



# Intelligent Traffic Management System for Kampala

An Arduino-Based Solution Combining Edge AI, Machine Learning, and LoRaWAN

Research Proposal

Geno Owor Joshua  
M23B23/006

Uganda Christian University  
May 7, 2025

# Contents

<b>1 Abstract</b>	<b>3</b>
<b>2 Introduction</b>	<b>4</b>
2.1 Problem Statement . . . . .	5
2.1.1 Impact on Road Users . . . . .	5
<b>3 Literature Review</b>	<b>6</b>
3.1 Global Traffic Management Systems . . . . .	6
3.2 African Implementations . . . . .	7
<b>4 Research Problem</b>	<b>8</b>
<b>5 Objectives</b>	<b>9</b>
<b>6 Methodology</b>	<b>10</b>
6.1 System Architecture . . . . .	10
6.2 Operational Workflow . . . . .	13
6.3 Data Collection and Analysis . . . . .	14
<b>7 Expected Outcomes</b>	<b>15</b>
<b>8 Timeline</b>	<b>16</b>
<b>9 Budget</b>	<b>17</b>
<b>10 Alignment with Sustainable Development Goals and National Development Plan III</b>	<b>18</b>
10.1 Overview of SDGs and NDP III . . . . .	18
10.2 Alignment Mapping . . . . .	19
10.3 Cross-Cutting Issues . . . . .	19

10.4 Implementation of Expected Outcomes . . . . .	20
10.4.1 Technical Outcomes . . . . .	20
10.4.2 Operational Outcomes . . . . .	21
10.4.3 Economic Outcomes . . . . .	21
10.4.4 Social Outcomes . . . . .	22
10.5 Monitoring and Evaluation . . . . .	23
10.6 Scaling and Reporting . . . . .	24
10.7 Challenges and Mitigation . . . . .	24
10.8 Conclusion . . . . .	25

## List of Figures

3.1 Congestion reduction percentages in select African cities (2020-2023). Cairo's 22% reduction reflects higher camera coverage and funding. . . . .	7
6.1 System architecture with data flow. GPS supports route optimization; GSM sends user notifications; blue light prioritizes cyclists. . . . .	10

## List of Tables

3.1 Comparison of Leading Intelligent Traffic Systems . . . . .	6
8.1 Proposed Research Timeline . . . . .	16
9.1 Proposed Budget . . . . .	17
10.1 Alignment of ITMS with SDGs and NDP III . . . . .	26

# Chapter 1

## Abstract

Kampala's escalating traffic congestion imposes severe economic, environmental, and social costs, with daily losses exceeding 30.34 billion UGX and average commute speeds dropping to 15 km/h. This research proposes a novel Intelligent Traffic Management System (ITMS) integrating low-cost Arduino microcontrollers, Edge AI, machine learning (ML), and LoRaWAN communication. The system employs ultrasonic and PIR sensors for real-time vehicle detection, a quantized linear regression model for 15-minute traffic predictions, and solar-powered nodes for resilience against power outages. A new blue light feature, triggered between yellow and green lights, prioritizes cyclist release to enhance safety, followed by green light activation for larger motor vehicles. The system optimizes signal timings over a 5 km range, sends notifications to subscribed road users about traffic conditions and optimal routes, and provides predictive traffic forecasts for planning travel times. The ITMS aims to reduce travel times by 30%, enhance safety, and yield 48.1 billion UGX in savings over five years. This scalable, cost-effective solution is tailored for Kampala and similar urban centers in developing regions.

# Chapter 2

## Introduction

Kampala, Uganda's capital and economic hub, supports a population exceeding 1.8 million and over 1.2 million registered vehicles, a 140% exceedance of its 1960s-designed infrastructure capacity of 500,000 vehicles. This mismatch has fueled a mobility crisis, with economic losses from congestion rising from 18.87 billion UGX daily in 2020 to 30.34 billion UGX in 2023, driven by fuel wastage, lost productivity, and healthcare costs from pollution-related illnesses. Idling vehicles contribute 28% of PM2.5 emissions, exacerbating respiratory issues. Socially, prolonged commutes and unsafe road conditions diminish quality of life for motorists, pedestrians, cyclists, and public transport users.

