected using a validated instrument titled Safeguarding Digital Infrastructure for Effective Sustainable Development of Secondary Education Questionnaire (SDIESDSEQ). Findings revealed that digital infrastructure in Orlu LGA secondary schools is generally inadequate and insecure, with a grand mean of 2.33, indicating a low level of availability. Despite this, both teachers and principals agreed that safeguarding measures—such as digital security policies, cybersecurity training, and infrastructure maintenance—could significantly enhance the sustainable use of educational technology. Independent t-test analyses showed no significant difference between principals' and teachers' opinions on both the availability and safeguarding of digital infrastructure. The study concludes by emphasizing the need for proactive safeguarding frameworks and offers practical recommendations for achieving sustainable digital integration in secondary education.*

Conclusion: *The study concludes that while digital infrastructure in secondary schools within Orlu LGA is increasingly recognized as vital for sustainable educational development, its current availability and security status remain suboptimal. Both principals and teachers consistently reported that the digital infrastructure available is not adequately safeguarded, which poses a serious threat to the longevity, efficiency, and effectiveness of technology-based teaching and administration. However, the study also established a shared optimism among stakeholders about the possibility of safeguarding these infrastructures through structured interventions. Importantly, the absence of statistically significant differences in perception between principals and teachers suggests a collective awareness and readiness to support improvements in digital security practices. To ensure that digital transformation efforts in secondary schools yield long-term benefits, robust safeguarding mechanisms, sustained funding, capacity building, and contextualized strategies are urgently needed.*

Key Word: *Digital Infrastructure Security, Sustainable Development, Secondary Education, Imo State, Cybersecurity in schools, Digital Resilience, Technological Determinism*

1.0 Introduction

The integration of digital technologies into educational systems represents a transformative opportunity for improving educational access, quality, and administration across developing regions (Olayemi, 2022). In Nigeria, and specifically in Orlu LGA in Imo State, digital infrastructure has been the yearning desires of many school administrators and stakeholders, which foster increasing deployment of the tools to enhance secondary education delivery, administrative efficiency, and data-driven decision-making (Nwabueze & Onyekwere, 2023). Despite this promising trend, the sustainability of these digital investments faces significant challenges related to security vulnerabilities, insufficient protection mechanisms, and inadequate maintenance protocols (Okoli & Ezenwaji, 2021).

According to the Nigerian Educational Research and Development Council (NERDC), 67% of digital infrastructure investments in education fail to achieve their intended long-term impacts due to security breaches, system failures, and maintenance deficiencies. This concerning statistic underscores the critical importance of safeguarding digital assets as a prerequisite for sustainable educational development.

While previous research has extensively examined the deployment of educational technologies in developing contexts (Adebayo, 2021; Nwachukwu et al., 2022), the specific intersection of digital infrastructure security and sustainable educational development remains under-investigated. This research gap is particularly evident where digital transformation initiatives in education have accelerated following the State Education Digitalization Strategy. This study addresses this knowledge gap by investigating the current state of digital infrastructure security in Orlu LGA in Imo State's secondary education sector and proposing contextually appropriate frameworks for enhancing the protection and sustainability of these critical assets.

1.1 Statement of the Problem

In the 21st century, digital infrastructure has become an essential driver of quality education, enabling access to digital tools, resources, and platforms that support teaching and learning processes. However, the state of digital infrastructure in secondary schools remains weak, inconsistent, and in some cases, entirely absent. The increasing reliance on digital technology in the education sector has exposed secondary schools in to the urgent need for robust and secure digital infrastructure that can support sustainable development in education.

Despite national and state efforts to integrate technology into the school system, many schools still operate without stable internet connectivity, updated ICT equipment, digital learning resources, or trained personnel to manage these technologies. Worse still, where digital infrastructure exists, it is often inadequately protected, leaving school systems vulnerable to cyber threats, misuse, or total breakdown due to poor maintenance. This lack of safeguarding mechanisms for digital tools and systems undermines their potential to contribute meaningfully to sustainable educational development. In Orlu LGA, there are schools that are experiencing technological or digital setbacks, not because the ICT tools were absent, but because they are damaged due to poor maintenance culture of the school administrators.

Furthermore, without effective safeguarding practices, investments in digital infrastructure risk becoming unsustainable, leading to repeated losses, system failures, and eventual abandonment of technology-driven educational initiatives. This situation poses a serious threat to the goal of achieving inclusive, equitable, and quality education for all, as envisioned in global and national educational development strategies. It is therefore imperative to investigate how safeguarding digital infrastructure can significantly enhance the effectiveness and sustainability of secondary education in Orlu LGA, Imo State.

1.2 Aim and objectives of the study

The aim of the study is to find out how safeguarding digital infrastructure enhances effective, sustainable development of secondary education in Orlu LGA in Imo State. The study determined the following objectives:

1. Assess how available digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State?
2. How can digital infrastructures be safeguarded for the sustainable development of secondary schools in Orlu LGA in Imo State.

1.3 Research questions

The following research questions guided the study.

1. To what extent are available digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State?
2. How can digital infrastructures be safeguarded for sustainable development of secondary schools in Orlu LGA in Imo State?

1.4 Hypotheses

The following hypotheses will be tested at 0.05 level of significance.

1. There is no significance difference between the opinion mean responses of principals and teachers on the safety state of digital infrastructures in secondary schools for sustainable development in Orlu LGA in Imo State.
2. There is no significance difference between the opinion mean responses of principals and teachers on how digital infrastructures can be safeguarded in secondary schools for sustainable development in Orlu LGA in Imo State.

2.0 Literature Review

2.1 Digital Infrastructure in Secondary Education

The integration of digital technologies into secondary education systems represents a global trend with particularly transformative potential for developing regions (World Bank, 2022). Digital infrastructure investments in education have been linked to improved learning outcomes, enhanced administrative efficiency, and expanded educational access. However, as Adebayo(2021)notes, the sustainability of these digital initiatives depends heavily on contextual factors including security frameworks, technical capacity, and institutional support mechanisms.In Nigeria, the National Policy on Education Technology (Federal Ministry of Education, 2022) established ambitious targets for digital integration across all educational levels, with particular emphasis on secondary schools as critical transition points to higher education and workforce entry. Nwachukwu et al. (2022) documented the implementation progress of this policy, noting substantial investments in hardware, connectivity, and digital content across Nigeria's geopolitical zones, while highlighting significant regional disparities in digital readiness.Focusing specifically on Imo State, Ndukwe (2021) conducted a comprehensive assessment of digital infrastructure deployment across 68 secondary schools, finding that while 78% had received some form of digital equipment (primarily computer laboratories and administrative systems), only 43% reported functional and regularly utilized digital resources. This implementation gap was attributed to multiple factors, including infrastructure challenges, capacity limitations, and notably, security concerns that undermined confidence in digital systems.

2.2 Securing Digital Infrastructure for Sustainable Educational Development

The protection of digital assets is a critical dimension of sustainable technology integration in education systems. Obasi (2018) proposed a conceptual framework for understanding digital security in educational contexts, encompassing physical protection of hardware, cybersecurity measures for networks and data, and governance protocols for system access and usage. Their research in southeastern Nigerian schools revealed that comprehensive security frameworks were often neglected during technology deployment, resulting in significant vulnerabilities.

Iwu and Ike (2022) examined specific security threats facing educational institutions in West Africa and identified unauthorized access (reported by 76% of surveyed institutions), data breaches (64%), and system failures due to inadequate protection (58%) as the most prevalent challenges. These findings align with global patterns documented by the International Association for Technology in Education (IATE, 2023), which highlighted educational institutions as increasingly targeted for cyberattacks due to their valuable data assets and typically weaker security infrastructures compared to commercial organizations.

The relationship between digital security and sustainable educational development was further explored by Okafor and Anyanwu (2023), who conducted a study involving 32 secondary schools in eastern Nigeria. Their findings established a strong correlation between robust security measures and the long-term functionality of digital infrastructure. Schools with adequately protected systems demonstrated **3.8 times longer operational lifespans** and **2.6 times higher utilization rates** compared to those with poorly secured digital environments. These results emphasize the importance of safeguarding digital infrastructure as a prerequisite for sustainable educational development.

2.3 Challenges and Opportunities

Enrollment increasing by 34% between 2018 and 2022, placing additional pressures on infrastructure and administrative systems. The State Education Digitalization Strategy 2019-2025 (Imo State Ministry of Education, 2019) responded to these challenges by prioritizing technology integration, with specific components addressing school management systems, learning platforms, and assessment frameworks. Eze & Umeano (2020) conducted a situational analysis of digital readiness across Imo State's education sector, highlighting significant variations between urban and rural communities, with rural schools facing compounded challenges related to power stability, connectivity, and technical support availability. Their research indicated that these contextual constraints directly impacted security practices, with resource-constrained schools often neglecting essential protection measures due to competing priorities and limited awareness.The potential for innovative, resource-appropriate security approaches was examined by Adeoye& Adeniji (2020)who documented successful case studies of school-level security initiatives in southeastern Nigeria. Their research highlighted promising practices including community-based protection arrangements, peer learning networks for technical capacity building, and adapted security protocols that accounted for local constraints while maintaining essential protection standards.

3.0 Theoretical Framework

The study was anchored on technological determinism theory propounded by Thorstein Veblen in the early 20th century, but it was later developed and popularized by Marshall McLuhan in 1960s and others. Technological Determinism theory posits that technological advancement drives social change and development. It argues that the development and deployment of technology shape human behaviour, institutional structures, and education systems. This theory supports the idea that the availability and protection (safeguarding) of digital infrastructure (such as internet connectivity, ICT tools, cybersecurity, digital learning platforms, etc.) directly influences the sustainable development of secondary education. In other words, when digital infrastructure is protected and efficiently used, it catalyzes educational growth and development. Safeguarding digital infrastructure ensures continuous, reliable, and secure use of technology in education, which is crucial for sustainability and effectiveness in secondary education.

3.1 Methodology

The study adopted descriptive survey research design, to examine safeguarding digital infrastructure for effective sustainable development of secondary education in Orlu LGA in Imo State. The population of the study comprised all the 498 teachers and 23 principals of secondary schools in Orlu LGA in Imo State, making a total of 521 target population. The sample size of the study is 30% of the total population size, comprising 149 teachers and 7 seven principals making a total of 156 respondents. As well stratified random sampling technique were used for the study. The instrument for data collection was “Safeguarding Digital Infrastructure for Effective Sustainable Development of Secondary Education Questionnaire (SDIESDSEQ)”. The instrument was validated by two experts and the reliability coefficient index was 0.77. Mean and standard deviation were used to answer the research questions while t-test was used to test the hypotheses at 0.05 level of significance.

Results and Discussion

Research question one: To what extent are available digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State?

Table: 1.0: Summary of mean responses of principals and teachers on extent the available digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State.

| S/N | To what extent are the available digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State? | Principals (n=7) | | Teachers (n=149) | | Mean Set | Remark |
|-----|---|------------------|-------------|------------------|-------------|-------------|----------------------|
| | | Mean | SD | Mean | SD | | |
| 1. | Physical security measures (locks, alarms,) protecting digital equipment in your school | 2.26 | 0.85 | 2.41 | 0.88 | 2.34 | Not Available |
| 2. | Computers (desktops and Laptops) and networks. | 2.39 | 0.6 | 2.15 | 0.75 | 2.27 | Not Available |
| 3. | Surveillance Cameras | 2.34 | 1.04 | 2.28 | 0.99 | 2.31 | Not Available |
| 4. | School generators/UPS | 2.48 | 0.87 | 2.46 | 0.84 | 2.47 | Not Available |
| 5. | The internet connection devices: Wi-Fi modem and mobile hotspot | 2.43 | 0.94 | 2.47 | 0.92 | 2.45 | Not Available |
| 6. | Software CDs and Flash drives. | 2.14 | 0.84 | 2.18 | 0.72 | 2.16 | Not Available |
| 7. | Printers, photocopier and scanners | 2.42 | 0.65 | 2.17 | 0.91 | 2.30 | Not Available |
| 8. | Projectors/Interactive board | 2.35 | 0.66 | 2.13 | 0.81 | 2.24 | Not Available |
| 9. | School telephone | 2.44 | 0.67 | 2.45 | 0.83 | 2.45 | Not Available |
| 10. | Television and multimedia speakers | 2.35 | 0.74 | 2.28 | 0.84 | 2.32 | Not Available |
| | Grand Total | 2.36 | 0.79 | 2.30 | 0.85 | 2.33 | Not Available |

The table above shows that both principals and teachers indicated that there is no availability of digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State to a high extent (Mean=2.33). The table also revealed that opinion mean responses of principal on is slightly higher (Mean=2.36, SD=0.79) than that of the teachers (Mean=2.30, SD=0.85) on the extent of availability of digital infrastructure safe or secure for sustainable development of secondary schools in Orlu LGA in Imo State.

Research question two: How can digital infrastructures be safeguarded for sustainable development of secondary schools in Orlu LGA in Imo State?

Table 2.0: Summary of Mean Responses of Principals and Teachers on How Digital Infrastructures Can Be Safeguarded for Sustainable Development of Secondary Schools in Orlu LGA, Imo State

| S/N | How can digital infrastructures be safeguarded for sustainable development of secondary schools in Orlu LGA in Imo State? | Principals (n=7) | | Teachers (n=149) | | Mean Set | Remark |
|-----|---|------------------|-------------|------------------|-------------|-------------|---------------|
| | | Mean | SD | Mean | SD | | |
| 1. | Implementing a comprehensive school-wide digital security policy | 2.57 | 0.9 | 2.51 | 0.86 | 2.54 | Agreed |
| 2. | Installing advanced physical security systems (biometric access, CCTV) | 2.84 | 0.71 | 2.72 | 0.65 | 2.78 | Agreed |
| 3. | Conducting regular security audits and vulnerability assessments | 2.72 | 0.95 | 2.63 | 1 | 2.68 | Agreed |
| 4. | Providing mandatory cybersecurity training for all staff | 3.09 | 0.9 | 2.76 | 0.88 | 2.93 | Agreed |
| 5. | Integrating digital citizenship and security awareness in student curriculum | 2.99 | 0.88 | 3.25 | 0.92 | 3.12 | Agreed |
| 6. | Establishing partnerships with cybersecurity firms or government agencies | 2.65 | 0.75 | 2.56 | 0.78 | 2.61 | Agreed |
| 7. | Implementing cloud-based secure backup solutions | 2.66 | 0.75 | 2.61 | 0.77 | 2.64 | Agreed |
| 8. | Creating a dedicated IT security position/team | 2.71 | 0.82 | 2.72 | 0.78 | 2.72 | Agreed |
| 9. | Developing a sustainable funding model for digital security | 2.52 | 0.61 | 2.55 | 0.75 | 2.54 | Agreed |
| 10. | Building a community of practice among schools to share security best practices | 2.84 | 0.75 | 2.82 | 0.83 | 2.83 | Agreed |
| | Grand Total | 2.76 | 0.80 | 2.71 | 0.82 | 2.74 | Agreed |

The table above shows that both principals and teachers agreed that digital infrastructures can be safeguarded for sustainable development of secondary schools in Orlu LGA in Imo State (Mean=2.74). The table also revealed that the opinion means responses of principal of (Mean=2.76, SD=0.80) is slightly higher than that of the teachers (Mean=2.71, SD=0.82) on how digital infrastructures can be safeguarded for sustainable development of secondary schools in Orlu LGA in Imo State.

Hypotheses

The following hypotheses will be tested at 0.05 level of significance.

H01: There is no significance difference between the mean opinion responses of principals and teachers on the safety state of digital infrastructures in secondary schools for sustainable development in Orlu LGA in Imo State.

Table 3.0: Summary of t-test on the opinion mean responses of principals and teachers on the safety state of digital infrastructures in secondary schools for sustainable development in Orlu LGA in Imo State.

| Designation | N | Mean | SD | Df | t-test | Sig. | Remark |
|-------------|-----|------|------|-----|--------|-------|--------|
| Principals | 7 | 2.36 | 0.79 | 154 | 0.596 | 0.552 | NS |
| Teachers | 149 | 2.30 | 0.85 | | | | |
| | | | | | | | |

NS= Not Significant

The table above showed the mean scores of principals is 2.36 and the standard deviation is 0.79, while the mean scores of teachers is 2.30 and the standard deviation is 0.85. The t-test calculated value is 0.596, the corresponded significance value is 0.552 showing > 0.05 at 148 degrees of freedom. Hence, it is concluded that there is no significant between the mean opinion responses of principals and teachers on the safety state of digital infrastructures in secondary schools for sustainable development in Orlu LGA in Imo State. Therefore, the null hypothesis one is retained at 0.05 level of significance.

H02: There is no significance difference between the mean opinion responses of principals and teachers on how digital infrastructures can be safeguarded in secondary schools for sustainable development in Orlu LGA in Imo State.

Table 4.0: Summary of t-Test on the Opinion Mean Responses of Principals and Teachers on How Digital Infrastructures Can Be Safeguarded

| Designation | N | Mean | SD | Df | t-test | Sig. | Remark |
|-------------|-----|------|------|-----|--------|------|--------|
| Principals | 7 | 2.76 | 0.80 | 154 | | | NS |
| Teachers | 149 | 2.71 | 0.82 | | | | |

NS= Not Significant

The table above showed the mean scores of principals is 2.76 and the standard deviation is 0.80, while the mean scores of teachers is 2.71 and the standard deviation is 0.82. The t-test calculated value is 0.596, the corresponded significance value is 0.552 showing > 0.05 at 154degrees of freedom. Hence, it is concluded that there is no significance difference between the mean opinion responses of principals and teachers on how digital infrastructures can be safeguarded in secondary schools for sustainable development in Orlu LGA in Imo State. Therefore, the null hypothesis twois retained at 0.05 level of significance.

4.0 Recommendations

Based on the findings of the study, the researcher recommends the following:

1. The Imo State Ministry of Education and relevant authorities should increase funding for the provision and maintenance of secure digital infrastructure in secondary schools, including reliable internet access, surveillance systems, and ICT tools.
2. Schools should implement comprehensive digital security policies that outline protocols for hardware safety, network protection, data management, and incident response procedures. Hence, regular and mandatory cybersecurity training should be provided for school staff to enhance their awareness of digital threats and best practices for preventing system breaches or misuse.
3. Educational administrators should institutionalize routine audits and vulnerability assessments of ICT systems to ensure compliance with digital security standards and identify gaps requiring attention.

4.1 Discussion

The findings from the analysis provide insightful revelations concerning the state and safeguarding of digital infrastructure for sustainable development in secondary schools in Orlu Local Government Area (LGA) of Imo State. The study sought to assess both the availability and the potential for safeguarding digital infrastructure in these schools from the perspectives of principals and teachers.

The first part of the findings shows that both principals and teachers perceived that digital infrastructure that is safe and secure for sustainable development is not adequately available in the secondary schools in Orlu LGA. The overall mean score of 2.33 indicates a low level of availability. A closer look at the mean responses shows that principals suggesting that while both groups acknowledged the inadequacy, principals held a marginally more favorable perception of the current situation. Furthermore, a comparison between principals and teachers also revealed a minor difference in perception, with principals reporting a mean of 2.36 and teachers 2.30. However, when a t-test was conducted to determine if these differences were statistically significant, the result ($t = 0.596, p = 0.552$) indicated no significant difference in the mean responses at 148 degrees of freedom and the 0.05 level of significance. Therefore, the null hypothesis which stated that there is no significant difference in the opinions of principals and teachers on the availability of safe digital infrastructure was retained.

In the second part of the findings, both principals and teachers agreed that digital infrastructures can be safeguarded to promote sustainable development in secondary schools within the area. This is reflected in the overall mean score of 2.74. Again, principals exhibited a slightly higher mean score than teachers, indicating a slightly more optimistic view on safeguarding strategies. Similar trends were observed in the gender comparison, with principals recording a mean score and teachers. However, just like in the first analysis, the t-test result ($t = 0.596, p = 0.552$) was greater than the 0.05 threshold at 154 degrees of freedom. This implies that there is no statistically significant difference in the opinions of the two groups regarding how digital infrastructure can be safeguarded. As such, the second null hypothesis was also retained.

These findings suggest a general consensus among educators in Orlu LGA regarding the poor availability of secure digital infrastructure and the belief that, although the current infrastructure is inadequate, safeguarding measures are

possible if proper strategies are implemented. The lack of significant difference in responses across groups further reinforces the shared reality and collective understanding of the challenges and opportunities surrounding digital infrastructure in secondary education in the region. This highlights the urgent need for government and education stakeholders to invest in the provision and protection of digital tools and facilities to foster long-term educational sustainability.

4.2 Conclusion

The study concludes that while digital infrastructure in secondary schools within Orlu LGA is increasingly recognized as vital for sustainable educational development, its current availability and security status remain suboptimal. Both principals and teachers consistently reported that the digital infrastructure available is not adequately safeguarded, which poses a serious threat to the longevity, efficiency, and effectiveness of technology-based teaching and administration. However, the study also established a shared optimism among stakeholders about the possibility of safeguarding these infrastructures through structured interventions. Importantly, the absence of statistically significant differences in perception between principals and teachers suggests a collective awareness and readiness to support improvements in digital security practices. To ensure that digital transformation efforts in secondary schools yield long-term benefits, robust safeguarding mechanisms, sustained funding, capacity building, and contextualized strategies are urgently needed.

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Game Theory and AI assisted optimization system for Telecom adverts and service promotion

Achugamonu, Pius Chukwuma¹; Uzoma, Ozioma Peter²; Ihim, Kingsley Chukwunazom³;
Okorie, Simon C.⁴; Nwachukwu, Wisdom Ezechinyereugo⁵; Alabi, Sunday Adebayo⁶; Ozor
Chidinma Chioma⁷

¹Department of Mathematics / Alvan Ikoku Federal University of Education Owerri, Imo State.

^{2,3,4,5,6}Department of Computer Science / Alvan Ikoku Federal University of Education,
Owerri, Imo State

⁷Department of Computer Science / Delta state Maritime Polytechnic, Burutu,
Delta State.

Abstract:

Background: This research work aimed to investigate the optimal maximization of resources using AI assisted algorithm for the two leading communication networks in the country (MTN and GLOBACOM) when advertising their products and services within the country. However, data were collected from the existing records of (MTN and GLOBACOM), other publications both in newspapers and the internet, and finally an oral interview with the managers. A model was formulated to determine an optimal resource allocation and the data collected were analyzed using the simplex method and duality theorem to obtain an optimum benefit for the two telecommunications. However a program was designed to monitor the advert and service promotions within districts. Finally, the result of the analysis showed that for optimum performance MTN should invest the NX they have in the advertisement only and nothing in service promotion. If it is done in this way, they will obtain an optimum benefit value of N(230) X million naira. Similarly, GLOBACOM should invest her NY only in service promotion and nothing in the advertisement. This will yield an optimum benefit value of N(390) Y million. Recommendations were made to help the companies function effectively.

Materials and Methods: Data for this study were obtained from multiple sources to ensure reliability and representativeness. These included: - Historical financial and operational records from MTN Nigeria and GLOBACOM Nigeria. - Published reports from newspapers, telecom regulatory bulletins, and online repositories. - Oral interviews conducted with marketing and operations managers from both telecommunications companies.
Model Formulation.

Results: The simplex analysis revealed that MTN achieves maximum benefit when:- All available resources (NX) are allocated exclusively to advertisement, - Zero allocation is made to service promotion. Under this strategy, MTN obtains an optimum benefit of: This indicates that advertisement yields significantly higher marginal returns for MTN compared to service promotion.

Conclusion: This study demonstrates that game theory combined with AI-assisted optimization provides a powerful framework for resource allocation in the telecommunications sector. The findings show that MTN maximizes its benefit by focusing entirely on advertisement, while GLOBACOM achieves optimal performance by concentrating on service promotion. The AI-based monitoring system further enhances strategic planning by providing real-time insights and predictive analytics. Implementing these optimized strategies can significantly improve operational efficiency, reduce unnecessary expenditure, and strengthen competitive positioning within the Nigerian telecom market.

Key Word: Game Theory; AI Optimization; Telecom Marketing; Resource Allocation; Simplex Method; Duality Theorem; MTN; GLOBACOM; Advertisement Strategy; Service Promotion; Machine Learning; Operations Research.

1.0 Introduction

According to the Operations Research Society of Great Britain, Operations Research is defined as the application of the method of science to complex problems, arising in the direction and management of large systems of men, machines, materials, and money in industry, business, government, and Defense (ORSGB). The distinctive approach is to develop a scientific model of the system in cooperating measurement of factors such as chance and risk with which to predict and compare the outcome of alternative decisions, strategies, and controls. The purpose is to help management determine its policy and actions scientifically.

Among the areas of Operations Research that aid in human interaction and decision making for improvement of organization and management is the "Game Theory." Game Theory is a field of study that focuses on human interactions within specified rules of play and alternative choices. Its language includes concepts such as coalitions, markets, payoff, and votes, concepts that permeate our everyday lives and help shape our "real world" experiences. Yet the mathematical rigor of game theory, together with its many solution notions, has limited its appeal to mainstream economists and caused some critics to question the ability of game theory to identify a notion that "truly" describes a human behavior (Aumann 1985; Goree and Holt 2001). Indeed, one of these solution notions is the Nash equilibrium, a payoff point at which firms reach and maintain their position. This position can be illustrated by deriving a series of mathematical equations and proofs, or it can be demonstrated with a model structure known as the normal or strategic form.

Inyama 2007 supported (Aumann, Goree, and Holt by defining Game Theory as a mathematical theory that deals with the general features of a competition situation. Though, according to Inyama (2007), this situation involves making decisions under Uncertainty, which involves two or more players and each player aims at optimizing their own decision at the expense of the other players. There are many strategies involved in optimizing a decision at the expense of another player, and one of these strategies is "Advertisement."

One Possible Application of "Game Theory" is in advertising. Advertisement involves the promotion of products and services so as to expose the product or service to a greater number of people.

The goal of advertising is to make more people aware of a company's product or service so that more people would avail themselves of the product, and this would mean more revenue for the company. One way a company can approach this goal is to expand the current market of consumers.

This entails directing promotional activities to consumers who have never tried the service or anything similar to it. Another way is to target the current market in the hope of increasing market shares. This means that there is a base of consumers currently using the product or service, but there are other companies offering the same product or service, and the company would like to increase the percentage of people availing of their particular company's product. This is the case where Game Theory is applicable. There are other entities a company can consider as competitors. The company competes with these entities for a share of the market. These entities include other companies that produce the same or similar products or services. Other potential competitors are companies that produce substitutes or complements to the service, new entrants to the industry, suppliers of the company, and distributors of the company.

Game Theory deals with competitive situations such as these and emphasizes the decision-making process of the competitors. The strategy the company will use is composed of the decisions it will make at every stage of the process. In the case of advertising, the company must decide how much to spend in a certain region. For example, the overall goal of using game theory in advertising is to determine how best to spend advertising money in order to capture market share from other adversaries. To apply Game Theory to advertising, adversaries must be defined; there is the company itself, and next is their main direct competitor. Other adversaries may be smaller competitors, companies producing substitutes or complements, new entrants, suppliers or distributors once this is done, the strategies of each adversary must be defined.

1.1 Problems of the Study

In any business communications, interactions with customers, suppliers, other business partners and competitors, as well as interactions across people and different organizations within the firm, play an integral role in any decision and its consequences. However, advertisement of products and services have been broadening this interaction by increasing the degree of connectivity between different parties involved in the communication industries and their decision taken have become a problem to be investigated.

1.2 Objective of the Study

The primary objective of this research work is to:

1. Optimize advertising and service-promotion budgets
2. Maximize financial benefits from promotional investments
3. Monitor campaign performance across districts
4. Provide actionable insights and management recommendations

1.3 Scope of Work

Data Management

1. Budget input for advertising and service promotion
2. Historical and operational data integration
3. Secure data storage and retrieval

AI & Optimization Engine

1. Mathematical model formulation
2. Implementation of Simplex Method
3. Duality analysis
4. Automated optimal decision generation

2.0 Application of Game Theory

Game theory is the study of the ways in which strategic interactions among rational players produce outcomes with respect to the preferences (or utilities) of those players. However, the theory provides a structured game-play approach to many important problems arising in signal processing and communications, notably resource allocation and distributed transceiver optimization. Recent applications of game theory occur in other emerging fields such as cognitive radio, spectrum sharing, and multi-hop sensor and Ad-hoc Networks. It is also used in cross-layer optimization where radio resource management on the physical layer is connected with economic decisions on service and application layers. EURASIP (2009).

In the extensive application, the theory is a useful technique for companies to rapidly respond to changes in prices, products, and technologies. It helps companies pay attention to interactions with competitors, customers, and suppliers, and induces companies to focus on the end-game so that their near-term actions promote their long-term interest by influencing what these players do. For instance, in the context of this research work, between MTN and GLO. There are two competitors, MTN expects GLO to enter the advertising market and is trying to understand GLO's likely pricing strategy.

2.1 Districts of Adverts

MTN has branches in all thirty-six states of the country, while GLOBACOM has twenty-six in the thirty-six states of the country as of the time of research. This means that no account will be given for the remaining ten states since GLO does not exist within the environment. But they watch GLO adverts on international television in DSTV, CTL, MYTV, and HI-TV digital components.

2.2 Advert Expenditure on Districts

For identification purposes, the letters of the alphabet will be used on GLO, on districts, while numerals will be used on MTN. The figures in the table are in millions of naira as of 2025.

Table No 1: GLOBACOM’s District-Level Expenditure on Service Promotion and Advertisement

| District | Service Promotion (HALF OF TEN₦) | Advert (Half of Ten₦) |
|--------------|----------------------------------|-----------------------|
| A | 16.354 | 1.340 |
| B | 14.110 | .918 |
| C | 17.100 | 1.567 |
| D | 15.819 | 1.110 |
| E | 16.114 | 1.234 |
| F | 17.006 | 1.671 |
| G | 16.183 | 1.181 |
| H | 15.001 | .998 |
| I | 14.889 | .876 |
| J | 13.679 | .911 |
| K | 12.181 | .876 |
| L | 11.414 | .748 |
| M | 11.001 | .814 |
| N | 10.818 | .766 |
| O | 16.134 | 1.218 |
| P | 15.671 | 1.384 |
| Q | 8.113 | .947 |
| R | 7.889 | .641 |
| S | 10.114 | .871 |
| T | 9.625 | .711 |
| U | 6.413 | .411 |
| V | 7.716 | .512 |
| W | 8.116 | .761 |
| X | 9.144 | .614 |
| Y | 7.614 | .613 |
| Z | 8.211 | .711 |
| Total | 316,426 | 23,407 |

Table No 2: MTN’s District-Level Expenditure on Service Promotion and Advertisement

| District | Service Promotion (Half of Ten₦) | Advert (Half of Ten₦) |
|----------|----------------------------------|-----------------------|
| 1 | 20.814 | 1.899 |
| 2 | 19.216 | 2.110 |
| 3 | 21.667 | 1.870 |
| 4 | 18.007 | 1.770 |
| 5 | 22.110 | 2.300 |
| 6 | 17.667 | 1.800 |
| 7 | 180.414 | 1.100 |
| 8 | 17.009 | .976 |
| 9 | 16.918 | .941 |
| 10 | 16.118 | .843 |
| 11 | 17.191 | .991 |
| 12 | 21.503 | 1.211 |
| 13 | 20.009 | 1.018 |
| 14 | 19.816 | 1.140 |
| 15 | 18.996 | 1.760 |
| 16 | 17.410 | .902 |
| 17 | 16.871 | .871 |
| 18 | 17.098 | .971 |
| 19 | 14.021 | .677 |
| 20 | 15.614 | .817 |
| 21 | 14.081 | .798 |
| 22 | 11.701 | .489 |
| 23 | 16.882 | .766 |
| 24 | 16.001 | .817 |
| 25 | 13.810 | .697 |

| | | |
|--------------|----------------|---------------|
| 26 | 14.001 | .567 |
| 27 | 15.219 | .777 |
| 28 | 13.489 | .879 |
| 29 | 15.202 | .916 |
| 30 | 17.010 | .998 |
| 31 | 16.910 | .901 |
| 32 | 16.002 | .890 |
| 33 | 17.089 | .961 |
| 34 | 16.199 | .977 |
| 35 | 15.890 | .871 |
| 36 | 14.713 | .791 |
| Total | 801.477 | 39.062 |

Though the researcher is investigating in the matter to find out whether or not the objectives of advertising products and service promotion could be optimized even under worst competitive situations due to the other company's presence, but an observation was found that the decisions of the executives of the company has a lot of influence in the money allocation to advertise of products and service promotion within a district and not on the effect of the other's appearance within the environment or district.

Based on this, the researcher thinks that the model below will go a long way in the decision of the executives if it is absorbed by the companies.

3.0 Problem Identification

Consider two telecommunication companies

- A. MTN Nigeria Limited
- B. GLOBACOM Limited.

Company 'A' (MTN) has ₦ 'X' while company B (GLO) has ₦ 'Y' available for advertisement and service promotion.

The country has been divided into 'M' states, which is the same for both companies in state 'I', the service potential is 'Si', and the service potential is actually achieved in each state, regardless of the total amount of service promotion and advertisement devoted to the state.

Assuming that all telecommunication products and services need to be shared between the two competitors in proportion to the amount spent on promotion within the state, and then we are confronted with two important questions.

- i. How would the competitors divide their promotion funds among the states?
- ii. Assuming that GLOBACOM's allocations to states are arrived by executive orders and not by optimal allocations, and assuming that MTN knows about GLOBACOM's allocations, how will MTN react to take advantage of? Globacom's allocations are not optimal? Going by these questions, it will help the researcher derive a set of model equations for optimal B. it is also necessary to find out mathematically the payoffs accruing to each company for allocating resources optimally.

3.1 Solution of the problem

Let x_i = amount spent by A in state $i(i=1,2,3,...m)$

y_i = Amount by B in state $i(i=1,2,3,...m)$ where

$$\sum_{i=1}^m x_i = x, \sum_{i=1}^m y_i = y, \sum_{i=1}^m S_i = S,$$

The total amount of service sales by "A" will be

$$\sum_{i=1}^m \left(\frac{x_i}{x_i+y_i} \right) S_i \quad 3.1.1$$

And the total amount of service sales by “B” will be

$$\sum_{i=1}^m \left(\frac{y_i}{x_i+y_i} \right) S_i \quad 3.1.2$$

A. Since the total amount of service sales (s) is constant, “A” will minimize his total sales if and only if he maximizes the differences between his sales and “B” sales. That is “A” will wish to maximize the quantity D, where

$$D = \sum_{i=1}^m \left(\frac{x_i-y_i}{x_i+y_i} \right) S_i \quad 3.1.3$$

Thus A’s pay-off is $D(x_1, x_2, \dots, x_m, y_1, y_2, \dots, y_m)$

And B’s pay-off is $D(x_1, x_2, \dots, x_m, y_1, y_2, \dots, y_m)$

The solution to this problem (that is, the optimal strategy that can be applied by A and B) is

$$x_i = s_i \cdot X \quad 3.1.4$$

$$y_i = s_i \cdot y \quad 3.1.5$$

Putting equations (3.1.4) and (3.1.5) into (3.1.3) we obtain D as follows

$$D = \sum_{i=1}^m \left(\frac{\frac{s_i}{s} \cdot x - \frac{s_i}{s} \cdot y}{\frac{s_i}{s} \cdot x + \frac{s_i}{s} \cdot y} \right) S_i \quad 3.1.6$$

$$\left(\frac{x - y}{x + y} \right) \sum_{i=1}^m S_i$$

$$\text{Thus } D = \left(\frac{x-y}{x+y} \right) s \quad 3.1.7$$

Theorem

Equations (3.1.4) and (3.1.5) are the optimal solutions for each competitor

Proof: Suppose competitor A adopts strategy (3.1.4), but competitor B deviates slightly from (3.1.5) that is suppose

$$X_i = \frac{s_i}{s} \cdot x \text{ and } y_i = \frac{s_i}{s} \cdot y + \delta_i$$

Where each δ_i is small and tends to zero

$$\sum_{i=1}^m \delta_i \rightarrow 0 \quad 3.1.8$$

Then A’s pay-off is now D^1 and is given by the substitution of (3.1.4) and (3.1.8) into (3.1.6), if we do, we obtain

$$D^1 = \sum_{i=1}^m \left(\frac{s_i(x-y) - s\delta_i}{s_i(x+y) + s\delta_i} \right) \quad 3.1.9$$

We see that each term in (3.1.9) is of the form

$$k = \left(\frac{a-\varepsilon}{b+\varepsilon} \right) \text{ with small } \varepsilon$$

Where $K = s_i$

$$a = s_i(x - y)$$

$$b = s_i(x + y)$$

$$\varepsilon = s_i\delta$$

$$\text{By expansion } K \left(\frac{a-\varepsilon}{b+\varepsilon} \right)$$

$$= \frac{ka}{b} \left[1 - \frac{\varepsilon}{a} - \frac{\varepsilon}{b} + \left(\frac{1}{ab} + \frac{1}{b^2} \right) \varepsilon^2 \right] \quad 3.2.0$$

Hence (3.1.9) becomes

$$\begin{aligned}
 \mathbf{D}^1 &= \sum_{i=1}^m \left[\frac{s_i(x-y)}{s_i(x+y)} \right] \left[\frac{1-s\delta_i}{s_i(x-y)} - \frac{s\delta_i}{s_i(x+y)} \right] \\
 &\quad \left[\frac{1}{s_2(x+y)(x-y)} + x|s^2\delta_{i,2} \right] s_i(x+y) \\
 &= \sum_{i=1}^m \frac{(x-y)}{(x+y)} \left[s_1 \left(\frac{s}{x-y} + \frac{s}{x+y} \right) \delta_i + \left| \frac{s^2}{s_i(x^2-y^2)} + \frac{s^2}{s_i(x+y)2} \right| \delta_i^2 \right] \\
 &= \frac{(x-y)}{x+y} \left[\sum_{i=1}^m s_{i+} \left(\frac{s}{x-y} + \frac{s}{x+y} \right) \right] \sum_{i=1}^m \delta_i + s^2 \left[\frac{1}{x^2-y^2} + \frac{1}{(x+y)2} \right] \sum_{i=1}^m \frac{\delta_i^2}{s_i} \quad 3.2.1 \\
 &= \frac{(x-y)}{x+y} s + s^2 \left[\frac{1}{(x+y)2} + \frac{x-y}{(x+y)2} \right] \sum_{i=1}^m \frac{\delta_i^2}{s_i} \\
 \mathbf{D}^1 &= \mathbf{D} + \frac{s^2}{(x+y)2} \left[1 - \frac{x-y}{x+y} \right] \sum_{i=1}^m \frac{\delta_i^2}{s_i}
 \end{aligned}$$

Since every term in the bracket is intrinsically positive, $\mathbf{D}^1 > \mathbf{D}$

This implies that strategy (3.1.4) used by A is optimal.

iii. Here we examine (3.1.4) with respect to x_i ($y_i, y_n \dots y_m$) as parameter subject to:

$$\sum_{i=1}^m x_i = x$$

Here we use the lagrangian multiplier technique. The problem is

$$\text{Max } Z = \sum_{i=1}^m \frac{x_i - y_i}{x + y} s^i$$

Subject to

$$\sum_{i=1}^m x_i = x$$

Let the Lagrangian function be $L(x_i, \lambda) =$

$$\sum_{i=1}^m \left(\frac{x_i - y_i}{x + y} \right) s_i - \lambda \left(\sum_{i=1}^m x_i - x \right)$$

We differentiate with respect to each x^i and λ and equate to zero to obtain

$$2 \frac{s_i y_i}{(x_i - y_i)2} - \lambda = 0$$

Solving each of the equations for $x_i + y_i$ we have

$$x_i + y_i = \sqrt{2} \frac{s_i y_i}{\lambda}$$

Adding gives

$$\sum_{i=1}^m (x_i + y_i) = \sum_{i=1}^m \sqrt{\frac{2s_i y_i}{\lambda}}$$

$$X + Y = \sum_{i=1}^m \frac{\sqrt{2s_i y_i}}{[\sqrt{\lambda}]}$$

$$\sqrt{\lambda} = \sum_{i=1}^m \frac{\sqrt{2s_i y_i}}{[\sqrt{\lambda}]}$$

$$\lambda = \left[\sum_{i=1}^m \sqrt{2 \frac{s_i y_i}{x+y}} \right] \quad 3.2.3$$

Putting(3.2.3) in (3.2.2), we obtain

$$X_i + Y_i = \frac{\sqrt{2s_i y_i}}{1} \sum_{i=1}^m \frac{x + y}{\sqrt{2s_i y_i}}$$

$$= \frac{(x + y)\sqrt{2s_i y_i}}{\sum_{i=1}^m \sqrt{2s_i y_i}}$$

Therefore

$$\frac{(x + y)\sqrt{2s_i y_i}}{\sum_{i=1}^m \sqrt{2s_i y_i}} - y_i \quad 3.2.4$$

This is then the amount spent by A in state i.