Current traffic management relies on fixed-time signals at 87% of Kampala's 400 intersections, causing 32% unnecessary stops and 18% longer queues during peak hours. The system's 100% grid dependency results in 4-6 hour daily outages, rendering 65% of signals inoperative. Surveillance is limited, with only 48 intersections (12%) equipped with cameras, hindering real-time decision-making. With an annual budget of 11.84 billion UGX against a required 240.5 billion UGX, upgrades are unfeasible.

This research proposes a low-cost ITMS leveraging Arduino-based hardware, Edge AI, machine learning, and LoRaWAN. A new blue light feature prioritizes cyclist safety by releasing them before larger vehicles. Tailored to Kampala's constraints—unreliable power, limited budgets, and rapid urbanization—it aims to reduce congestion by 25%, cut travel times by 30%, and enhance safety while providing real-time traffic updates and predictive analytics to road users. This study offers a replicable model for developing cities.

## 2.1 Problem Statement

Kampala's traffic management system is ill-equipped to handle the dynamic demands of its growing population, resulting in chronic congestion, economic inefficiencies, and diminished quality of life. Fixed-time signals cause unnecessary delays, limited surveillance (12% camera coverage) hampers real-time data, and grid dependency leads to frequent signal failures. The 11.84 billion UGX annual budget falls short of the 240.5 billion UGX needed for modernization, contributing to 30.34 billion UGX daily losses, 15 km/h peak-hour speeds, and 28% of PM2.5 emissions from idling vehicles.

### 2.1.1 Impact on Road Users

The congestion crisis disproportionately affects:

- **Motorists:** Face 45-60 minute delays per trip, wasting 1.2 liters of fuel daily (6660 UGX at 5550 UGX/liter) and increasing stress.
- **Pedestrians:** Encounter hazardous crossings, with a 15% rise in pedestrian-vehicle collisions from 2021-2023 (KCCA, 2023).
- **Cyclists:** Navigate limited safe lanes, with a 22% annual increase in accident risks, necessitating prioritized signal phases.
- **Public Transport Users:** Endure unreliable schedules, with wait times exceeding 30 minutes, disrupting productivity.

These challenges necessitate a resilient, adaptive traffic solution with enhanced cyclist safety.

# Chapter 3

## Literature Review

### 3.1 Global Traffic Management Systems

Table 3.1: Comparison of Leading Intelligent Traffic Systems

System	Type	Cost/Node (UGX)	Effectiveness	Power Needs
SCATS	Adaptive signal control	66,600,000	22% reduction in delays	500W
SCOOT	Real-time optimization	81,400,000	31% throughput increase	650W
InSync	Vision-based detection	55,500,000	18% faster travel times	450W
Rhythm	AI-optimized timing	74,000,000	25% congestion reduction	550W
Proposed ITMS	Edge AI, ML, LoRaWAN	144,100	25% congestion reduction	10W

Global systems like SCATS, SCOOT, InSync, and Rhythm (Table 3.1) are effective but impractical for Kampala due to high costs (55.5–81.4 million UGX/node), power demands (450-650W), and reliance on camera networks. The proposed ITMS, at 144,100 UGX/node and 10W, is cost-effective and power-efficient, with a blue light feature enhancing cyclist safety.