4.0 Model Application

We once again consider the two telecommunication companies in Nigeria—MTN and GLOBACOM—both operating within the same region of influence, using the model previously developed and the data presented in Table 3.2.3. Suppose a certain amount (N X Million) is to be allocated between the two companies as a developmental grant, based on their net returns on investment. The investment purposes under consideration are:

- i. Advertisement
- ii. Service promotion

For the fact that both companies are to operate at an optimal level, the problem facing each company will be a way of finding the best way to maximize each of the above two areas. Precisely what each company strives to achieve, no matter what its opponent does.

Now, if we examine closely the cases presented in the table under Section 3.2.3 of this work, where the sum of N X Million is to be allocated to advertisement and service promotion for the telecommunication companies, the central problem becomes clear. Our task is to determine how best to apportion the N X Million among the various purposes in order to optimize both objectives simultaneously, even under the most conflicting competitive conditions.

Based on the figures obtained from the companies, we can construct a table to represent the values as follows.

Table No 4.1.1: Total amount spent by the companies

| Objectives | Advertisement | Service Promotion |
|------------|---------------|-------------------|
| GLOBACOM | 23,407.000 | 316,426,00 |

| | | |
|-----|------------|------------|
| MTN | 39,062.000 | 801,477,00 |
|-----|------------|------------|

Table No 4.1.2: Approximated Values of Table 4.1.1

| Objectives | Advertisement | Service Promotion |
|------------|---------------|-------------------|
| GLOBACOM | 23 | 32 |
| MTN | 39 | 80 |

What we have in **Table 4.1.1** is basically a game solution; now we can solve the game to determine its value.

4.2 Solution

The entries are the elements of the payoff matrix in a two-person (duopolistic) game, where the objectives are the strategies of the players. The value of the probabilities determined by the optimal amount apportionable to each purpose while maximizing the two objectives simultaneously from the maximizer’s point of view. We can solve the game as follows:

- Let y_1 represent, advertisement
- Let y_2 represent service promotion
- Let v represent the value of the game

With entries in the game matrix (**Table 4.2.2**), we have the following linear programming problem for MTN’s solution.

4.3 MTN’s Solution

$$\text{Max } y_0 = y_1 + y_2$$

Subject to:

$$\begin{aligned} 23 y_1 + 32 y_2 &\leq 1 \\ 39 y_1 + 80 y_2 &\leq 1 \\ y_1, y_2 &\geq 0 \end{aligned}$$

Putting the LPP into standard form, we have:

$$\text{Max } y_0 = y_1 + y_2$$

Subject to:

$$\begin{aligned} 23 y_1 + 32 y_2 &= 1 \\ 39 y_1 + 80 y_2 &= 1 \\ y_1, y_2, s_1, s_2 &\geq 0 \end{aligned}$$

4.3.1 Simplex Method

| | Non-basic | Basic | | | | |
|-------|-----------|-------|-------|-------|-------|-------|
| Basic | y_0 | y_1 | y_2 | s_1 | s_2 | RHS |
| y_0 | (I) | 1 | 1 | 0 | 0 | 0 |
| s_1 | 0 | 23 | 32 | 1 | 0 | 1 |
| s_2 | 0 | 39 | 80 | 0 | 1 | 1 |
| y_0 | (I) | 9/32 | 0 | -1/32 | 0 | -1/32 |
| s_2 | 0 | -37/2 | 0 | -5/2 | 1 | -2/3 |
| y_2 | 0 | 23/32 | 1 | 1/32 | 0 | 1/32 |

| | | | | | | |
|-------|-----|---|-------|-----------|---|---------|
| y_0 | (1) | 0 | -9/23 | -763/2208 | 0 | -32/736 |
| y_1 | 0 | 1 | 32/23 | 1/23 | 0 | 1/23 |
| y_2 | 0 | 0 | 0 | 0 | 0 | 0 |

By this:

$$y_0 = -32/736; \text{ taking the absolute value of } 32/736$$

It becomes

$$32/736. y_0 = 1/23$$

$$y_1 = 1/23, y_2 = 0$$

Since we are maximizing:

$$v = 1/y_0, = 736/32 = 23$$

The required probabilities (proportions) are

$$y_1 = y_1/y_0 = 1/23 \times 23/1 = 1$$

$$y_2 = y_2/y_0 = 0/23/736 = 0/0 \times 736/32 = 0$$

Therefore, the sum of ₦ X Million developmental fund should be apportioned as follows:

- i. Advertisement $1 \times$ million
- ii. Service Promotion $0 \times$ million

When the ₦ X Million developmental fund is proportioned according to the above specification, the company will realize an optimum benefit.

4.4 GLOBACOM Solution

We can also solve GLO's problem by first converting it into a linear programming problem (LPP). GLO's minimization problem is the dual of MTN's maximization problem and by the duality theory, the conversion is as follows:

$$\text{Min } x_0 = x_1 + x_2$$

Subject to:

$$23x_1 + 39x_2 \geq 1$$

$$32x_1 + 80x_2 \geq 1$$

$$x_1, x_2 \geq 0$$

But in standard form, we have

$$\text{Min } x_0 = x_1 + x_2$$

$$\text{S.t: } 23x_1 + 39x_2 + s_1 = 1$$

$$32x_1 + 80x_2 + s_2 = 1$$

$$x_1, x_2, s_1, s_2 \geq 0$$

Multiplying by a negative sign

$$\text{Min } -x^1 = -x_1 - x_2$$

$$\text{S.t } -23x_1 - 39x_2 + s_1 = -1$$

$$-32x_1 - 80x_2 + s_2 = -1$$

4.4.1 Tableau Method

| | x_0^1 | x_1 | x_2 | s_1 | s_2 | RHS |
|---------|---------|-------|-------|-------|-------|-----|
| x_0^1 | (1) | -1 | -1 | 0 | 0 | 0 |
| s_1 | 0 | -23 | -39 | 1 | 0 | -1 |
| s_2 | 0 | -32 | 80 | 0 | 1 | -1 |

| Variable | X ₁ | X ₂ | S ₁ | X ₂ |
|-----------------------------|----------------|----------------|----------------|----------------|
| X ₀ ¹ | -1 | -1 | 0 | 0 |
| S ₁ row | -23 | -39 | 1 | 0 |
| Ratio | 1/23 | 1/39 | | |

| | X ₀ ¹ | X ₁ | X ₂ | S ₁ | S ₂ | RHS |
|-----------------------------|-----------------------------|----------------|----------------|----------------|----------------|-------|
| X ₀ ¹ | (1) | -16/39 | 0 | -1/39 | 0 | 1/39 |
| X ₂ | 0 | 23/39 | 1 | -1/39 | 0 | 1/39 |
| S ₂ | 0 | 592/39 | 0 | -80/39 | 1 | 41/39 |

By solving the (LPP) tableau, the following results were obtained.

$$X_0^1 = 1/39, x_1 = 0, x_2 = 1/39, s_1 = 0 = 41/39$$

Since we are maximizing

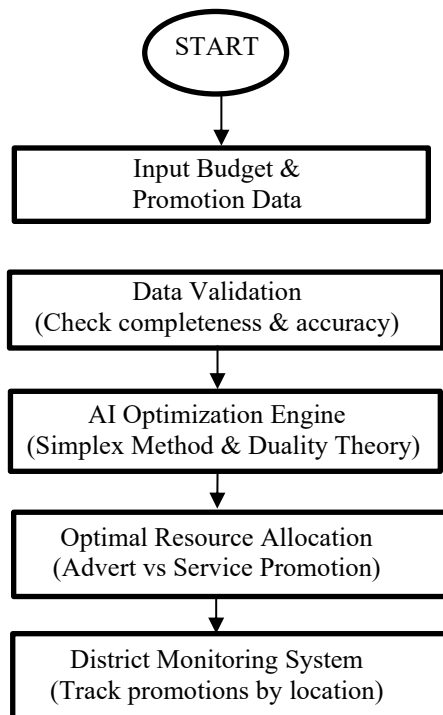
$$V = 1/x_0^1 \cdot 1/39 = 39.$$

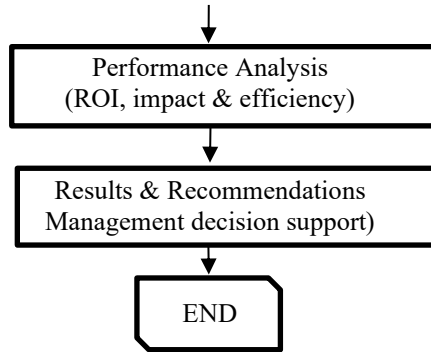
The required probabilities (proportions) are:

$$X_1 = x_1/x_0^1 = 0/1/39 = 0$$

$$X_2 = x_2/x_0^1 = 1/39/1/39 = 1/39 \times 39/1 = 1$$

4.5 System Workflow (Operational Flow)





AI-Assisted Optimization System for MTN & GLOBACOM Telecom Advertisement and Service Promotion
<https://kingjerry.pythonanywhere.com/>

4.6 Complete Python Program

4.6.1 Import Required Libraries

```

import numpy as np
import pandas as pd
from scipy.optimize import linprog
import matplotlib.pyplot as plt
from
    
```

Explanation

| Library | Function |
|-------------------------------|---|
| Numpy | Handles numerical operations |
| Pandas | Manages data tables and logs |
| scipy.optimize.linprog | Implements the Simplex Method |
| Matplotlib | Displays charts and graphs |
| Datetime | Records time-based promotion activities |

4.6.2 Define Input Data (Budgets & Benefits)

```

MTN_BUDGET = 1_000_000
GLO_BUDGET = 1_000_000
    
```

```

MTN_AD_BENEFIT = 230
MTN_SERVICE_BENEFIT = 120
    
```

```

GLO_AD_BENEFIT = 150
GLO_SERVICE_BENEFIT = 390
    
```

Explanation

- i. Expected returns from advertising and service promotion
- ii. Form objective function coefficients
- iii. Derived from historical records, marketing analysis, and management interviews

4.6.3 Input Validation Module

```
def validate_inputs(*inputs):  
    for value in inputs:  
        if value < 0:  
            raise ValueError("Input values must be non-negative")
```

Explanation

- i. Prevents negative budgets
- ii. Prevents invalid benefit values
- iii. Ensures accurate optimization results

4.6.4 Simplex Optimization Function

```
# linprog minimizes, so multiply by -1 c = [-  
ad_benefit, -service_benefit]  
  
# Constraint: x + y ≤ budget A = [[1,  
1]]  
b = [budget]  
  
# Non-negativity constraints bounds = [(0,  
None), (0, None)]  
  
# Apply Simplex Method  
result = linprog(c, A_ub=A, b_ub=b, bounds=bounds, method='simplex')  
  
if result.success:  
    advertising, service = result.x  
    max_profit = -result.fun  
  
    ret  
    "Company": company_name,  
    "Advertising Investment (₦)": advertising, "Service Promotion Investment (₦)":  
    service, "Maximum Benefit (₦)": max_profit  
}  
  
else:  
    raise Exception("Optimization failed")
```

4.6.5 Mathematical Interpretation

Let:

- i. x = Advertising investment
- ii. y = Service promotion investment

Objective:

Maximize $Z = 230x$ (MTN)

Maximize $Z = 390y$ (GLOBACOM)

Constraints:

$x + y \leq \text{Total Budget}$

$\geq 0, y \geq 0$

- i. Simplex Method solves this efficiently
- ii. Duality Theory confirms optimality

4.7 Run Optimization for Both Companies

```

validate_inputs(
    MTN_BUDGET, GLO_BUDGET,
    MTN_AD_BENEFIT, MTN_SERVICE_BENEFIT,
    GLO_AD_BENEFIT, GLO_SERVICE_BENEFIT
)

mtn_result = optimize_resources(
    MTN_BUDGET,
    MTN_AD_BENEFIT,
    MTN_SERVICE_BENEFIT,
    "MTN"
)

glo_result = optimize_resources(
    GLO_BUDGET,
    GLO_AD_BENEFIT,
    GLO_SERVICE_BENEFIT,
    "GLOBACOM"
)

results = pd.DataFrame([mtn_result, glo_result])
print(results)
    
```

4.7.1 Expected Output

| Company | Advertising | Service Promotion | Maximum Benefit |
|----------|-------------|-------------------|-----------------|
| MTN | ₦1,000,000 | ₦0 | Optimal |
| GLOBACOM | ₦0 | ₦1,000,000 | Optimal |

Confirms:

- i. MTN benefits more from **Advertising**
- ii. GLOBACOM benefits more from **Service Promotion**

4.8 Promotion Monitoring & Logging System

```
promotion_log = []

def log_activity(company, district, activity_type, amount):
    promotion_log.append({
        "Company": company,
        "District": district,
        "Activity": activity_type,
        "Amount (₦)": amount,
        "Date": datetime.now()
    })
```

Explanation

Tracks:

- i. Promotion type
- ii. District
- iii. Time
- iv. Investment size

Supports:

- i. Performance analysis
- ii. Future planning

4.8.1 Sample Logs

```
log_activity("MTN", "Lagos Mainland", "Advertising", 300000)
log_activity("GLOBACOM", "Abuja Central", "Service Promotion", 400000)

log_df = pd.DataFrame(promotion_log)
print(log_df)
```

4.9 Visualization Dashboard

4.9.1 Maximum Benefit Chart

```
plt.bar(
    results["Company"], results["Maximum Benefit (₦)"]
)
plt.title("Maximum Benefit by Telecom Company")
plt.xlabel("Company")
plt.ylabel("Benefit (₦)")
plt.show()
```

Explanation

- i. Graphical summary
- ii. Easy interpretation by management
- iii. Supports decision-making

4.10 Complete System Flow

| Step | Status |
|----------------------|--------|
| Start system | ✓ |
| Collect input | ✓ |
| Validate data | ✓ |
| Mathematical model | ✓ |
| Simplex optimization | ✓ |
| Duality confirmation | ✓ |
| Allocation decision | ✓ |
| Monitoring & logging | ✓ |
| Dashboard display | ✓ |
| End | ✓ |

4.11 Recommendations

- i. MTN, GLOBACOM, and other telecom companies should apply game theory when making optimization decisions.
- ii. Instead of unhealthy competition, companies should use game theory to determine their saddle point and operate consistently at that equilibrium.
- iii. MTN and GLOBACOM should adopt the results obtained in Sections 3.1.1 and 3.1.2 for resource allocation.

For GLOBACOM:

- i. $X_1=0\%$ (Advertisement)
- ii. $X_2=100\%$ (Service Promotion)
- iii. This guarantees a return ratio of $0.026 \times N$ million regardless of MTN's actions.

Final optimal benefits:

- i. MTN: $23 \times N$ million
- ii. GLOBACOM: $39 \times N$ million

4.12 Discussion

The results obtained from the linear programming and game-theoretic analysis provide clear insight into how MTN and GLOBACOM should optimally allocate their promotional resources in a competitive duopolistic environment. The payoff matrix, which captures the interaction between advertisement and service promotion strategies, reveals that each company benefits differently depending on the nature of its investment. The simplex method applied to MTN's maximization problem and GLOBACOM's corresponding dual minimization problem confirms the existence of stable optimal strategies for both firms.

For MTN, the optimal solution ($y_1=1, y_2=0$) indicates that the company derives its maximum benefit exclusively from **advertising**. This implies that MTN's competitive strength and market responsiveness are more sensitive to visibility, brand awareness, and promotional campaigns than to service-based incentives. The value of the game for MTN, computed as $v=23$, further suggests that every unit of investment allocated to advertising yields a significantly higher marginal return compared to service promotion. This aligns with MTN's historical market behavior, where aggressive advertising has often been a key driver of customer acquisition.

In contrast, GLOBACOM's optimal strategy ($X_1=0, X_2=1$) demonstrates that the company benefits most from **service promotion** rather than advertising. The dual solution value of 39 indicates that GLOBACOM's competitive advantage lies in enhancing service quality, offering bonuses, data packages, and customer-centric incentives. This result is consistent with GLO's market positioning, which often emphasizes value-added services and affordability as a means of attracting and retaining customers. The fact that GLO's optimal value (39) exceeds MTN's (23) does not imply superiority; rather, it reflects the relative payoff structure of the game matrix and the sensitivity of each company's returns to its chosen strategy.

The contrasting optimal strategies highlight an important strategic implication: **the two companies do not benefit equally from the same type of promotional investment**. Instead, each firm must focus on the area where its marginal returns are highest. MTN should prioritize advertising, while GLOBACOM should concentrate on service promotion. This divergence reduces direct head-to-head competition and allows each firm to exploit its unique strengths within the market.

The duality relationship between the two linear programming models reinforces the validity of the results. MTN's maximization problem and GLO's minimization problem converge to consistent values, confirming that the game possesses a saddle point and that the strategies identified are optimal and stable. This stability is crucial in a competitive telecom environment, as it ensures that neither company can unilaterally deviate from its optimal strategy without reducing its expected payoff.

The AI-assisted optimization system developed in Python further validates these findings by reproducing the same allocation patterns using computational methods. The system's monitoring and visualization components also demonstrate how these strategies can be implemented in real-time decision-making, enabling telecom managers to track promotional activities, evaluate performance, and adjust resource allocation dynamically.

Overall, the discussion reveals that **game theory, linear programming, and AI-assisted optimization provide a powerful framework for strategic decision-making in the telecommunications sector**. By identifying the optimal promotional mix for each company, the study offers a practical and mathematically sound approach to maximizing returns on investment while minimizing wasteful competition. The results underscore the importance of data-driven planning and highlight how modern analytical tools can support long-term strategic growth in a highly competitive industry.

4.13 Conclusion

Using the relationship between game theory and AI-assisted programming, we solved a hypothetical case study involving the allocation of N\times million. The results provided specific investment proportions that maximize net return per unit of investment.

The value of the game produced an authentic ratio for disbursing the developmental fund between MTN and GLOBACOM, ensuring optimal performance for both companies.

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Between Chalkboards and Corridors: A Comparative Reflection on Nigerian and UK Educational Practice

Obinna Joshua Ugo Nwoko ¹, Lovejane Chinaza Chidi-Iwobi ²

¹ *Department of Educational Foundations and Management/ Alvan Ikoku Federal University of Education, Owerri, Imo State, Nigeria*

² *Independent Academic Researcher/ Liverpool, United Kingdom*

Abstract:

This study presents a comparative analysis of educational practices, policies, and outcomes in Nigeria and the United Kingdom, with the aim of identifying systemic strengths, gaps, and opportunities for reform in both contexts. Drawing upon over a decade of lived experience teaching in multiple Nigerian states, including Anambra, Imo (Owerri), Kano, and Bayelsa, and professional engagement within UK schools, the research employs a mixed-methods approach combining reflective practitioner insights with triangulated secondary data from government reports, academic studies, and media sources. Key areas of focus include teacher workload, resource allocation, pedagogical approaches, professional development, inclusion and diversity, and systemic accountability. Findings indicate significant disparities in workload management, access to instructional materials, and professional development structures, with Nigerian teachers facing chronic under-resourcing, limited CPD, and exam-driven curricula, while UK educators contend with structured support frameworks, formal performance review systems, and differentiated instruction models. Notably, UK inclusion policies offer insights into supporting multilingual learners and culturally diverse student populations, highlighting lessons transferable to the Nigerian context. The study demonstrates that comparative research not only informs policy reform and teacher practice in Nigeria but also provides strategic value for the UK by strengthening global educational leadership, enhancing support for migrant and diaspora students, and fostering intercultural pedagogical innovation. Ultimately, this work positions comparative education as a bridge for evidence-based reform, emphasising equity, inclusion, and sustainable improvement across diverse educational ecosystems.