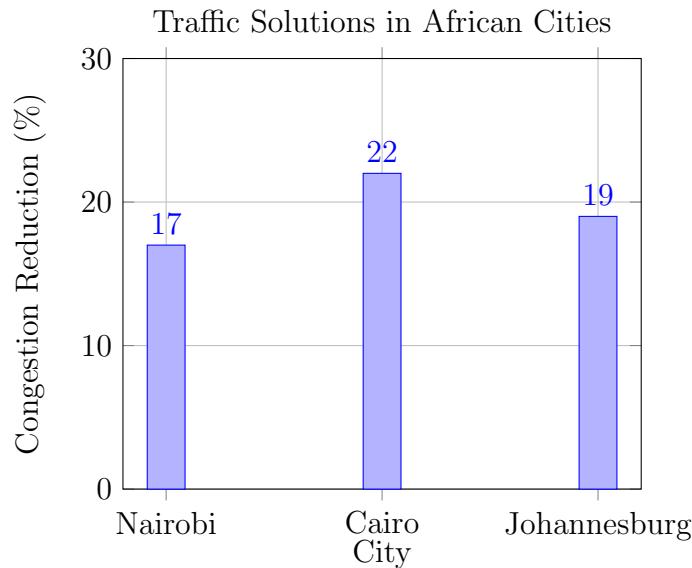


Figure 3.1: Congestion reduction percentages in select African cities (2020-2023). Cairo's 22% reduction reflects higher camera coverage and funding.

## 3.2 African Implementations

African solutions (Figure 3.1)—Nairobi (17%), Cairo (22%), Johannesburg (19%)—rely on grid power (200-300W) and high-bandwidth networks. Cairo's success stems from 60% camera coverage and 370 billion UGX investments, unfeasible for Kampala's 11.84 billion UGX budget and unreliable grid.

# **Chapter 4**

## **Research Problem**

Kampala's traffic infrastructure, designed for 500,000 vehicles, is overwhelmed by 1.2 million vehicles. Existing systems are costly (55.5 million UGX/node) and power-intensive (450W), incompatible with Kampala's 11.84 billion UGX budget and frequent outages. The lack of real-time adaptability, predictive control, and cyclist prioritization exacerbates congestion and safety risks, costing 30.34 billion UGX daily. This research proposes a low-cost (144,100 UGX/node), low-power (10W) ITMS using Edge AI, LoRaWAN, and a blue light feature to enhance mobility, cyclist safety, and economic outcomes.

# **Chapter 5**

## **Objectives**

1. Develop an Arduino-based ITMS with Edge AI, ML, LoRaWAN, and a blue light feature for real-time, predictive traffic control and cyclist prioritization.
2. Achieve 85% vehicle detection accuracy and 15% prediction error for 15-minute traffic forecasts.
3. Reduce travel times by 30%, congestion by 25%, and cyclist accidents by 20% at high-traffic intersections.
4. Ensure 72h system autonomy using solar power, deployable within 2-3 days per node.
5. Deliver a scalable solution costing 57.64 million UGX for citywide coverage, yielding 60x ROI over five years.