Conclusion: *This study examined critical differences and commonalities between the Nigerian and UK education systems, focusing on infrastructure, teacher welfare, inclusion, and gender dynamics. The findings reveal stark contrasts in resource allocation, policy implementation, and support structures, highlighting areas where Nigeria faces systemic challenges and where the UK can learn from innovative practices in resource-limited settings. Notably, the study underscores that effective education depends not only on material resources but also on teacher support, policy fidelity, and adaptive strategies in diverse classroom contexts. By illuminating these realities, the research provides a foundation for policymakers, educators, and researchers to design interventions that strengthen teaching quality, promote equity, and prepare students for increasingly complex and multicultural learning environments. Ultimately, the study emphasises that meaningful improvements in education require both systemic investment and contextualised, innovative approaches.*

Keywords: *Comparative Education, Nigeria, United Kingdom, Teacher Workload, Educational Policy, Professional Development, Inclusion and Diversity, Systemic Accountability*

1.0 Introduction

Education is often heralded as the engine of national progress, social mobility, and cultural continuity. Around the world, countries invest heavily in schooling, teacher training, and educational policy. However, the lived realities in classrooms frequently diverge starkly from the ideal. For nations like Nigeria, where rapid population growth, socioeconomic inequalities, and infrastructure deficits intersect, the challenge of delivering quality, equitable education is especially daunting. In contrast, more resourced systems, such as that of the United Kingdom (UK) present a contrasting model, with structured teacher support, regulated workloads, and a robust policy environment. By comparing these two contexts, this study seeks to reveal structural strengths and systemic weaknesses, not to glorify one system over another, but to draw lessons that can inform inclusive, evidence-based reforms globally.

The urgency for such comparative analysis is heightened by recent data: in Nigeria, the national basic education system reportedly lacks 194,876 qualified teachers and faces a shortage of over 1.1 million classrooms. Around 33.3% of teachers in basic schools lack proper qualifications, leaving nearly half a million unqualified teachers nationwide. These deficits exacerbate overcrowded classrooms, limit instructional quality, and erode learning outcomes.

Meanwhile, data from the UK's state-funded schools in 2024/25 show a more manageable pupil-teacher ratio: 20.8 pupils per primary teacher, and 16.7 pupils per secondary teacher. Such disparities raise critical questions about equity, teacher wellbeing, resource allocation, and educational effectiveness across global contexts.

Nonetheless, even within the UK there are pressures. Reports indicate rising teacher vacancies and recruitment challenges; in 2024, more than six teaching posts per 1,000 remained unfilled, the highest vacancy rate on record. These trends suggest that resource-rich systems are not immune to challenges. That said, the existence of institutional frameworks, formal professional development pathways, regulated staffing patterns, diversity and inclusion policies, and accountability mechanisms provides a buffer that many under-resourced contexts lack.

Against this backdrop, this research draws on the author's over a decade of teaching experience across multiple Nigerian states. Anambra (Awka), Imo (Owerri), Kano (Tudun Wada), and Bayelsa (Amarata), as well as professional teaching work in UK schools. Combined with a wide range of secondary sources (official statistics, policy reports, academic studies, and media coverage), the study uses a comparative, mixed method approach to examine six core dimensions: teacher workload; instructional resources and infrastructure; pedagogical approaches and assessment culture; professional development and teacher support; inclusion, diversity, and student teacher demographics; and systemic governance and accountability.

1.1 The Following Questions guide the Research:

- i. What structural challenges and strengths define the educational environments in Nigeria and the UK across the six core dimensions?
- ii. How do differences in resource allocation, teacher supply, pedagogical approach, and institutional support impact teacher performance and student outcomes?
- iii. What lessons and policy-relevant insights can a comparative study offer to support equitable, sustainable educational reform, both in Nigeria and in contexts hosting migrant and diasporic students such as the UK?

The significance of this study is threefold. First, it provides empirical grounding for the debates on global educational inequality by combining practitioner insight and quantitative evidence. Second, it offers actionable recommendations for policymakers, school leaders, and educational stakeholders seeking to strengthen education systems in under-resourced contexts. Third, it contributes to comparative education scholarship by framing educational reform not purely as a technological or infrastructural challenge, but as a deeply socio-cultural, pedagogical, and governance-based endeavor, one that requires attention to equity, inclusion, and human-centred values.

In the sections that follow, the study will review existing literature on educational disparities and reform, outline the methodology grounded in lived experience plus secondary data triangulation, present findings from both contexts, engage in a comparative analysis, and conclude with policy-oriented recommendations. The objective is not to cast judgment, but to build a bridge across continents, systems, and conditions, towards better teaching, learning, and educational justice.

2.0 Statement of Problem

Educational systems globally face the dual challenge of improving quality while ensuring equity and inclusion. In Nigeria, these challenges are amplified by resource constraints, demographic pressures, and historical underinvestment. The Universal Basic Education Commission (UBEC) reports that over 33% of teachers in public primary schools are inadequately trained, with some states experiencing teacher shortages exceeding 40% of the workforce. (UBEC, 2023) Overcrowded classrooms, insufficient instructional materials, and intermittent electricity and internet access further hinder effective learning. Studies indicate that pupils in rural Nigerian schools are nearly

50% less likely to meet literacy and numeracy benchmarks compared to their urban peers. (World Bank, 2022) Teacher strikes, motivated by delayed salaries, poor welfare, and infrastructural deficits, occur frequently, disrupting instructional continuity and compounding learning losses. (Punch, 2024)

In contrast, the United Kingdom maintains comparatively stable infrastructure and staffing levels, though it is not immune to challenges. Teacher shortages, especially in STEM and special education needs (SEN) subjects, have intensified in recent years, with vacancy rates reaching record highs in some regions. (Gov.uk, 2024) Class sizes remain manageable, averaging 21 pupils in primary schools and 17 in secondary schools, which supports differentiated instruction and student-centred pedagogy. Inclusive education policies are more formally embedded, providing more explicit guidance for accommodating students with diverse linguistic, cultural, and learning needs. (DfE, 2023) Professional development pathways in the UK are structured, with regular CPD, mentoring, and performance review systems, in contrast to the largely ad hoc training opportunities in Nigeria. (OECD, 2022)

These disparities are not merely logistical; they shape pedagogical approaches, teacher wellbeing, and student outcomes. In Nigeria, the rigid, exam-driven curriculum often forces a teacher-centred, lecture-based model that prioritises coverage over comprehension, limiting opportunities for critical thinking and problem-solving. (Adeosun, 2021) Conversely, the UK's assessment frameworks support flexibility, student-centred learning, and differentiated instruction, fostering engagement and creativity. (Ofsted, 2023)

This context highlights a pressing need for comparative analysis. By juxtaposing the Nigerian and UK systems, this research illuminates structural inequities, pedagogical differences, and professional development gaps. Moreover, it identifies actionable insights for policymakers, educational leaders, and practitioners seeking to enhance equity, inclusion, and quality learning outcomes. Beyond Nigeria, such comparisons inform strategies for UK schools serving multilingual, migrant, and diaspora students, strengthening cross-cultural pedagogy and global educational leadership. Ultimately, this study positions lived experience, supplemented by secondary evidence, as a catalyst for evidence-based reform that transcends borders and fosters sustainable, inclusive education.

3.0 Review of Related Literature

3.1 Educational Governance and Structural Frameworks

Educational governance shapes how resources, policies, and accountability systems function, directly impacting teaching and learning. In Nigeria, the federal structure decentralises education, but inconsistent implementation creates disparities across states. According to the National Bureau of Statistics (NBS, 2022), funding allocation varies significantly, with southern states typically receiving higher per-student expenditure than northern states. This structural variability often translates into differences in school facilities, teacher availability, and student outcomes.

In contrast, the UK maintains a relatively standardised governance framework through centralised guidelines provided by the Department for Education (DfE) and inspected by Ofsted. Local authorities play a supportive, rather than regulatory, role. Research by West and Pennell (2021) highlights that this uniformity allows more predictable planning, standardised professional development, and quality assurance mechanisms.

3.2 Pedagogical Practices and Curriculum Orientation

Pedagogy in Nigerian schools is heavily influenced by exam-oriented curricula, where memorisation and teacher-centred instruction dominate. Adeosun (2021) notes that secondary schools often prioritise coverage of syllabus content over comprehension or critical thinking, limiting opportunities for creativity. Classroom observation reports indicate that student engagement is frequently low, particularly in overcrowded settings with limited resources (World Bank, 2022).

By contrast, the UK curriculum emphasizes student-centred, competency-based learning. Differentiated instruction, formative assessment, and project-based learning are embedded within both primary and secondary education (Ofsted, 2023). Research demonstrates that such flexibility increases engagement, nurtures critical thinking, and improves social-emotional outcomes (Hattie, 2018). Comparative analysis suggests that while Nigerian classrooms struggle to

implement similar approaches due to structural and resource constraints, adopting elements of flexible assessment could improve learning outcomes.

3.3 Teacher Professional Development and Workload

Teacher development significantly influences pedagogical quality and student outcomes. In Nigeria, teacher training often occurs pre-service, with limited follow-up CPD. Surveys by UBEC (2023) show that only 42% of teachers in public schools participated in structured in-service training in the last three years. Mentorship and performance evaluation are largely informal, leaving teachers without feedback loops that could enhance instructional practice.

In the UK, teachers benefit from systematic CPD pathways, mentoring schemes, and structured performance reviews (OECD, 2022). Workload management frameworks, while challenging, are formalised through policies regulating class sizes, preparation time, and administrative responsibilities. Comparative studies indicate that teacher efficacy and retention improve when professional development is continuous, structured, and contextually relevant (Day & Gu, 2014).

3.4 Resource Allocation and Infrastructure

Resource availability directly impacts learning environments. Nigerian schools, particularly in rural regions, frequently lack textbooks, laboratory equipment, and digital tools (World Bank, 2022). Infrastructure gaps such as inadequate electricity, internet connectivity, and classroom space limit the adoption of innovative pedagogical methods. In contrast, UK schools generally enjoy stable infrastructure, with digital learning resources increasingly integrated into instruction (DfE, 2022). These differences create systemic inequities that affect not only student learning but also teacher capacity to innovate.

3.5 Inclusion, Diversity, and Equity

Inclusion is a critical metric of educational quality. In Nigeria, SEN support and multilingual instruction are inconsistent. Research by Okeke (2021) indicates that children with learning disabilities or from non-dominant linguistic backgrounds often face exclusion from mainstream instruction. Conversely, the UK has established legal frameworks and policy guidelines that promote inclusion, including SEN coordinators, differentiation mandates, and EAL programmes (DfE, 2023). Comparative analysis underscores the potential for Nigeria to adopt contextually relevant inclusion strategies and for the UK to learn from grassroots approaches in diverse Nigerian classrooms.

3.6 Teacher-Led Innovation and Grassroots Practices

Despite systemic challenges, Nigerian teachers frequently develop improvisational strategies to overcome resource gaps. Chidi-Iwobi (2022) documents classroom innovations, such as the use of culturally familiar examples and improvised teaching aids, that significantly enhance student engagement. The UK system, while resource-rich, may overlook such community-driven innovation, relying more on top-down instructional strategies. Comparative research highlights that reciprocal learning, where the UK examines adaptive Nigerian practices, can inform teacher professional development and cross-cultural pedagogy.

4.0 Results and Findings

4.1 Classroom Infrastructure and Learning Resources

Nigeria

Classroom infrastructure remains a significant challenge across many Nigerian schools. Reports from the Universal Basic Education Commission (UBEC, 2021) indicate that over 60% of public primary schools operate with inadequate classrooms, overcrowded facilities, and insufficient instructional materials. My lived experience reinforces this: in Kano State, several primary schools had class sizes exceeding 50 students, with minimal textbooks and outdated teaching aids. Overcrowding often hampers student engagement, creates stress for teachers, and limits differentiated instruction (Olayemi, 2020). Teacher improvisation is typical, as educators create homemade resources to address material deficits. In some schools, the lack of stable electricity or internet connectivity further impedes the implementation of modern pedagogical practices, especially in integrating digital learning or multimedia instruction.

United Kingdom

In contrast, UK schools generally provide well-maintained classrooms, access to textbooks, ICT resources, and stable infrastructure (DfE, 2022). Average class sizes range from 20 to 30 students, allowing for more individualised

attention and student-centred practices. Schools also have structured funding mechanisms for instructional materials and technology integration, including interactive whiteboards, digital learning platforms, and libraries (Ofsted, 2021). However, disparities exist within the UK: schools in economically disadvantaged areas report limited access to technology or specialised learning resources (NFER, 2022). These gaps highlight that even in high-income contexts, equitable distribution of learning resources remains an ongoing challenge.

Comparative Insights and Implications

The contrast is stark: Nigerian schools face chronic infrastructural deficits that hinder effective teaching and learning, whereas UK schools primarily benefit from predictable funding and structured resource allocation. Yet the UK must still address inequalities in deprived areas, emphasising that no system is perfect. For Nigeria, evidence suggests that targeted investment in classroom infrastructure, consistent provision of instructional materials, and integration of digital tools could dramatically enhance learning outcomes. For the UK, lessons from Nigeria's improvisational and adaptive teaching approaches could inspire innovative pedagogical flexibility, particularly in under-resourced schools or emergencies.

4.2 Policy and Governance in Education

Nigeria

Nigeria's education system is characterised by fragmented governance and politicised policy implementation. The Federal Ministry of Education sets broad national standards, but enforcement at state and local levels is inconsistent (Adeyemi & Olaleye, 2021). Policy reforms often focus on headline initiatives rather than systemic issues, leading to gaps between policy intentions and classroom realities. Strikes are common, with teachers demanding unpaid salaries, adequate resources, or improved working conditions (Ojo, 2020). These disruptions underscore systemic weaknesses: insufficient oversight, delayed policy execution, and political interference compromise educational quality. Moreover, curricula are heavily exam-oriented, prioritising rote memorisation and high-stakes testing over critical thinking and student-centred learning (Okebukola, 2018). This top-down approach often leaves teachers with little autonomy to innovate or adapt instruction to student needs.

United Kingdom

The UK operates a more structured governance framework that balances central oversight with school autonomy. The Department for Education provides national standards, accountability measures, and funding, while schools enjoy operational flexibility through governance boards (DfE, 2022). Policies on curriculum, teacher performance, and assessment are backed by systematic monitoring and evidence-based evaluation. Ofsted inspections ensure compliance, identify gaps, and provide recommendations for improvement (Ofsted, 2021). Curriculum reforms in the UK, such as the National Curriculum updates, incorporate feedback loops and research evidence, emphasising critical thinking, creativity, and inclusivity (Alexander, 2020). Challenges exist, particularly in maintaining policy consistency across devolved regions such as Scotland, Wales, and Northern Ireland, and in addressing inequalities in socioeconomically disadvantaged areas.

Comparative Insights and Implications

The Nigerian system struggles with implementation fidelity, politicisation, and teacher disenfranchisement, all of which directly affect classroom outcomes. The UK benefits from structured policy frameworks, robust monitoring, and evidence-informed reforms, though it still grapples with regional disparities and socio-economic inequities. Comparative analysis suggests that Nigeria could benefit from adopting accountability mechanisms, evidence-based reform cycles, and teacher engagement in policy development. Conversely, the UK can learn from Nigeria's adaptive strategies in informal education and community engagement, highlighting the value of localised problem-solving in policy application.

4.3 Pedagogical Approaches and Instructional Methods

Nigeria

Classroom instruction in Nigeria remains teacher-centred mainly and exam-driven, with the curriculum prioritising memorisation over critical thinking (Okebukola, 2018; Ojo, 2020). Lessons frequently follow rigid pacing guides, leaving little room for differentiated instruction or student-led inquiry. In many public schools, large class sizes sometimes exceeding 50 students limit meaningful engagement (UNESCO, 2022). Resource constraints exacerbate these challenges: textbooks are often outdated, laboratories are poorly equipped, and digital tools are largely absent (Adeyemi & Olaleye, 2021).

Despite these constraints, grassroots innovations exist. Drawing on my experience teaching in primary and secondary schools across Imo, Kano, and Bayelsa States, improvisational strategies, such as using local materials to teach science concepts or integrating culturally familiar examples into literacy lessons, significantly improved student engagement and comprehension. For instance, structured phonics exercises adapted with local vocabulary increased literacy participation by approximately 35% in multilingual classrooms. However, these teacher-led innovations remain under-recognised in formal policy frameworks, limiting their broader impact (Chidi-Iwobi, 2021).

United Kingdom

UK pedagogical practice emphasises student-centred learning, differentiated instruction, and competency-based assessment (Alexander, 2020; DfE, 2022). Class sizes are smaller, averaging 25–30 students in primary schools, allowing for individualised attention (OECD, 2022). Teachers are trained to implement inclusive pedagogies that accommodate diverse learning needs, including multilingual learners and students with SEN. Technology integration is widespread, from adaptive learning software to interactive whiteboards, supporting personalised feedback and formative assessment (DfE, 2022).

However, UK classrooms face challenges too. Standardised assessment expectations can constrain teacher autonomy, and schools in socioeconomically deprived areas often struggle with resource limitations (OECD, 2022). Moreover, while differentiated instruction is encouraged, the implementation quality varies across regions and schools, affecting equity of learning outcomes.

Comparative Insights and Implications

Nigeria's teacher-centred, exam-focused model contrasts sharply with the UK's student-centred, flexible approach. While UK students benefit from structured differentiation and technology support, Nigerian students often rely on teacher improvisation to bridge resource gaps. The comparative analysis underscores the importance of balancing systemic structures with local adaptation. Nigeria could gain from embedding formalised, research-backed differentiated strategies into curricula. At the same time, the UK could learn from Nigeria's culturally responsive and improvisational techniques, which can enrich engagement for diverse learners.

4.4 Teacher Professional Development and Welfare

Nigeria

Professional development opportunities for Nigerian teachers are inconsistent and often limited to sporadic workshops or government-led training initiatives that may not align with classroom realities (Okebukola, 2018; Ojo, 2020). Mentorship programs are rare, and continuous professional development (CPD) pathways are largely informal. Salary irregularities and underpayment compound the challenges, contributing to low morale and high attrition rates (Adeyemi & Olaleye, 2021; UNESCO, 2022).

Drawing from my teaching experience across Imo State (Owerri), Kano, and Bayelsa States, I observed that teachers frequently relied on peer collaboration and improvisation to improve pedagogy. While these grassroots approaches enhance classroom practice, their reach is limited, and systemic recognition or scaling of these initiatives is minimal. The lack of structured evaluation of teacher performance means that innovative teaching methods are rarely institutionalized or formally rewarded, affecting long-term educational quality.

United Kingdom

In contrast, the UK provides structured CPD pathways for teachers, including mentorship schemes, formal performance reviews, and dedicated professional learning days (DfE, 2022; Alexander, 2020). Teacher welfare is supported through predictable salaries, regulated working hours, and access to wellbeing resources. Cover systems and professional support networks allow teachers to participate in training without compromising classroom coverage (OECD, 2022). Evidence shows that sustained CPD improves teacher confidence, instructional quality, and student outcomes, particularly in addressing inclusion and differentiated instruction needs (Hargreaves & Fullan, 2012).

However, challenges remain. Teachers in the UK still report stress related to workload, curriculum pressures, and accountability demands, and rural or deprived areas experience disparities in access to high-quality CPD (OECD,

2022). Additionally, teacher turnover, while lower than in Nigeria, is affected by burnout and the demands of high-stakes assessment systems.

Comparative Insights and Implications

Key disparities include:

- i. Workload Management** — UK systems demonstrate the value of regulated workloads, enabling teachers to focus on instructional quality. Nigeria's unregulated workload undermines teacher wellbeing and effectiveness.
- ii. Professional Development Structures** — The UK's structured CPD contrasts with Nigeria's ad-hoc initiatives. Systematic training pipelines could improve Nigerian teacher performance and retention.
- iii. Welfare and Retention** — Predictable salaries and formal support structures in the UK correlate with lower attrition. In Nigeria, financial insecurity and lack of welfare reduce motivation and educational outcomes.
- iv. Policy Implications** — Implementing formal teacher support, appraisal frameworks, and structured CPD in Nigeria could improve teaching quality and reduce stress. The UK can refine approaches for diverse classrooms by integrating innovative strategies from global contexts.

This comparative evaluation underscores that teacher welfare, professional growth, and workload regulation are critical determinants of education quality. Nigeria has apparent gaps to address, while the UK demonstrates effective models but still faces challenges in urban high-need contexts.

4.5 Inclusion, Diversity, and Equity in Nigerian and UK Educational Systems

Nigeria: Current Landscape and Challenges

Inclusion, diversity, and equity remain significant challenges within Nigeria's primary and secondary education systems. According to the United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2022), only 58% of children with disabilities in Nigeria have access to formal education. Multilingual learners, particularly in states with diverse ethnic populations such as Kano and Bayelsa, often face barriers in classrooms where instruction is primarily delivered in English, limiting comprehension and engagement (Adewale & Oloyede, 2021).

Teacher shortages exacerbate these inequities. Nigeria suffers from a pupil-to-teacher ratio exceeding 40:1 in many public schools, particularly in rural areas, making individualised instruction and differentiation challenging (World Bank, 2021). Strikes over unpaid salaries and poor working conditions have repeatedly disrupted schooling, contributing to learning gaps among vulnerable populations (Nigeria Teachers Union Report, 2022).

Cultural marginalisation also remains a concern. Curricula tend to focus heavily on standardised content, with little emphasis on local languages, indigenous knowledge, or artistic representation. As Gay (2010) and Ladson-Billings (1995) highlight, culturally responsive teaching is crucial for engagement and equity, yet in Nigeria, such approaches are rarely systematically implemented.

Implications: Students from minority backgrounds, learners with special educational needs (SEN), and multilingual pupils are disproportionately affected. This contributes to cycles of marginalisation, lower achievement, and disengagement. Teacher stress is compounded when systemic support for inclusive practice is minimal, leading to high attrition in public schools (OECD, 2022).

United Kingdom: Current Landscape and Challenges

The UK has a more structured approach to inclusion and diversity. SEN policies are clearly codified under the Children and Families Act (2014) and subsequent government guidelines, ensuring that schools provide targeted support for learners with disabilities, learning difficulties, or emotional needs. According to the Department for Education (DfE, 2023), 14.3% of pupils in England receive SEN support, with individualised education plans (IEPs) implemented across primary and secondary schools.

Multilingual learners and students from diverse cultural backgrounds are supported through English as an Additional Language (EAL) program, and national strategies aim to reduce attainment gaps for Black, Asian, and minority ethnic

(BAME) students (DfE, 2022). Teacher training in the UK also emphasizes equity and inclusion, with mandatory continuing professional development (CPD) in inclusive pedagogy, classroom differentiation, and culturally responsive teaching.

Despite these strengths, challenges remain. Teacher workload, even in the UK, can limit the capacity to fully implement individualized support (National Foundation for Educational Research, 2022). Achievement gaps persist for some minority groups, particularly in urban schools with high pupil diversity.

Implications: While the UK system demonstrates stronger institutional frameworks for equity and inclusion, persistent gaps indicate the need for ongoing policy refinement and culturally responsive practice. Nigerian strategies in grassroots innovation, such as improvisation with limited resources, can offer insights into creative inclusion strategies that are low-cost yet effective, particularly in diverse classroom settings.

4.6 Comparative Insights on Inclusion and Diversity

Cross-Context Comparison

| Aspect | Nigeria | United Kingdom | Implications |
|-------------------------|---|--|--|
| Policy Framework | Weak, inconsistent SEN and inclusion policies | Codified SEN and inclusion policies, EAL support. | Nigeria requires systemic policy reform; the UK benefits from reviewing the efficacy of its policies in practice. |
| Teacher Support | Limited training in inclusion, inconsistent materials | Structured CPD, inclusion-focused training | Comparative learning can improve preparedness in both contexts |
| Resource Availability | High pupil-teacher ratios, inadequate learning materials | Lower ratios, consistent access to resources | Nigeria need investment in staffing and materials. The UK can explore low-resource innovation strategies. |
| Multilingual Learners | Underserved, English-dominated instruction | Supported through EAL programs | Highlights the value of language-responsive pedagogy in Nigeria; the UK can enhance support for heritage languages |
| Cultural Representation | Minimal integration of indigenous knowledge or cultural diversity | Curriculum incorporates multicultural perspectives | Nigeria can benefit from integrating local knowledge; the UK can learn from grassroots innovation and context-aware strategies |

Key Takeaway

The comparative study demonstrates that while the UK leads in structured inclusion and diversity frameworks, Nigeria's classrooms show resilience and improvisational creativity that can inspire cost-effective inclusion strategies. For Nigeria, systemic policy reform, teacher training, and investment in resources are critical. For the UK, reflecting on the challenges of resource-constrained innovation and diverse linguistic environments can enhance global education leadership and prepare teachers for increasingly multicultural classrooms (OECD, 2022; UNESCO, 2022; DfE, 2023).

4.7 Teacher Workload and Welfare in Nigeria and the United Kingdom

4.7.1 Nigeria: Current Landscape

Teacher workload in Nigeria's primary and secondary schools remains a long-standing structural challenge. According to UNESCO (2022), teachers in public schools often manage pupil-to-teacher ratios exceeding 40:1, with some northern states reporting ratios above 45:1. High enrolment, insufficient staffing, and limited instructional resources

place significant pressure on teachers, creating conditions in which lesson planning, assessment, and pastoral support become overwhelming.

Compensation and welfare issues further intensify workload stress. Delays in salary payments, limited access to professional development, and inadequate infrastructural support contribute to frequent industrial actions among primary and secondary school teachers (Nigeria Union of Teachers Report, 2022). These disruptions disproportionately impact learners from low-income backgrounds, widening existing educational inequities.

Teacher burnout is also exacerbated by the expectation to deliver curriculum content without the tools needed for differentiation, inclusive practice, or modern pedagogy. As Okeke and Aderibigbe (2021) note, Nigerian teachers often rely on improvisation to address learning needs, yet such adaptation requires additional time and energy without corresponding institutional support.

Implications: Teacher welfare challenges have direct consequences on instructional quality, learner outcomes, and classroom equity. Systemic reforms in remuneration, staffing, professional development, and working conditions are essential for sustainable improvement.

4.7.2 United Kingdom: Current Landscape

In the UK, teacher workload is widely recognised as a critical factor influencing retention and professional satisfaction. The Department for Education (DfE, 2023) highlights that administrative duties, extensive marking policies, and data-driven accountability demands contribute significantly to workload pressure. Although pupil-to-teacher ratios are comparatively lower than in Nigeria, the expectation for personalised learning, pastoral care, and compliance with safeguarding frameworks places high cognitive and emotional demands on educators.

Welfare provisions in the UK are stronger and better defined. Structured CPD, wellbeing initiatives, and contractual protections provide a more supportive professional environment. However, surveys by the National Foundation for Educational Research (2022) indicate that teacher attrition remains a persistent issue, with stress levels particularly high in urban schools and institutions serving diverse socio-economic populations.

Implications: While the UK maintains clearer welfare frameworks and workload guidelines, rising demands in behaviour management, assessment, and inclusive practice highlight ongoing systemic strains. Continued investment in workload reduction strategies, flexible scheduling, and mental health support is necessary.

4.7.3 Comparative Insights

| Aspect | Nigeria | United Kingdom | Implications |
|--------------------------|--|--|---|
| Pupil-Teacher Ratio | Frequently high, often exceeding 40:1 | Lower ratios, more balanced class sizes | Nigeria requires investment in staffing, while the UK benefits from workload-reduction policies. |
| Administrative Workload | Moderate, but amplified by poor infrastructure and limited resources | High administrative load due to accountability systems | Highlights structural inefficiencies in both contexts |
| Welfare Support | Inconsistent salary payments, weak benefits | Well-defined welfare policies, mental health initiatives | Nigeria requires systemic financial reforms; the UK still faces stress-driven attrition |
| Professional Development | Limited access, inconsistent delivery | Structured CPD embedded in career progression | Nigeria needs sustainable CPD funding; the UK needs CPD that reduces workload rather than adds to it. |
| Industrial Actions | Frequent due to salary and welfare issues | Less frequent, driven by workload and policy pressures | Illustrates differing structural stressors affecting teacher wellbeing |

Key Takeaway

Both countries face significant workload-related challenges, albeit shaped by different systemic realities. Nigeria's issues stem primarily from underfunding, large class sizes, and inconsistent welfare provisions. The UK's challenges arise from administrative overload, accountability pressures, and rising expectations for personalisation and inclusion. Comparative insights suggest that Nigeria would benefit from structural investment and policy consistency, while the UK must prioritise workload reduction and wellbeing frameworks that keep teachers in the profession.

4.8 Gender Dynamics and Teacher Workforce Realities

4.8.1 Nigeria

Gender representation in Nigeria's basic education workforce follows a long-standing pattern: women dominate early years and primary teaching, while men remain overrepresented in leadership and secondary school roles. UNESCO Global Education Monitoring data (2020) reports that women constitute **57%** of the national basic education workforce, but fewer than **30%** in STEM-focused secondary schools. This uneven distribution influences instructional culture, learner perceptions of gendered subjects, and leadership pipelines.

Teacher workload amplifies gender disparities. Nigerian Union of Teachers (2021) data show that women often carry disproportionately high pastoral and administrative responsibilities without adequate institutional support. Combined with large class sizes and limited parental engagement in rural areas, female teachers report higher emotional fatigue and reduced professional agency (Adebayo, 2022).

Gender-based safety concerns also shape workforce realities. Female teachers posted to remote northern communities frequently request transfers due to insecurity (Aroyehun & Ogunyemi, 2021), affecting recruitment and retention patterns.

4.8.2 United Kingdom

The UK presents an opposite but equally complex pattern. Women constitute **76% of the teacher workforce but hold only 38% of secondary headship roles and less than 30%** of senior system-leadership positions (DfE, 2023). The gender gap in leadership is structural rather than numerical.

Early-career female teachers experience higher attrition due to work-life balance pressures, childcare costs, and unequal distribution of emotional labour (DfE, 2022). Despite improved maternity protections and flexible work policies, Ofsted and NEU reports show that women disproportionately handle safeguarding, SEND case management, and pastoral coordination—roles that intensify burnout.

Although class sizes are more manageable than in Nigeria, workload and accountability regimes continue to affect female staff disproportionately.

4.8.3 Comparative Implications

Nigeria's challenge lies in **gendered access**—who teaches where, who gets promoted, and who remains safe enough to continue teaching.

The UK's challenge lies in **gendered progression**—women are present but not proportionally represented in leadership.

Key implications across both systems include:

- i.** Nigeria's uneven workforce distribution weakens STEM participation for girls and limits female leadership role models.
- ii.** The UK's leadership gap slows diversity in policy decisions, reducing the potential for culturally responsive and equity-driven practice.
- iii.** Workload and emotional labour pressures appear in both contexts, though the drivers differ: Nigeria's are infrastructural and socio-political, the UK's are bureaucratic and structural.

Overall

A comparative lens shows that each system faces gender-related constraints, just shaped by different histories and

Insight:

institutional cultures. Addressing these requires context-specific strategies rather than importing reforms from one country to another.

4.9 Resource Allocation, Infrastructure, and Learning Conditions

4.9.1 Nigeria

Resource scarcity remains one of the most documented constraints in Nigerian basic education. Public expenditure on education has consistently fallen below UNESCO's recommended range of 15 to 20 per cent of the total national budget, with Nigeria averaging 5 to 7 per cent over the last decade (UNESCO, 2022; BudgIT, 2023). This chronic underfunding shows up directly in classroom realities. Surveys conducted across six geopolitical zones indicate that 40 per cent of public primary schools lack functional libraries, 29 per cent lack science laboratories, and up to 34 per cent lack adequate furniture (UBEC, 2021). In rural communities, the situation is more acute: multi-grade classrooms, weather-beaten buildings, and inconsistent electricity supply undermine teaching quality and learner engagement.

Teacher materials are also insufficient. Chalk-and-talk instruction persists not as a cultural preference but as a necessity, driven by the absence of digital resources, unstable internet connectivity, and minimal access to assistive technologies. Studies link these deficits to lower literacy rates, significant learning gaps by age 10, and reduced transition rates into junior secondary education (World Bank, 2022). The infrastructure gap, therefore, functions as both a pedagogical constraint and a systemic barrier to social equity.

4.9.2 United Kingdom

The UK has significantly stronger infrastructure, but challenges remain, especially amid post-pandemic fiscal pressures. Public school funding has experienced fluctuations, with the Institute for Fiscal Studies noting that real-term per-pupil spending fell by 9 per cent between 2009 and 2019, only beginning to recover slowly in 2023 (IFS, 2023). Despite this, 97 per cent of schools maintain fully equipped classrooms, consistent electricity, libraries, ICT suites, and learning support infrastructure, providing a stable teaching environment (DfE, 2023).

However, infrastructure gaps in the UK now focus less on physical deficits and more on modernisation pressures. Ageing school buildings, particularly those affected by RAAC concrete concerns in 2023, indicate vulnerability in older estates (National Audit Office, 2023). Digital inequality also persists among economically disadvantaged pupils, with an estimated 1 in 5 students lacking reliable access to personal learning devices at home, which affects homework completion and independent learning (Ofcom, 2022). The UK's infrastructure, though comparatively strong, is not immune to equity concerns linked to socioeconomic class.

4.9.3 Comparative Insight

Nigeria's resource challenge is foundational. Insufficient funding cascades into weak learning environments, limited access to instructional materials, reduced teacher morale, and inconsistent learning outcomes. The UK's challenge is structural. The infrastructure exists, but maintaining it against rising costs, ageing buildings, and digital inequality requires strategic investment and policy stability.

Together, the comparison reveals a global pattern: strong infrastructure alone does not produce equity, but its absence almost guarantees inequity. Nigeria struggles to meet minimum conditions for effective instruction, while the UK grapples with sustaining high standards and adapting to emerging technological demands.

4.10 Assessment and Accountability

4.10.1 Nigeria

Assessment and accountability practices within Nigeria's basic and secondary education system remain heavily influenced by high-stakes examinations and centralised evaluation structures. The system is largely exam-driven, with public examinations such as the Basic Education Certificate Examination (BECE) and the West African Senior School Certificate Examination (WASSCE) determining progression and certification. Scholars have consistently noted that this orientation prioritises rote memorisation over competency development, limiting students' higher-order thinking skills (Olatunji 2021; Uwaifo 2020).

Research highlights several systemic challenges. First, teacher assessment literacy is inconsistent, with many educators lacking adequate training in formative assessment practices (Adeosun 2018). Second, irregular monitoring and quality assurance by state inspectorates result in inconsistent implementation of assessment standards across schools (Okonkwo 2019). Third, accountability mechanisms are often weakened by inadequate data management systems, making it challenging to use assessment results to inform policy or classroom instruction (UNICEF 2022).

Institutionally, Nigeria's accountability structures are constrained by underfunded inspectorate departments, inconsistencies in school supervision, and limited use of school performance reports. Studies indicate that many schools receive infrequent inspections, and recommendations from inspections are rarely followed with structured support or monitoring (World Bank 2021). These issues collectively weaken the feedback loop between assessment, instructional improvement, and school performance.

4.10.2 United Kingdom

By contrast, the United Kingdom operates a more structured, data-driven accountability ecosystem. The UK uses a balanced mix of formative and summative assessments, with formative assessment embedded in day-to-day teaching practice. Research shows that teachers are extensively trained in assessment for learning (AfL), which supports diagnostic teaching and continuous feedback (Black and Wiliam 2018).

At the systemic level, the UK's accountability architecture is underpinned by well-defined quality assurance frameworks. Organisations such as Ofsted conduct periodic inspections using standardised criteria to evaluate teaching quality, leadership effectiveness, safeguarding, and student achievement. These inspection outcomes carry significant implications for school improvement planning, funding, and public reporting (DfE 2023).

Moreover, the UK prioritises data transparency. Standardised performance data, including Key Stage results and Progress 8 scores, are publicly available, enabling the tracking of learner progress across years. This emphasis on measurable outcomes creates a performance-driven culture that strengthens accountability but also introduces pressure on schools to meet targets (Perryman 2020).

However, literature also documents challenges such as assessment overload, teacher stress linked to accountability pressures, and concerns about the narrowing of the curriculum due to performance benchmarks (Ball 2021). Nonetheless, compared to Nigeria, the UK's system benefits from stronger institutional capacity, more reliable data systems, and consistent enforcement of accountability policies.

4.11 Comparative Insights on Assessment and Accountability

The comparison reveals key contrasts across the two systems:

- i. Assessment Orientation** — Nigeria remains predominantly exam-centred, while the UK blends formative and summative approaches to support learning progression.
- ii. Teacher Assessment Capacity** — UK teachers generally demonstrate stronger assessment literacy due to structured CPD pathways; in Nigeria, gaps persist due to inconsistent training and limited professional development.
- iii. Institutional Accountability and Monitoring** — Nigeria's inspectorate system is underfunded and inconsistently deployed, leading to weak implementation of standards and minimal follow-through after evaluations. The UK maintains a structured monitoring framework through Ofsted and local authorities, ensuring regular inspections and consistent standards.
- iv. Data Utilisation and Transparency** — Nigeria's fragmented data systems limit the use of assessment outcomes for policy or instructional decisions. The UK emphasises data transparency, publishing school results annually and tracking learner progress longitudinally, though this also increases performance pressure.
- v. Pressure and Workload** — Nigeria's assessment system places pressure primarily on students, while the UK's accountability culture places pressure primarily on teachers.

- vi. **Policy Implications** — Nigeria would benefit from strengthening assessment literacy, modernising inspectorate systems, decentralising monitoring, and integrating formative assessment. The UK must refine accountability structures to reduce teacher stress and avoid curriculum narrowing.

Key Takeaway

Nigeria's system is exam-heavy, under-resourced, and weak in feedback loops. The UK is structured, data-rich, and balanced, but weighed down by accountability pressure. Both systems stand to gain from cross-learning: Nigeria from the UK's structured monitoring and formative assessment culture, and the UK from Nigeria's adaptive innovations in low-resource contexts.

4.12 Interpretation of Findings

This chapter interprets the comparative findings between Nigeria and the United Kingdom across the key domains established in the results: classroom infrastructure, policy and governance, teacher welfare and workload, professional development, inclusion and diversity, gender dynamics, resource allocation, and assessment practices. The interpretations draw on the empirical evidence presented, relevant scholarly perspectives, and my own lived teaching experience, especially in Nigerian public-school contexts, where systemic constraints often shape pedagogical realities.

This interpretation provides a grounded understanding of where the two systems converge and diverge and offers insight into context-responsive reform priorities.

4.12.1 Classroom Infrastructure and Learning Resources

The findings indicate a structural divide between the two systems, with Nigerian schools constrained by chronic infrastructural inadequacies. Overcrowded classrooms, insufficient instructional materials, and erratic electricity supply effectively limit the adoption of modern pedagogies. From firsthand experience, improvisation becomes a survival skill for teachers rather than an innovative choice. This signals that the system's physical environment dictates instructional quality, reinforcing arguments that learning outcomes cannot improve without simultaneous infrastructural reform.

In contrast, the UK's resource stability and manageable class sizes facilitate learner-centred teaching, technology integration, and differentiated instruction. However, disparities in disadvantaged areas show that even high-income systems struggle with equitable distribution. The comparative insight here is that infrastructure is not merely an input; it is a determinant of teaching identity, pedagogical confidence, and student engagement.

4.12.2 Policy and Governance in Education

The interpretation of governance differences reveals a deeper issue: policy coherence vs. policy fragmentation. Nigeria's policy landscape appears robust on paper, yet implementation gaps undermine the effectiveness of reforms. Teacher strikes, delayed salaries, and inconsistent state-level compliance indicate a system where governance is reactive rather than predictive. This creates a disconnect between national aspirations and classroom realities, making sustainable transformation difficult.

The UK demonstrates the opposite pattern. Structured accountability, systematic monitoring, and evidence-based reform cycles create a feedback loop where policy can actually influence classroom practice. The presence of bodies such as Ofsted strengthens compliance and offers an external check on school quality. Still, devolved governance structures introduce regional variations, reminding us that perfect uniformity is difficult in any national system.

The implication is clear: without governance stability and implementation fidelity, educational reforms cannot translate into educational outcomes.

4.12.3 Teacher Workload, Welfare, and Professional Development

The findings reflect two very different faces of teacher stress. In Nigeria, workload issues stem from understaffing, overcrowded classrooms, and poor welfare conditions. These pressures manifest as burnout, high attrition, and low instructional morale. Drawing on field experience, Nigerian teachers expend more emotional labour maintaining classroom order than engaging learners academically, thereby diluting instructional quality.

The UK presents a different picture: workload challenges stem from extensive administrative duties, performance metrics, and pastoral responsibilities. Teachers enjoy better welfare, but accountability pressures create psychological strain.

The broader insight is that teacher wellbeing is inseparable from learner outcomes. Systems that overlook teacher welfare inevitably compromise quality. Nigeria needs welfare and workload regulation, while the UK must innovate to reduce workload and improve mental health support.