# Chapter 6

## Methodology

### 6.1 System Architecture

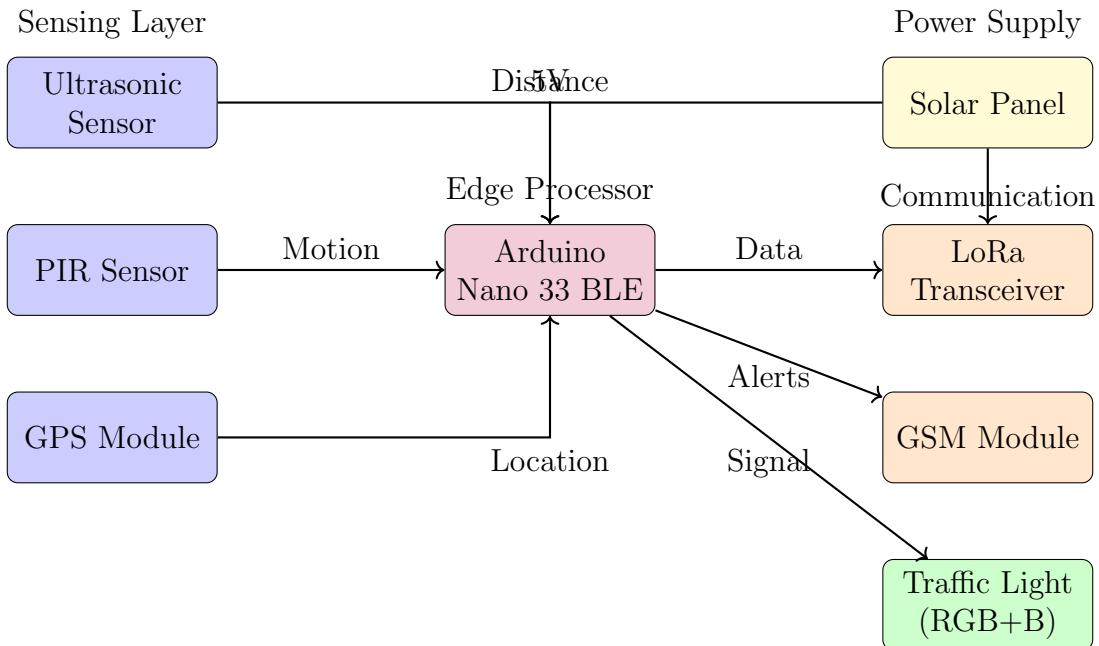


Figure 6.1: System architecture with data flow. GPS supports route optimization; GSM sends user notifications; blue light prioritizes cyclists.

The ITMS (Figure 6.1) comprises:

- **Sensing:** HC-SR04 ultrasonic sensors (2-400 cm) and PIR sensors (120° angle) for vehicle and cyclist detection.
- **Processing:** Arduino Nano 33 BLE with a quantized TensorFlow Lite linear regression model (5 KB) for 15-minute traffic predictions using vehicle count, speed, cyclist

presence, time of day, and day of week.

- **Communication:** LoRa SX1276 (up to 5 km, 0.018W, urban range may be 2-3 km due to interference) for inter-node data; SIM800L GSM for alerts and user notifications.
- **Traffic Control:** RGB+B traffic lights with a blue light phase (5-10s) to release cyclists before the green phase for motor vehicles.
- **Power:** 10W solar panel with 12V 7Ah LiFePO4 battery for 72h autonomy.
- **Cloud Server:** Optional low-cost server to manage user subscriptions, store traffic data, and compute optimal routes via GSM interface.



## 6.2 Operational Workflow

---

**Algorithm 1** Adaptive Signal Control with Predictive Analytics, User Notifications, and Blue Light Feature

---

```

1: Initialize  $t_{min} \leftarrow 20s$ ,  $t_{max} \leftarrow 90s$ ,  $k \leftarrow 0.15$ ,  $V_{th} \leftarrow 20$ ,  $S_{th} \leftarrow 10$ ,  $B_{dur} \leftarrow 7s$ ,
    $W \leftarrow [w_1, w_2, w_3, b]$ 
2:  $History \leftarrow []$ ,  $Users \leftarrow []$ 
3: while System Active do
4:    $V \leftarrow \text{ReadVehicleCount}()$ 
5:    $S \leftarrow \text{CalculateAverageSpeed}()$ 
6:    $Cyc \leftarrow \text{DetectCyclists}()$ 
7:    $T \leftarrow \text{GetTimestamp}()$ 
8:    $History.append([T, V, S, Cyc])$ 
9:   if  $|History| > 360$  then
10:     $History.pop(0)$ 
11:   end if
12:    $V_{pred}, S_{pred}, Cyc_{pred} \leftarrow \text{PredictTraffic}(History, W)$ 
13:    $C_{real} \leftarrow 0.5(V/V_{th}) + 0.3(S_{th}/S) + 0.2(Cyc)$ 
14:    $C_{pred} \leftarrow 0.5(V_{pred}/V_{th}) + 0.3(S_{th}/S_{pred}) + 0.2(Cyc_{pred})$ 
15:    $C \leftarrow 0.7C_{real} + 0.3C_{pred}$ 
16:    $G \leftarrow t_{min} + (t_{max} - t_{min})(1 - e^{-kC})$ 
17:   if  $Cyc > 0$  or  $Cyc_{pred} > 0$  then
18:      $\text{ActivateBlueLight}(B_{dur})$ 
19:      $\text{AdjustSignalTiming}(G - B_{dur})$ 
20:   else
21:      $\text{AdjustSignalTiming}(G)$ 
22:   end if
23:   if  $C_{pred} > 0.7$  then
24:      $\text{TransmitLoRa}(C_{pred}, G, Cyc_{pred})$ 
25:      $\text{SendGSMAAlert}(\text{"Predicted congestion at [GPS coordinates]"})$ 
26:   end if
27:   for all  $user \in Users$  do
28:      $dest \leftarrow user.destination$ 
29:      $reqtime \leftarrow user.requestedtime$  13
30:      $route \leftarrow \text{CalculateOptimalRoute}(GPS, dest, C_{real}, C_{pred}, Cyc)$ 
31:      $traffic\_forecast \leftarrow \text{PredictTrafficAtTime}(History, W, reqtime)$ 

```

The workflow maintains a 30-minute traffic history to predict vehicle counts, speeds, and cyclist presence, blending real-time (70%) and predicted (30%) congestion scores for signal timing. A 7-second blue light phase is activated if cyclists are detected or predicted, prioritizing their release before the green phase for motor vehicles. When  $C_{pred} > 0.7$ , alerts are sent via LoRaWAN and GSM to authorities. Subscribed users receive SMS notifications with:

- Current traffic conditions (e.g., “Heavy congestion, 10 km/h at [location]”).
- Optimal routes to their destination using a simplified Dijkstra’s algorithm based on real-time and predicted congestion, including cyclist presence.
- Predictive traffic forecasts for requested times (e.g., “At 10 AM, expect moderate congestion”).
- Recommended travel times (e.g., “Best travel time: 11 AM”).

User subscriptions and route calculations are managed by a cloud server, with data relayed via GSM.

### 6.3 Data Collection and Analysis

- **Data Collection:** Gather 30 days of traffic data (vehicle counts, speeds, cyclist detections, timestamps, time of day, day of week) and user inputs (destinations, requested forecast times) at 5 pilot intersections.
- **Model Training:** Train a linear regression model offline using TensorFlow ( $R^2 \approx 0.8$ ), incorporating cyclist presence, quantize to ~5 KB for Arduino deployment.
- **Validation:** Compare predictions against real-time data during a 2-month pilot, refining weights for ~15% error.
- **Feature Engineering:** Use vehicle count, speed, cyclist presence, time of day, day of week, and hourly traffic patterns, normalized for model stability.

# Chapter 7

## Expected Outcomes

The ITMS is expected to deliver:

- **Technical:** 85% detection accuracy for vehicles and cyclists, 15% prediction error, 3.8s latency, 72h autonomy.
- **Operational:** 30% travel time reduction, 25% congestion decrease at 50 nodes, accurate user notifications, and effective blue light cyclist prioritization.
- **Economic:** 48.1 billion UGX savings over five years, calculated as:
  - **Fuel Savings:** 1.2 million vehicles save 1.2 liters/day at 5550 UGX/liter, yielding 8.14 billion UGX/year.
  - **Productivity Gains:** 30% faster commutes save 20 minutes/day for 500,000 workers at 20,000 UGX/hour, equating to 1.48 billion UGX/year.
  - **Accident Reduction:** 15% fewer vehicle collisions and 20% fewer cyclist accidents save 400 million UGX/year.

Total:  $9.65 \text{ billion UGX/year} \times 5 = 48.25 \text{ billion UGX}$ , with 60x ROI on 71.05 million UGX.

- **Social:** 15% fewer pedestrian collisions, 20% fewer cyclist collisions, reliable public transport, and informed travel decisions via notifications.