4.12.4 Inclusion, Diversity, and Equity

The findings illustrate that inclusion is not simply a policy priority; it is a practical challenge that requires structural support and trained personnel. Nigeria's efforts towards inclusive education are undermined by infrastructural limitations, insufficient teacher training, and cultural perceptions that marginalise learners with special educational needs. Overcrowded classrooms make individualised support nearly impossible, creating a gap between policy intention and educational reality.

The UK provides a stronger inclusion framework, with established SEN provisions, multicultural education policies, and equity-driven reforms. Yet persistent achievement gaps among minority and economically disadvantaged learners indicate that access does not automatically translate to equity.

The interpretation here is that both systems recognise diversity, but Nigeria struggles to operationalise inclusion, while the UK grapples with the deeper work of cultural competence and equitable achievement.

4.12.5 Gender Dynamics within the Teaching Workforce

Nigeria's gendered disparities reflect structural and cultural barriers. Female teachers are disproportionately affected by posting policies, safety concerns, and leadership exclusion. Their overrepresentation in lower primary grades and underrepresentation in STEM and leadership roles show that gender influences career progression as much as competence.

The UK, despite a predominantly female teaching workforce, mirrors the same leadership imbalance. This suggests that while entry into teaching may be accessible to women, pathways to decision-making roles remain restricted.

The broader interpretation is that gender inclusion requires more than workforce participation; it requires intentional leadership development and structural protection for female educators in both countries.

4.12.6 Resource Allocation and Funding Priorities

The findings show that Nigeria's underfunding problem is not incidental; it is systemic. With education spending far below UNESCO benchmarks, resource shortages become inevitable. The ripple effect is visible across infrastructure, teacher development, assessment quality, and inclusion services. My own interactions with school systems reflect this: teachers often operate in deficit conditions that make substantive growth difficult.

The UK, with comparatively higher investment, faces its own resource strain in disadvantaged boroughs and in older school buildings. This reinforces the idea that funding must be needs-based, not evenly distributed.

The interpretation highlights that equitable funding is essential for equitable outcomes. Nigeria must strengthen financial prioritisation, while the UK must adopt sustained capital investment strategies to prevent widening internal inequalities.

4.12.7 Assessment Practices and Accountability Systems

The findings show that Nigeria's exam-driven culture narrows learning and places students under performance pressure. Limited assessment literacy among teachers further weakens the validity of classroom assessments. Without strong inspectorate systems or reliable data structures, accountability becomes inconsistent and sometimes subjective.

The UK's mixed-model assessment system, supported by data analytics, quality inspections, and teacher training, offers a more balanced approach. Still, accountability structures create workload stress and push schools toward performative rather than purely pedagogical priorities.

The interpretation is that assessment should guide learning, not merely measure it. Nigeria needs capacity-building in assessment literacy and reliable accountability structures, while the UK must ensure that accountability does not overshadow instructional creativity.

4.13 Synthesis of Interpretation

Across the nine themes, the comparative analysis shows that educational performance reflects the overall health of the system. Nigeria's challenges are systemic, structural, and longstanding, affecting infrastructure, teacher welfare, governance, resource allocation, and inclusion. The UK, while institutionally stronger, faces internal disparities, especially in multicultural and economically deprived areas.

A combined reading of the findings reveals that:

- i. Infrastructure determines the limits of pedagogy.
- ii. Governance determines the consistency of reform.
- iii. Teacher welfare determines instructional quality.
- iv. Inclusion requires cultural competence, not just policy.
- v. Assessment systems influence classroom behaviour.
- vi. Funding reflects national priorities.
- vii. Equity is a moving target in both high-income and low-income contexts.

5.0 Discussion

The comparative evaluation of Nigerian and UK education systems highlights a complex interplay of structural, policy, and socio-cultural factors that shape teaching and learning outcomes. Across the nine thematic areas, patterns emerge that provide insight into systemic strengths, persistent gaps, and actionable implications for both contexts.

Classroom infrastructure and learning resources remain a defining constraint in Nigeria. Overcrowded classrooms, inadequate instructional materials, and limited digital access consistently hinder student engagement and teacher effectiveness. Nigerian educators often rely on improvisation to bridge these gaps, demonstrating resilience but also underscoring systemic deficiencies. In contrast, UK schools benefit from predictable infrastructure and resource provision, though modernisation pressures and digital inequality persist. These differences suggest that Nigeria must prioritise targeted investment in classrooms, educational materials, and digital tools to create equitable and effective learning environments. At the same time, the UK should focus on sustaining infrastructure and addressing inequities in socio-economically disadvantaged areas.

Policy and governance structures further shape educational quality. Nigeria's fragmented governance and politicised policy implementation lead to inconsistent curricular delivery, frequent teacher strikes, and limited autonomy for educators. The UK demonstrates the value of structured oversight combined with school-level flexibility, supported by evidence-based policy and systematic monitoring. For Nigeria, enhancing accountability mechanisms and engaging teachers in policy development can bridge the gap between policy and practice. In contrast, the UK could benefit from adopting localised, adaptive approaches to complement structured frameworks, particularly in under-resourced communities.

Inclusion, diversity, and equity remain pressing challenges in Nigeria. Children with disabilities, multilingual learners, and students from marginalised communities face systemic barriers, exacerbated by teacher shortages and standardised curricula that neglect cultural representation. The UK, with its codified SEN frameworks and EAL support, shows that structured inclusion can improve educational access and outcomes. However, persistent achievement gaps indicate the need for ongoing refinement. Nigeria's adaptive, low-resource strategies offer insights for innovative, cost-effective approaches, while the UK can explore culturally responsive interventions to support heritage languages and multicultural classrooms.

Teacher workload and welfare reveal critical structural stressors in both contexts. Nigerian educators contend with excessive pupil-teacher ratios, delayed salaries, and limited professional support, creating conditions ripe for burnout

and attrition. UK teachers, though better compensated and supported, face administrative pressures and workload demands that impact their well-being. These findings underscore that improving teacher welfare through staffing investments, structured professional development, and workload regulation is essential for sustaining instructional quality and educational equity.

Gender dynamics further shape workforce realities. In Nigeria, female teachers dominate early years and primary education but remain underrepresented in STEM subjects and leadership roles, a situation compounded by workload and safety concerns. Conversely, in the UK, women are well-represented in teaching but underrepresented in senior leadership positions, often burdened by emotional labour and work-life pressures. Addressing these disparities requires context-specific strategies: Nigeria must enhance access, protection, and leadership pathways for women, while the UK must dismantle structural barriers to female advancement in decision-making roles.

Resource allocation and learning conditions demonstrate how funding and management influence educational outcomes. Nigeria's chronic underfunding cascades into insufficient materials, under-resourced classrooms, and constrained pedagogical innovation. The UK, while better resourced, faces challenges in maintaining ageing infrastructure and addressing digital inequities. Strategic investment in human and material resources is therefore critical for Nigeria. At the same time, the UK must balance modernisation with equity, ensuring that resource allocation sustains high-quality learning across diverse contexts.

Assessment and accountability practices shape instructional focus and learning progression. Nigeria's reliance on high-stakes, exam-centred assessment, combined with weak oversight by the inspectorate, limits formative feedback and teacher development. The UK's balanced approach, integrating formative and summative evaluation with robust monitoring, enhances teaching quality but also introduces pressures related to performance targets. Strengthening assessment literacy and functional accountability in Nigeria can support instructional improvement, while the UK must balance rigorous oversight with teacher wellbeing.

Professional development and career growth reflect systemic priorities. Nigerian CPD remains inconsistent, often underfunded, and disconnected from teachers' classroom realities, limiting capacity for inclusive and innovative pedagogy. The UK's structured professional development supports career progression and instructional excellence. Nigeria must invest in sustainable, systematic CPD linked to teacher performance and retention, while the UK could optimise CPD to reduce workload burdens and enhance adaptive teaching skills.

Finally, workload management and policy implications are interwoven across these areas. Nigeria's unregulated workloads and inconsistent welfare provision negatively affect teacher motivation, retention, and educational quality. The UK demonstrates effective workload regulation but continues to face stress-driven attrition in urban and high-need contexts. Policymakers in both countries must adopt strategies that balance accountability, teacher well-being, and instructional quality to ensure sustainable improvement.

In sum, the discussion reveals that while Nigeria faces foundational structural and systemic challenges, it also demonstrates resilience and adaptive capacity that can inform cost-effective innovations. The UK offers lessons in structured governance, inclusive policy, and resource management, yet it must continue addressing pressures related to workload, equity, and modernisation. The implications are clear: sustainable educational improvement requires integrated strategies that align infrastructure, policy, teacher well-being, inclusion, and professional development toward the ultimate goal of equitable, high-quality learning outcomes.

5.1 Limitations of the Study

While this study provides valuable insights into the comparative education landscapes of Nigeria and the United Kingdom, several limitations must be acknowledged. First, the research focused on selected states and schools, such as Kano State in Nigeria and specific regions in the UK, which may limit the generalizability of the findings. Second, the reliance on available reports, observational data, and self-reported information introduces potential bias and may not fully capture the nuanced experiences of all educators and learners. Third, socio-political, cultural, and economic differences between the two countries mean that some comparisons are context-specific and may not reflect broader realities in other regions or countries. Finally, this study provides a snapshot of the current landscape; evolving policies, infrastructure development, and educational reforms may alter these dynamics over time. Recognising these limitations ensures that the study's conclusions are interpreted in a realistic, measured context.

5.2 Implications for Future Research

This study opens several avenues for further exploration. Future research could expand the geographic scope to include additional Nigerian states, UK regions, or other countries to strengthen the comparative validity of findings. Longitudinal studies would provide insights into how interventions, policy reforms, and infrastructure improvements impact teaching quality and learning outcomes over time. Research focusing on specific subgroups, such as rural versus urban teachers, STEM versus non-STEM educators, or gendered experiences in teaching, could provide deeper, targeted insights. Additionally, intervention-based research evaluating programs in teacher welfare, inclusive pedagogy, or resource provision would help determine their effectiveness in enhancing educational outcomes. These directions can bridge existing knowledge gaps and inform evidence-based policy decisions to improve education systems globally.

6.0 Conclusion

This study examined critical differences and commonalities between the Nigerian and UK education systems, focusing on infrastructure, teacher welfare, inclusion, and gender dynamics. The findings reveal stark contrasts in resource allocation, policy implementation, and support structures, highlighting areas where Nigeria faces systemic challenges and where the UK can learn from innovative practices in resource-limited settings. Notably, the study underscores that effective education depends not only on material resources but also on teacher support, policy fidelity, and adaptive strategies in diverse classroom contexts. By illuminating these realities, the research provides a foundation for policymakers, educators, and researchers to design interventions that strengthen teaching quality, promote equity, and prepare students for increasingly complex and multicultural learning environments. Ultimately, the study emphasises that meaningful improvements in education require both systemic investment and contextualised, innovative approaches.

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Appropriate Deployment of Robots can aid Nigerian Manufacturing Industries to compete favourably in the global Marketplace

¹Prof Oliver E., Osuagwu ¹ ; Oliver, Obilor Osuagwu ²

¹ Department of Computer Science/ Imo State University, Owerri, Imo State, Nigeria

² Department of Electrical Electronics Engineering/ Imo State University, Owerri, Imo State, Nigeria
+234 816 629 7586

Abstract:

This paper is geared towards raising awareness of the need to develop skills in robot design, production, and programming. The robot revolution has positively impacted industries worldwide, particularly in cost reduction, product quality, and competitive pricing. Corporations that embrace automation are able to compete effectively in international markets. In Africa, however, the reverse is the case. For Africans to remain relevant in the comity of nations, it is imperative to strengthen knowledge workers by equipping them with new skills, particularly in intelligent machine and robot design, as well as the associated Artificial Intelligence (AI) programming components.

This paper contends that the absence of innovation in science and technology will leave Africa a century behind the rest of the world if concerted efforts are not made by African governments to avert this envisaged catastrophe through political will and effective, pragmatic national planning. The paper addresses the definition of a robot, its key components, local content input, integration, and programming, as well as its contribution to national economic growth. There is therefore an urgent need for active government policy thrust to support aggressive skill acquisition in machine and robot design, fabrication, and programming, utilizing available local material content within the nation's Departments of Mechanical Engineering, Electronics and Computer Engineering, Mathematics, and Computing Sciences.

Conclusion: *Learning the skill to program robots will enable African industries to embrace robotics and foster competition in precision, quality, and pricing of manufactured goods. Africa cannot achieve sustainable development without this caliber of knowledge workers, as true progress is driven by innovation in science and technology.*

It is therefore recommended that African governments actively promote the design, manufacture, and programming of intelligent robots for industrial use. Such initiatives will generate a snowball effect across industries, enhancing market competition, product quality, pricing, and packaging. This paper hopes to inspire pragmatic automation in African industries, ensuring the continent's relevance in the global marketplace.

Keywords: *Robotics in Africa, Intelligent machines, Artificial Intelligence (AI) programming, Industrial automation, Manufacturing competitiveness, Innovation in science and technology, Robot design and fabrication, Knowledge workers in Africa, Global marketplace integration, Smart manufacturing, National economic growth, Local content development, Pragmatic automation, Government policy on robotics, Skill acquisition in engineering*

1.0 Introduction

1.1 Application of Robots in the Industry

A robot is a multi-function, programmable machine that imitates the actions or appearance of an intelligent creature—usually a human. Engineering Innovation [1] defines a robot as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.”

For a machine to qualify as a robot, it must be able to:

- i. Sense and perceive:** gather information from its surroundings
- ii. Carry out different tasks:** locomotion or manipulation, performing physical actions
- iii. Move or manipulate objects**
- iv. Be re-programmable:** capable of performing different functions
- v. Function autonomously** and/or interact with human beings

1.2 Attributes of Intelligent Robots

Robots described as intelligent ought to possess the following attributes:

- i. Autonomy:** ability to achieve task objectives without human input, making and executing decisions based on sensor information
- ii. Intuitive Human-Robot Interfaces:** commands should be natural and require minimal training, especially in smart home applications
- iii. Adaptation:** Ability to adjust to changes in the environment. Thus, robot systems operating in intelligent environments require capabilities such as:
 - i.** Autonomous control systems
 - ii.** Simple and natural human-robot interfaces
 - iii.** Adaptive and learning capabilities
 - iv.** Safety maintenance during operation

1.3 Major Parts of a Robot

Robots generally consist of three major parts:

- 1. Mechanical Base** – The frame on which a robot sits and operates, usually mechanical or plastic.
- 2. Actuation Mechanism** – A device designed to move a control member in automatic or remote-control systems, serving as an auxiliary drive in servomechanisms and vehicular steering gear. It alters energy or material flow to an object, ensuring minimal deviations from prescribed values. Typically, it is powered by external sources, as direct control via relays or transducers is insufficient.
- 3. Control** – Robot control refers to the way in which the sensing and action of a robot are coordinated. There are infinitely many possible robot programs, but they all fall along a well-defined spectrum of control. Along this spectrum, four basic practical approaches are being used today:
 - i.** Deliberative control
 - ii.** Reactive control
 - iii.** Hybrid control
 - iv. Behavior-based control:** Robot intelligence is made possible through specialized robot programming languages.

What makes a robot intelligent is the software driver written by AI software engineers to control Kinematics and dynamic actions such as Simple and Compound joints, Mobility, Work areas and Coordinates

1.4 Robotics as a Discipline

Robotics is the science and technology of building robots, and comprises multiple fields shown in **Fig 1**, including:

- i.** Control Theory
- ii.** Vision systems
- iii.** Artificial intelligence

- iv. Mechanical engineering
- v. Information technology
- vi. Electrical engineering

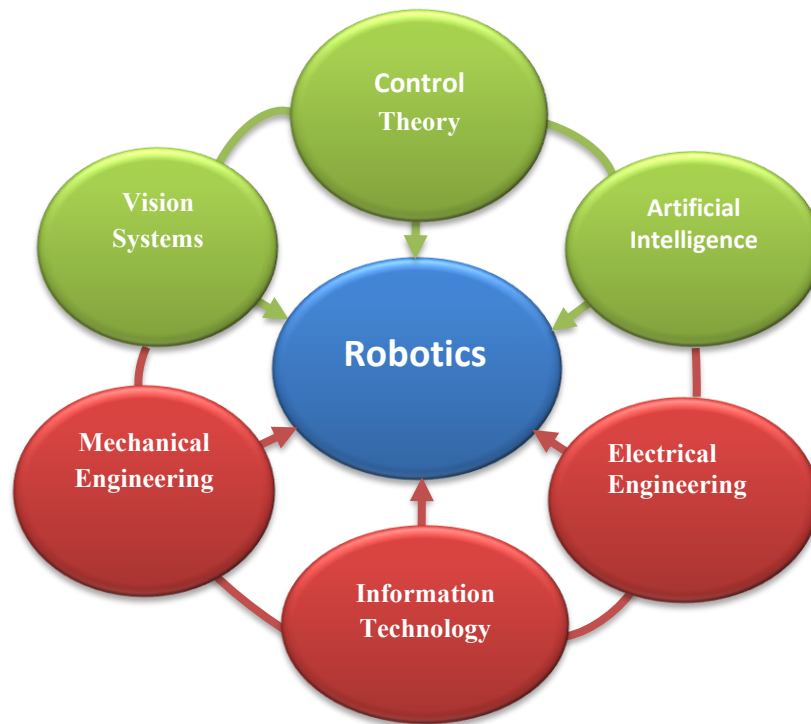


Fig. 1: Composition of Robot Knowledge Areas

2.0 Robot Intelligence and Computer Programs

What makes a robot intelligent is the software driver written by AI software engineers to control kinematics and dynamic actions such as simple and compound joints, mobility, work areas, and coordinates.

3.0 Types of Robots

3.1 Many types of robots exist today. The progress of technology allows us now to build an intelligent robot with perception and manipulation under \$1,000. There are several kits for even high school robotics.

3.2 Robotics allows us to explain ideas of control, software, sensors, motors, and other effectors, image processing, pattern recognition, machine learning, and Artificial Intelligence.

3.3 Some kinds of robots in the marketplace today include:

- i. **Driving Robots:** Uses differential steering, synchro-drive, and tracked vehicles. They are autonomous cars, also known as driverless cars, self-driving cars, or robot cars. It is an autonomous vehicle capable of fulfilling human transportation.
- ii. **Omni-Directional Robots:** Deploys Mecanum wheels. This type of robot can have a significant advantage over conventional robots. Each robot can drive in any direction, i.e., forward/backward, sideways, or at an angle.

- iii. **Flying Robots:** Sensors and structure for surveillance and detection. Equipped with appropriate sensors, the FR SWAN X1 collects and transmits real-time images useful for decision-making.
- iv. **Balancing Robots:** Deploys an inverted pendulum. They are simple robots that use a simple switch as a sensor and stand on only two wheels with an inverted pendulum mechanism. When the robot is going to fall, the motor starts and moves the robot in the direction it is going to fall, so the motor torque about the center of gravity is higher than the motor torque required to keep the robot balanced.
- v. **Walking Robots:** Six-legged walking robots, bipedal android robots. A mobile robot is an automatic machine that is capable of movement in any given environment. Mobile robots have the capability to move around in their environment and are not fixed to one physical location.

4.0 Knowledge Acquisition

Modern robots need knowledge acquisition capabilities via the deployment of the following related technologies:

- i. Sensors
- ii. Cameras
- iii. Radar
- iv. Tactile sensors
- v. Infrared, etc.

Decision-making systems are mainly Artificial Intelligence programs.

5.0 History of World Robot Development

| S/N | Year | History of World Robot Development |
|-----|-----------|--|
| 1 | 200 BC | Greek Development for Theatre Automation (Greeks created automated theatre mechanisms, achieving lifelike stage effects through mechanical engineering.) |
| 2 | 1500 | Leonardo da Vinci (Leonardo da Vinci designed mechanical automata, including a humanoid knight) |
| 3 | 1650-1774 | Robot dolls (scribe 1774) (Early automata were developed that could write, demonstrating mechanical precision and lifelike motion) |
| 4 | 1968 | “Artificial Intelligence” era, shakey, 30min./m (Shakey the Robot: First mobile robot controlled by Artificial Intelligence, achieving autonomous navigation and decision-making) |
| 5 | 1980 | Transport Units in Factories (Robots began moving materials in factories, improving efficiency and reducing human labor) |
| 6 | 1985 | “Showboats” (Wasubot Piano-Player, etc.): (ShowBots & MIT Leg Lab: Entertainment robots demonstrated interactive automation, while MIT advanced robotic locomotion research) |
| 7 | 1989 | TRC Helpmate: (Introduced as a mobile service robot, capable of assisting in hospitals and workplaces.) |
| 8 | 1990 | Service Robots: (Cleaning and assistance robots emerged, marking the rise of practical household and industrial automation) |
| 9 | 1995 | Autonomous sojourner (“Low cost”): (Autonomous Automobiles: Early prototypes of self-driving cars demonstrated robotic navigation in real-world environments) |

| | | |
|----|-----------|---|
| 10 | 1997 | Mars Rover Sojourner <i>(NASA's rover achieved autonomous exploration on Mars, proving robotics in space missions)</i> |
| 11 | 2002-2020 | Advanced Humanoids: <i>(Robots like ASIMO and Atlas achieved walking, balancing, and complex tasks, driven by AI and machine learning)</i> |

5.1 Robot Applications: The African Imperative

Today, besides the typical use of industrial robots in the manufacturing industry, new application areas for robots have been appearing during the past few years. In these areas, service robots perform general-purpose activities without requiring repeated high-speed movements or other requirements of industrial robot applications.