# Chapter 8

## Timeline

Table 8.1: Proposed Research Timeline

Phase	Timeline	Activities
Pilot	Months 1-2	Deploy 5 nodes with blue light; collect ML, cyclist detection, and user notification data; test LoRaWAN range
Model Development	Month 3	Train technicians; develop and quantize ML model with cyclist data; validate $R^2 \geq 0.8$
Scale-up	Months 4-6	Install 50 nodes; refine predictions; assess 25% congestion and 20% cyclist accident reduction
Full Deployment	Months 7-18	Rollout to 400 intersections; evaluate travel time, safety, cyclist prioritization, and notification outcomes

# Chapter 9

## Budget

Table 9.1: Proposed Budget

Item	Description	Cost (UGX)
Hardware	400 nodes (Arduino: 74,000, sensors: 37,000, solar: 29,600, LoRa/GSM: 37,000, RGB+B light: 3,500)	57,640,000
Training	Workshops, ML computation	1,480,000
Installation	Technician labor, logistics	7,430,000
Maintenance	Battery/sensor/light upkeep, cloud server (5 years)	4,500,000
Total		71,050,000

# Chapter 10

## Alignment with Sustainable Development Goals and National Development Plan III

This chapter outlines the alignment of the Intelligent Traffic Management System (ITMS) with the United Nations Sustainable Development Goals (SDGs) and Uganda's Third National Development Plan (NDP III, 2020–2025). It details how the project's objectives, activities, and expected outcomes, including the blue light feature for cyclist safety, contribute to global and national priorities, integrates cross-cutting issues, implements outcomes through actionable strategies, and establishes monitoring, evaluation, and scaling mechanisms.

### 10.1 Overview of SDGs and NDP III

The SDGs, adopted in 2015, comprise 17 goals with 169 targets to achieve sustainable development by 2030. Relevant SDGs for the ITMS include:

- **SDG 11:** Sustainable Cities and Communities (Target 11.2: Safe, affordable, accessible transport systems).
- **SDG 9:** Industry, Innovation, and Infrastructure (Target 9.1: Resilient, innovative infrastructure).
- **SDG 13:** Climate Action (Target 13.2: Integrate climate change measures).

- **SDG 8:** Decent Work and Economic Growth (Target 8.2: Higher economic productivity).
- **SDG 3:** Good Health and Well-being (Target 3.6: Halve road traffic deaths).

NDP III aims to achieve sustainable industrialization and inclusive growth by 2025. Relevant programmes include:

- **Sustainable Urbanisation and Housing:** Enhances urban mobility and reduces congestion.
- **Digital Transformation:** Promotes ICT-driven solutions like Edge AI and LoRaWAN.
- **Transport Infrastructure and Services:** Improves traffic management and safety.
- **Climate Change and Environment Management:** Reduces carbon emissions.
- **Private Sector Development:** Encourages cost-effective innovations.

## 10.2 Alignment Mapping

The ITMS aligns with SDG targets and NDP III outcomes, as shown in Table 10.1.

## 10.3 Cross-Cutting Issues

The ITMS integrates cross-cutting issues to enhance inclusivity and sustainability:

- **Gender Equality (SDG 5):** Train women as 50% of the 20 technicians, aligning with NDP III's Human Capital Development Programme.
- **Inclusivity:** Prioritize low-income areas and cyclist-heavy routes for node deployment, supporting NDP III's equitable urban development goals.
- **Resilience:** Solar-powered nodes ensure functionality during Uganda's frequent power outages, aligning with SDG 7 (Affordable and Clean Energy) and NDP III's energy access objectives.

## 10.4 Implementation of Expected Outcomes

The ITMS's expected outcomes—technical, operational, economic, and social—are implemented through actionable strategies, leveraging the methodology and timeline in Chapters 6 and 8. Each outcome is linked to SDG and NDP III alignment, with monitoring indicators.