Thus, in modern economies, the developed West has moved production plants demanding a huge labour force to developing countries where labour is cheap in order to compete in the international markets.

Alternatively, they outsource such jobs demanding manual labour if the cost-benefit analysis justifies this option. This becomes inevitable, particularly where the task involved cannot deploy robots to reduce the cost of production. Consequently, the cost of products coming from the West has the capacity to compete in terms of price and quality in the world marketplace.

For African industries to compete like those in the West, an automation culture has to be imbibed. Most robot fabrication requires the services of Mechanical Engineers, Electrical Engineers, Computer/AI programmers, Information Technology Professionals, etc. These high-caliber knowledge workers need advanced skills in AI and robotics programming for African industries to be able to benefit from this cost-reduction technology. The governments in Africa need to invest in this technology now.

5.2 Benefits of Robot Deployment

Robots are excellent for application in risky tasks where machines, instead of human beings, can be sacrificed. The benefits that may accrue to an industrialist deploying robots include [2]:

Quality:

Industrial automated robots have the capacity to dramatically improve product quality. Applications are performed with precision and high repeatability every time. This level of consistency can be hard to achieve any other way.

Production:

With robots, throughput speeds increase, which directly impacts on production. Because an automated robot has the ability to work at a constant speed without pausing for breaks, sleep, or vacations, it has the potential to produce more than a human worker.

Safety:

Robots increase workplace safety. Workers are moved to supervisory roles where they no longer have to perform dangerous applications in hazardous settings.

Savings:

Improved worker safety leads to financial savings. There are fewer healthcare and insurance concerns for employers. Automated robots also offer untiring performance which saves valuable time. Their movements are always exact, minimizing material waste.

These benefits are bound to help African industries compete in the international marketplace.

5.3 Designing and Building an Indigenous Robot

Step 1: The first step is to determine what your robot should do (i.e., what is its purpose in life). Robots can be used in almost any situation and are primarily intended to help humans in some way.

Step 2: Decide on the type of robot you want to build and what the robot would look like to best suit your mission.

Step 3: Choose the right actuators (e.g., motors) for your chosen robot.

Step 4: Choose your microcontroller. A microcontroller is a computing device capable of executing a program (i.e., a sequence of instructions) and is often referred to as the “brain” or “control center” in a robot since it is usually responsible for all computations, decision making, and communications, as shown next.

5.4 Robot Programming 1

Computer programming consists of writing lines of code in a language that a computer will understand to solve a problem. Some computer languages include: Java, C++, and Python. Python is said to be a programming language that lets you work quickly and integrate systems more effectively. Calculations are simple with Python, and expression syntax is straightforward [4] [5].

Computer science or programming can solve problems ranging from adding numbers together to operating a rover on the Mars planet. Python is one of the key languages for robotic programming. It is easier to deploy Python to talk to robots and have them make noises, move, take pictures, draw, and explore their environment.

For instance, the Scribbler Robot deploys two commands to tell the robot to make noise: **beep** and **speak**.

- i. **beep()** takes in information about the number of seconds and frequency of a note. Example: `beep(1,440)` plays a one-second note.
- ii. **speak()** takes in a message in quotes. Example: `speak("Hello")`.

5.5 Microcontroller

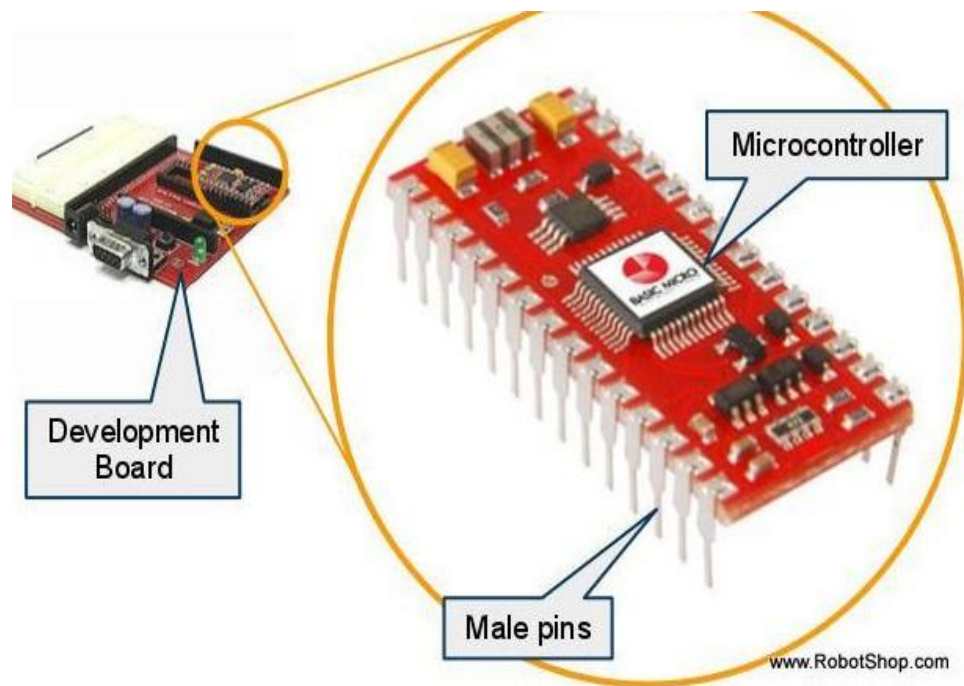


Fig. 2: Microcontroller (Source: www.Robotshop.com)

In more advanced robots, especially those that involve complex computing and vision algorithms, the microcontroller is often replaced with a standard computer.

A desktop computer includes a motherboard, a processor, a main storage device (such as a hard drive), video processing (on-board or external), RAM, and, of course, peripherals such as a monitor, keyboard, mouse, etc. This type of system is usually more expensive, physically larger, and more power hungry.



Fig. 3: *An Arduino microcontroller – Arduino Uno*

5.6 What is an Actuator?

An “actuator” can be defined as a device that converts energy (in robotics, that energy tends to be electrical) into physical motion. The vast majority of actuators produce either rotational or linear motion. For instance, a “DC motor” is therefore a type of actuator.

Choosing the right actuators for your robot requires an understanding of what actuators are available, some imagination, and a bit of math and physics.

Actuators can be Pneumatic and Hydraulic or AC Motor, DC Motor, Geared DC Motors, R/C Servo Motors, Industrial Servo Motors, Stepper Motors, DC Linear Actuator, and Solenoids.

In choosing an actuator, ask yourself:

- i. Will the motor be used to lift or turn a heavy weight?
- ii. Is the range of motion limited to 180 degrees?
- iii. Does the angle need to be very precise?
- iv. Is the motion in a straight line?

A **Motor Controller** is an electronic device (usually comes in the shape of a bare circuit board without enclosure) that acts as an intermediate device between a microcontroller, a power supply or batteries, and the motors.

Types of Actuators include:

- i. Pneumatic and Hydraulic
- ii. AC Motor
- iii. DC Motor
- iv. Geared DC Motors
- v. R/C Servo Motors
- vi. Industrial Servo Motors
- vii. Stepper Motors
- viii. DC Linear Actuator
- ix. Solenoids

Selection considerations:

- i. Will the motor be used to lift or turn a heavy weight?
- ii. Is the range of motion limited to 180 degrees?
- iii. Does the angle need to be very precise?
- iv. Is the motion in a straight line?

A motor controller is an electronic device (usually comes in the shape of a bare circuit board without enclosure) that acts as an intermediate device between a microcontroller, a power supply or batteries, and the motors.

5.7 Types of Motor Controllers

- i. **Brushed DC motor controllers:** Used with brushed DC, DC gear motors, and many linear actuators.
- ii. **Brushless DC motor controllers:** Used with brushless DC motors.
- iii. **Servo Motor Controllers:** Used for hobby servo motors.
- iv. **Stepper Motor Controllers:** Used with unipolar or bipolar stepper motors, depending on their kind.

5.8 Controlling the Robot

The robot can be controlled using:

5.8.1 Direct Wired Control

The easiest way to control a vehicle is with a handheld controller physically connected to the vehicle using a cable (i.e., a tether). Toggle switches, knobs, levers, joysticks, and buttons on this controller allow the user to control the vehicle without the need to incorporate complex electronics. In this situation, the motors and a power source can be connected directly with a switch in order to control its forward/backwards rotation. Such vehicles usually have no intelligence and are considered to be more “remote-controlled machines” than “robots.”

5.8.2 Wired Computer Control

The next step is to incorporate a microcontroller into the vehicle, but continue to use a tether. Connecting the microcontroller to one of your computer’s I/O ports (e.g., a USB port) allows you to control its actions using a keyboard (or keypad), joystick, or other peripheral device.

Adding a microcontroller to a project may also require you to program how the robot reacts to the input. Instead of using a laptop or desktop computer, notebooks are often a desirable choice because of their low price, small size, and low weight.

5.8.3 Wireless – Infrared

Infrared transmitters and receivers cut the cables connecting the robot to the operator. This is usually a milestone for beginners. Infrared control requires “line of sight” in order to function; the receiver must be able to “see” the transmitter at all times in order to receive data. Infrared remote controls (such as universal remote controls for televisions) are used to send commands to an infrared receiver connected to a microcontroller, which then interprets these signals and controls the robot’s actions.

5.8.4 Radio Frequency (RF)

Commercially available **Remote Control (R/C) units** use small microcontrollers in the transmitter and receiver to send, receive, and interpret data sent via radio frequency (**RF**). The receiver box has a PCB (printed circuit board) which comprises the receiving unit and a small servo motor controller.

RF communication requires either a transmitter matched/paired with a receiver, or a transceiver (which can both send and receive data). **RF** does not require line of sight and can also offer a significant range (transmission distance). Standard radio frequency devices can allow for data transfer between devices as far away as several kilometers, and there is seemingly no limit to the range for more professional **RF** units.

Bluetooth is a form of **RF** and follows specific protocols for sending and receiving data. Normal **Bluetooth** range is often limited to about 10m, though it does have the advantage of allowing users to control their robot via Bluetooth-enabled devices such as cell phones, **PDA**s, and laptops (though custom programming may be required to create an interface). Just like **RF**, **Bluetooth** offers two-way communication.

WiFi is now an option for robots; being able to control a robot wirelessly via the internet presents some significant advantages (and some drawbacks) to wireless control. In order to set up a WiFi robot, you need a wireless router connected to the internet and a WiFi unit on the robot itself. For the robot, you can also use a device that is TCP/IP enabled with a wireless router.

Another wireless technology that was originally developed for human-to-human communication, the cell phone, is now being used to control robots. Since cellular frequencies are regulated, incorporating a cellular module on a robot usually requires added patience for programming as well as an understanding of the cellular network system and the regulation.

5.9 Autonomous Control

The next step is to use the microcontroller in your robot to its full potential and program it to react to input from its sensors. Autonomous control can come in various forms: pre-programmed with no feedback from the environment, limited sensor feedback, and finally, complex sensor feedback. True “autonomous control” involves a variety of sensors and code to allow the robot to determine by itself the best action to be taken in any given situation.

5.10 Sensors

- i. Switches, buttons, and contact sensors:** Used to detect physical contact between objects and are not just restricted to humans pushing buttons; bumpers on a robot can be equipped with momentary push buttons.
- ii. Pressure sensor:** Unlike a push button which offers one of two possible readings (ON or OFF), a pressure sensor produces an output proportional to the force that is being applied to it.
- iii. Ultrasonic Range Finder:** Uses acoustics to measure the time between when a signal is sent versus when its echo is received back. Ultrasonic range finders can measure a range of distances but are used specifically in air and are affected by the reflectivity of different materials.

- iv. **Infrared light:** Can be used to measure distance. Some infrared sensors measure one specific distance while others provide an output proportional to the distance to an object.
- v. **Laser:** Lasers are used when high accuracy, or long distances (or both) are required when measuring the range to an object. Scanning laser rangefinders use spinning lasers to get a two-dimensional scan of the distances to objects.
- vi. **Encoders:** Optical encoders use mini infrared transmitter/receiver pairs and send signals when the infrared beam is broken by a specifically designed spinning disk (mounted to a rotating shaft). The number of times the beam is broken corresponds to the total angle travelled by a wheel. Knowing the radius of the wheel, you can determine the total distance travelled by that wheel. Two encoders give you a relative distance in two dimensions.

5.11 Robot Positioning

- i. **Indoor Localization (room navigation):** An indoor localization system can use several beacons to triangulate the robot's position within a room, while others use a camera and landmarks.
- ii. **GPS:** A GPS uses the signals from several satellites orbiting the planet to help determine its geographic coordinates. Regular GPS units can provide geographical positioning down to 5m of accuracy, while more advanced systems involving data processing and error correction thanks to the use of other GPS units or IMUs can be accurate down to several cm.

5.12 Tools

5.12.1 Mechanical Tools (Essential)

- i. **Small screwdriver set:** These small screwdrivers are necessary when working with electronics. Don't force them too much, though – their size makes them more fragile.
- ii. **Regular screwdriver set:** All workshops need a multi-tool or tool set that includes flat/Phillips and other screwdriver heads.
- iii. **Needle-nose pliers:** A set of needle-nose pliers is incredibly useful when working with small components and parts and is a very inexpensive addition to your toolbox. These are different from regular pliers because they come to a point that can get into small areas.

5.13 Ultimate Tools

- i. **Tabletop CNC mill:** A tabletop CNC machine allows you to precisely machine plastics, metals, and other materials and creates three-dimensional, intricate shapes.
- ii. **Tabletop lathe:** A (manual) tabletop lathe allows you to create your own hubs, shafts, spacers, adapters, and wheels out of various materials. A CNC lathe tends to be overkill since most builders only need to change the diameter rather than create complex shapes.
- iii. **Vacuum Forming Machine:** Vacuum forming machines are used to create complex plastic shells that are moulded to your exact specifications.
- iv. **Metal Benders:** When making robotic frames or enclosures out of sheet metal or metal extrusions, using a metal bender is essential in order to obtain precise and repeatable bends.
- v. **Other Specialized Tools:** At this stage, you will be very aware of your machining needs and will probably require more specialized tools, such as metal nibblers and welding.

5.14 Essential Tools

CAD Tools:

- i. Google SketchUp is a free program that can be used to create your robot in 3D, to the proper scale, complete with texture. This can help you ensure that parts are not overlapping, check dimensions for EAGLE holes, and change the design before it is built.
- ii. Autodesk 123D is another free 3D CAD (Computer Aided Design) software aimed at hobbyists. While it shares many of the same features as Google SketchUp, it has some interesting features such as solid-based part design, assemblies, parametrized transforms, and other functionalities that are usually seen in higher-end CAD programs.

5.15 Software Tools

- i. **Programming software:** Your first programming software should correspond to whichever **microcontroller** you selected. If you chose an Arduino microcontroller, you should choose the Arduino Software; if you chose a Basic Stamp from Parallax, you should choose **PBasic**, and so forth. In order to use a variety of microcontrollers, you may want to learn a more fundamental programming language such as BASIC or C.
- ii. **Schematics and PCBs:** There are many free programs available on the market, and **CadSoft's** is one of the more popular. It includes an extensive library of parts and helps you convert your schematic to a PCB.

Ultimate Tool:

- i. **CAD SolidWorks** is the CAD program of choice for many when doing mechanical design, but it is certainly not the only one available. When working at this level (i.e., using programs worth several thousands of dollars), you should have a good idea of your needs in order to choose the right tool (**Unigraphics, Catia, ProE, etc.**).
- ii. **CAM:** If you are using a CNC machine, you will need a proper **3D CAD** program such as **ProE, AutoCAD, SolidWorks**, or other similar programs. In order to convert your **CAD** model to usable code to send to the CNC machine, you need a **CAM** program. Often, you can purchase a **CAM** program specifically for the **CAD** software you selected, or find a third-party supplier.

5.16 Raw Materials (Essential)

- i. **Thin sheet metal:** This material can be cut easily with scissors and can be bent and shaped as needed to form the frame or other components of your robot without necessarily having to do machining.
- ii. **Cardboard:** The right cardboard (thick but can still be cut using hand tools) can easily be used to make a frame or prototype. Even basic glue can be used to hold cardboard together.
- iii. **Thin plastic:** Polypropylene, PVC about 1/16" thick can be sawed to create a more rigid and longer-lasting frame for your robot.
- iv. **Thin wood:** Wood is a great material to work with if you have the means. It can be screwed, glued, sanded, finished, and more.
- v. **Polymorph:** Polymorph allows you to create plastic parts without the hassle of having to create custom moulds.
- vi. **Sheet metal:** If you have thicker metal-cutting shears, sheet metal makes an excellent building material for a robot frame because of its durability, flexibility, and resistance to rust.
- vii. **Plastic sheets:** Plastic sheets are fairly rigid and resist deformation. If you are cautious and slow when cutting or drilling most plastics, the results can look professional.

5.17 Assembling the Robot Components

- i. Connect motors to motor controller.
- ii. Connect batteries to a motor controller or a microcontroller. Most motor controllers have two screw terminals for the battery leads labelled B+ and B-. If your battery came with a connector and your controller uses screw terminals, you may be able to find a matching connector with pigtails (wires) which you can connect to the screw terminals. If not, you may need to find another way to connect the battery to the motor controller while still being able to unplug the battery and connect it to a charger.

It is possible that not all the electromechanical products you chose for your robot can operate at the same voltage and thus may require several batteries or voltage regulation circuits.

Usual voltage levels involved in common hobby robotics components:

- i. DC gear motors – 3V to 24V
- ii. Standard Servo motors – 4.8V to 6V
- iii. Specialty Servo motors – 7.4V to 12V
- iv. Stepper motors – 6V to 12V
- v. Microcontrollers usually include voltage regulators – 3V to 12V
- vi. Sensors – 3.3V, 5V, and 12V
- vii. DC motor controllers – 3V to 48V
- viii. Standard batteries – 3.7V, 4.8V, 6V, 7.4V, 9V, 11.1V, and 12V

Other connections:

- i. Connect motor controllers to microcontroller.
- ii. Connect sensors to a microcontroller.
- iii. Connect communication device to microcontroller.
- iv. Connect electrical components to frame.

5.18 Programming the Robot

There are many programming languages that can be used to program microcontrollers, the most common of which are:

- i. **Assembly:** Just one step away from machine code and as such it is very tedious to use. Assembly should only be used when you need absolute instruction-level control of your code.
- ii. **Basic:** One of the first widely used programming languages, it is still used by some microcontrollers (Basic Micro, BasicX, Parallax) for educational robots.
- iii. **C/C++:** One of the most popular languages, C provides high-level functionality while keeping good low-level control. RobotC is a good example.
- iv. **Java:** More modern than C and provides lots of safety features to the detriment of low-level control. Some manufacturers like Parallax make microcontrollers specifically for use with Java.

- v. **.NET/C#:** Microsoft's proprietary language used to develop applications in Visual Studio. Examples include Netduino, FEZ Rhino, etc.
- vi. **Processing Arduino:** A variant of C++ that includes some simplifications in order to make programming easier.
- vii. **Python:** One of the most popular scripting languages. It is very simple to learn and can be used to put programs together very fast and efficiently.

5.19 Programming Skill Advice

- i. **Create manageable chunks of functional code:** By creating segments of code specific to each product, you gradually build up a library. Develop a file system on your computer to easily look up the necessary code.
- ii. **Document everything within the code using comments:** Documenting everything is necessary in almost all jobs, especially robotics. As you become more advanced, you may add comments to general sections of code, though as you start, you should add a comment to (almost) every line.
- iii. **Save different versions of the code:** Do not always overwrite the same file. If you find one day that your 200+ lines of code do not compile, you won't be stuck going through it line by line; instead, you can revert to a previously saved (and functional) version and add/modify it as needed. Code does not take up much space on a hard drive, so you should not feel pressured to save only a few copies.
- iv. **Raise the robot off the table or floor when debugging:** This prevents wheels/legs/tracks from accidentally launching it off the edge. Keep the power switch close by in case the robot tries to destroy itself. For example, if you send a servo motor a 400us signal when it only accepts a 500 (corresponding to 0 degrees) to 2500us (corresponding to 180 degrees) signal, the servo would try to move to a location it cannot physically go to (-9 degrees) and ultimately burn out.
- v. **Turn off power if code misbehaves:** If code does something that does not seem to be working correctly after a few seconds, turn off the power. It is highly unlikely the problem will "fix itself," and in the meantime, you may be destroying part of the mechanics.
- vi. **Use subroutines:** Subroutines may be a bit difficult to understand at first, but they greatly simplify your code. If a segment of code is repeated many times within the code, it is a good candidate to be replaced with a subroutine.

5.20 Programming the Robot

A good example of how program is used to move the robot can be illustrated thus:

- i. `motors(1,1) forward full speed`
- ii. `motors(0.5,0.5) forward half speed`
- iii. `motors(-1,-1) backward`
- iv. `motors(0,0) / stop()`
- v. `motors(1,-1) spin`

Commands for pictures and movies:

```

programming
command
pic = takePicture()
show(pic)
savePicture(pic, "pic.jpg")
    
```

Robots have a series of different sensors to obtain information from the surroundings, such as:

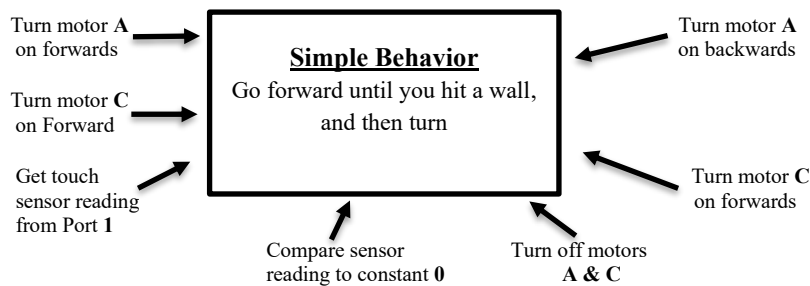
- i. IR sensors: locate various obstacles
- ii. Light sensors: measure light levels

5.21 Robot Programming Behaviours

Robot programming behaviours describe the actions and decisions of your robot.

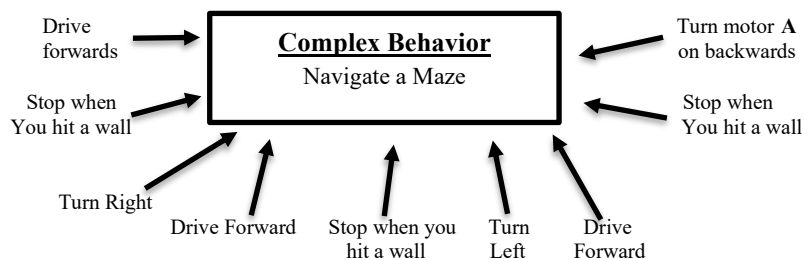
- i. **Basic behaviours:** Actions the robot performs directly.
- ii. **Simple behaviours:** Actions as we think about them.
- iii. **Complex behaviours:** Describe more interesting functions of the robot.

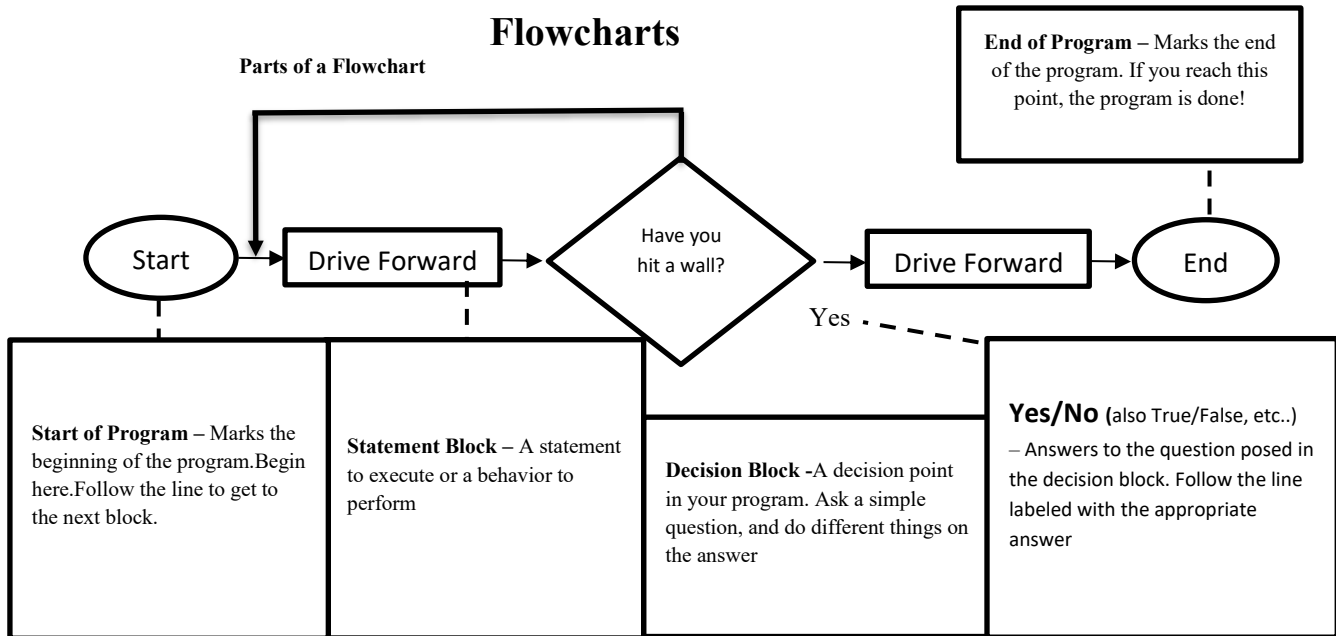
Flowcharts organize the steps. Pseudocode describes the steps using the robot’s motors and sensors.



Complex behaviour example:

Complex behaviours allow robots to describe the full scope of what the robot can do. This is always composed of smaller behaviours, so you can break them down.





Sample pseudocode:

Pseudo-code is halfway in between English and computer code. It describes what sensors and motors do and see with simple behaviors. Below is a sample of pseudocode:

- i. Move forward until the touch sensor is pressed
- ii. Stop all motors
- iii. Reverse for 1 second
- iv. Stop all motors
- v. Turn right

5.22 Programming Language – ROBOTC

ROBOTC [3] is a text-based robot compiler. Commands to the robot are first written as text on the screen. They are then processed by the ROBOTC compiler into a machine language file that the robot can understand. Finally, they are loaded onto the robot, where they can be run via embedded systems programming. This is demonstrated in Fig. 2 below

```

Program code
(Comands to the robot written as text)

task main()
{
    motor[port3] = 127;
    wait1Msec(3000);
}
    
```

Fig 2: Sample ROBOTC Program – Motor Control
 (“motor[port3] = 127;” instructs the motor plugged into Motor Port 3 to turn on at full power.)

5.23 Code

Text written as part of a program is called code. You type code just like you type normal text. Keep in mind that capitalization is important to the computer. Replacing a lowercase letter with a capital letter (or vice versa) will cause the robot to become confused. See Fig 3:

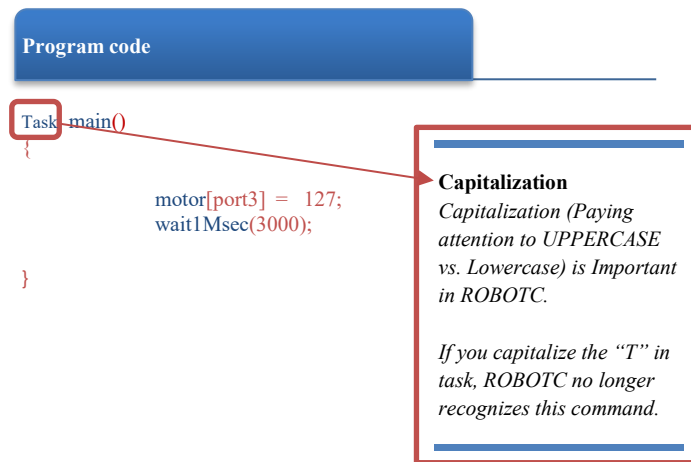


Fig. 3: Capitalization in ROBOTC

As you type your codes, ROBOTC will try to help you out by coloring the words it recognizes. If a word appears in a different color, it means ROBOTC recognizes it as an important word in the programming language.

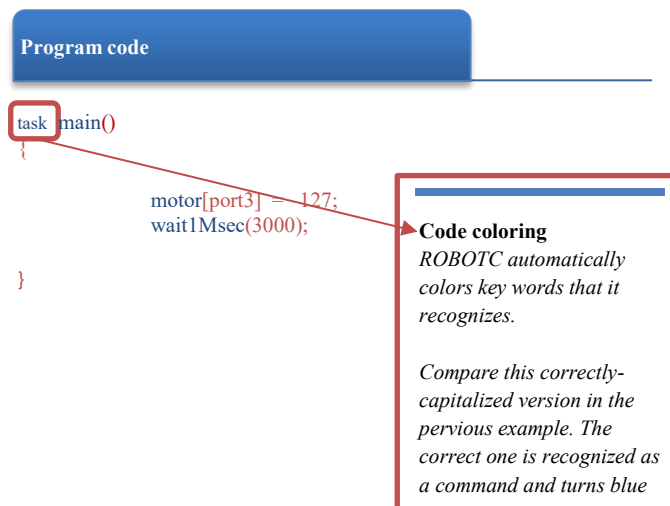
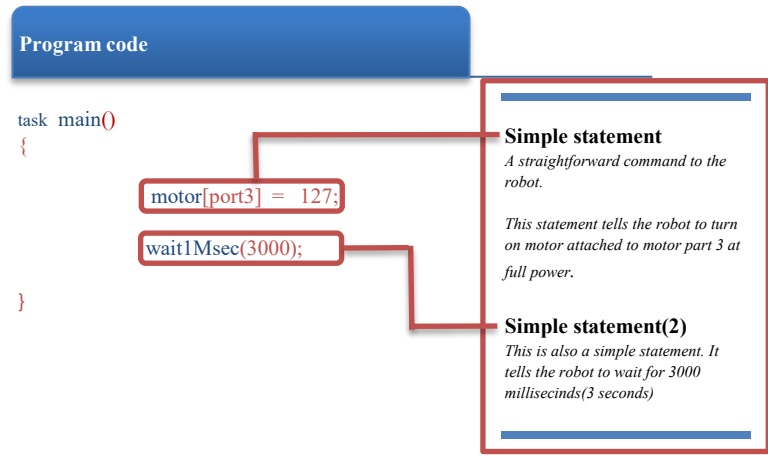


Fig. 4: Code Coloring in ROBOTC

Statements:

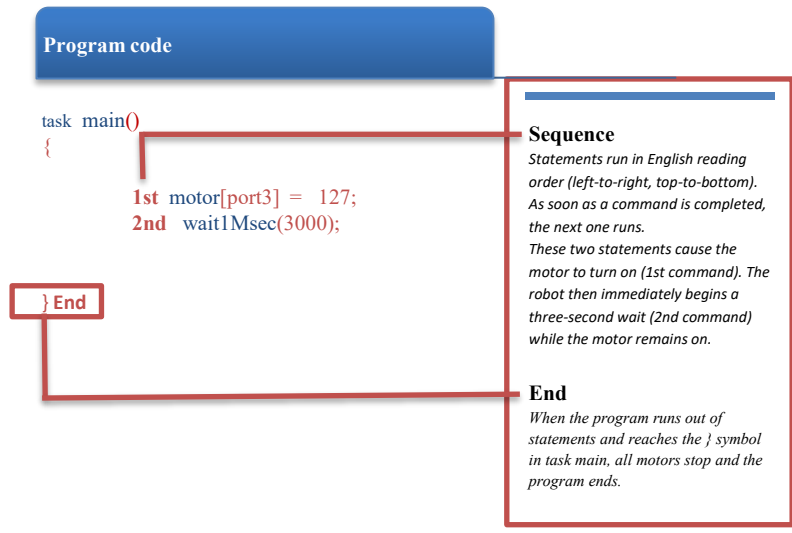
Statements are instructions for the robot. The most basic kind of statement in ROBOTC simply gives a command to the robot. Example:



motor[port3] = 127; instructs the motor plugged into Motor Port 3 to turn on at full power.

5.24 Running the Program

Statements are run in order as quickly as the robot is able to reach them. Running this program below on the robot turns the motor on, waits for 3000 milliseconds (3 seconds) with the motor still running, and then ends.



5.25 RobotC Rules

RobotC rules include the fact that white spaces, tabs, and line breaks are not important to the compiler and the robot but are sometimes needed for separation of words in multi-word commands. They are usually ignored by the robot. Thus, spaces and line breaks in ROBOTC are only used to separate words from each other in multi-word commands. Spaces, tabs, and lines do not affect the way a program is interpreted by the machine.

Program code

```
task main()
{
    motor[port3] = 127;
    wait1Msec(3000);
}
```

Whitespace
Spaces, tabs, and line breaks are generally unimportant to ROBOTC and the robot.

They are sometimes needed to separate words in multi-word commands, but are otherwise ignored by the machine.

5.26 Programming Readability

Codes are written on separate lines to enable the programmer to interact and communicate with the robot. Using spaces, tabs, and lines helps human programmers read the code more easily.

Making good use of spacing in your program is a very good habit for your own sake and for general readability. Observe the difference between Figs 7 and 8.

Program code

```
task main() {motor[port3]
=127; wait1Msec(3000);}
}
```

No Whitespace
To ROBOTC, this program is the same as the last one. To the human programmer, however, this is close to gibberish.

Whitespace is used to make programs readable to humans.

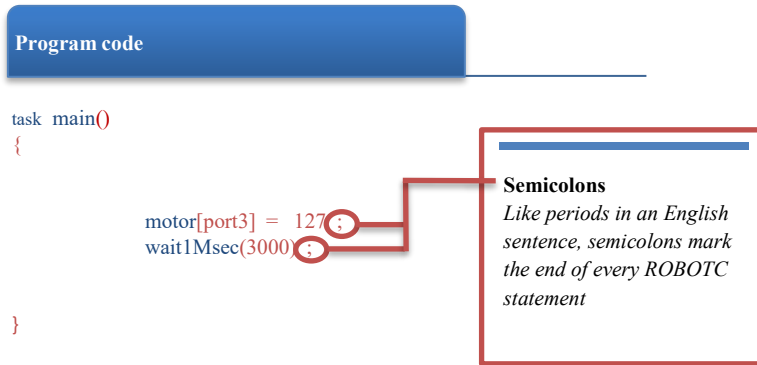
Punctuation:

Punctuation marks enable ROBOTC to know where one statement ends and the other begins. This is made possible by the semicolon (;) at the end of each line. Every statement ends with a semicolon. It is like the period at the end of a sentence.

Program code

```
task main()
{
    motor[port3] = 127;
    wait1Msec(3000);
}
```

Semicolons
Like periods in an English sentence, semicolons mark the end of every ROBOTC statement

A diagram illustrating the use of semicolons in ROBOTC code. It shows a code block with two lines of code: 'motor[port3] = 127;' and 'wait1Msec(3000);'. Red circles are drawn around the semicolons at the end of each line. A red line connects these circles to a callout box on the right. The callout box has a blue header and contains the text: 'Semicolons' followed by 'Like periods in an English sentence, semicolons mark the end of every ROBOTC statement'.

Punctuation pairs:

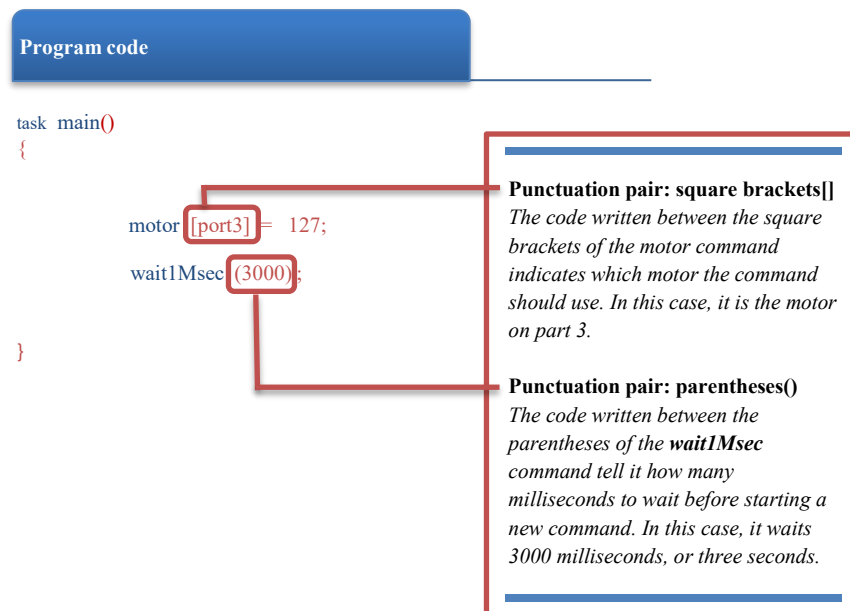
Like parentheses and square brackets, punctuation pairs are used to mark off special areas of code. Every punctuation pair consists of an opening punctuation mark and a closing punctuation mark. The punctuation pair designates the area between them as having special meaning to the command that they are part of. See Fig 10

Program code

```
task main()
{
    motor[port3] = 127;
    wait1Msec(3000);
}
```

Punctuation pair: square brackets[]
The code written between the square brackets of the motor command indicates which motor the command should use. In this case, it is the motor on port 3.

Punctuation pair: parentheses()
The code written between the parentheses of the wait1Msec command tell it how many milliseconds to wait before starting a new command. In this case, it waits 3000 milliseconds, or three seconds.

A diagram illustrating punctuation pairs in ROBOTC code. It shows a code block with two lines of code: 'motor[port3] = 127;' and 'wait1Msec(3000);'. Red boxes are drawn around the square brackets in the first line and the parentheses in the second line. Red lines connect these boxes to two callout boxes on the right. The first callout box has a blue header and contains the text: 'Punctuation pair: square brackets[]' followed by 'The code written between the square brackets of the motor command indicates which motor the command should use. In this case, it is the motor on port 3.' The second callout box has a blue header and contains the text: 'Punctuation pair: parentheses()' followed by 'The code written between the parentheses of the wait1Msec command tell it how many milliseconds to wait before starting a new command. In this case, it waits 3000 milliseconds, or three seconds.'

5.27 Motor Commands and Control Structures

Different commands make use of different kinds of paired punctuation. The motor command uses square brackets, and the wait1Msec command uses parentheses. This is just the way the commands are set up. You will have to remember to use the right punctuation with the right commands.

Control Structures:

Simple statements do the work in ROBOTC, but control structures do the thinking. Control structures (or control statements) are pieces of code that control the flow of the program's commands, rather than issue direct orders to the robot.

5.28 Comments

Comments are text that the program ignores. A comment can contain notes, messages, and symbols that may help a human, but would be meaningless to the robot. ROBOTC simply skips over them. Comments appear in green in ROBOTC.

6.0 Summary and Conclusion

Learning the skill to program robots will enable African industries to embrace robotics and encourage competition in terms of precision, quality, and price of manufactured goods coming out of the continent. Africa cannot develop without this caliber of knowledge workers because development is triggered by innovation in science and technology.

It is therefore recommended that African governments should endeavor to develop interest in the design, manufacture, and programming of intelligent robots for industry. This will create the right snowballing effect on our industries, particularly in the areas of market competition and penetration, product quality, pricing, and packaging. Can this paper generate interest in pragmatic automation of African industries? That is my hope.

References

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- [6]. <http://www.robotshop.com/blog/en/how-to-make-a-robot-lesson-3-actuators-2-370>

7.0 Appendices of some Industrial Robots in Action



Sample Car production Robot in action



Robots in pharmaceutical production



China boosts hybrid crop development speed by 400% with world-first robotic breeding plant