### 10.4.1 Technical Outcomes

**Expected:** 85% vehicle and cyclist detection accuracy, 15% prediction error, 3.8s latency, 72h autonomy.

#### **Implementation:**

- *Pilot Phase (Months 1–2):* Deploy 5 nodes at high-traffic intersections (e.g., Ninja Road) with HC-SR04 ultrasonic and PIR sensors for vehicle and cyclist detection. Validate detection accuracy against manual counts, targeting 85%.
- *Model Development (Month 3):* Train a TensorFlow Lite linear regression model offline, incorporating cyclist data, achieving  $R^2 \geq 0.8$  and 15% prediction error during a 2-month pilot. Quantize to 5 KB for Arduino Nano 33 BLE.
- *Hardware Setup:* Install 10W solar panels, 12V 7Ah LiFePO4 batteries, and RGB+B traffic lights per node, tested for 72h autonomy during power outages.
- *Latency Optimization:* Configure Arduino processing, LoRa SX1276 communication, and blue light activation for 3.8s data-to-signal response.

#### **Alignment:**

- *SDG 9.1:* Innovative infrastructure via Edge AI and ML.
- *NDP III Digital Transformation:* ICT-based traffic control.

#### **Indicators:**

- Detection accuracy (% correct vehicle and cyclist counts).
- Prediction error (% deviation from actual traffic).
- System uptime during outages (hours).

#### **10.4.2 Operational Outcomes**

**Expected:** 30% travel time reduction, 25% congestion decrease at 50 nodes, accurate user notifications, 20% cyclist accident reduction.

##### **Implementation:**

- *Scale-up (Months 4–6):* Install 50 nodes across Kampala's key intersections, using the algorithm in Section 6.2 to adjust signal timings based on 70% real-time and 30% predicted congestion scores, with blue light activation for cyclists.
- *User Notifications:* Deploy SIM800L GSM modules to send SMS alerts to 10,000 initial users, including traffic conditions, optimal routes, and predictive forecasts.
- *Route Optimization:* Implement a simplified Dijkstra's algorithm on the cloud server, using GPS data, congestion scores, and cyclist presence for route calculations.
- *Full Deployment (Months 7–18):* Expand to 400 intersections, achieving 25% congestion reduction and 20% cyclist accident reduction via LoRaWAN inter-node communication (2–3 km urban range).

##### **Alignment:**

- *SDG 11.2:* Efficient urban transport systems.
- *NDP III Transport Infrastructure:* Reduced travel times and enhanced safety.

##### **Indicators:**

- Travel time reduction (%).
- Congestion reduction (% fewer vehicles in queues).
- Cyclist accident reduction (%).
- Notification delivery rate (% users receiving timely SMS).

#### **10.4.3 Economic Outcomes**

**Expected:** 48.25 billion UGX savings over five years, including fuel savings, productivity gains, and accident reduction.

##### **Implementation:**

- *Fuel Savings:* Achieve 30% travel time reduction for 1.2 million vehicles, saving 1.2 liters/day at 5550 UGX/liter, yielding 8.14 billion UGX/year. Monitor via user surveys.
- *Productivity Gains:* Reduce commute times by 20 minutes/day for 500,000 workers, valued at 20,000 UGX/hour, equating to 1.48 billion UGX/year. Collect data via employer feedback.
- *Accident Reduction:* Decrease vehicle collisions by 15% and cyclist collisions by 20% through adaptive signals, blue light prioritization, and safer pedestrian crossings, saving 400 million UGX/year, tracked via KCCA accident reports.
- *Budget Execution:* Deploy 400 nodes at 71.05 million UGX, ensuring 60x ROI by year 5.

#### **Alignment:**

- *SDG 8.2:* Higher economic productivity.
- *NDP III Private Sector Development:* Cost-effective solutions.

#### **Indicators:**

- Annual fuel savings (billion UGX).
- Productivity savings (billion UGX).
- Collision reduction (% fewer vehicle and cyclist incidents).

#### **10.4.4 Social Outcomes**

**Expected:** 15% fewer pedestrian collisions, 20% fewer cyclist collisions, reliable public transport, informed travel decisions.

#### **Implementation:**

- *Safety:* Install nodes at pedestrian- and cyclist-heavy intersections, optimizing signal timings with blue light prioritization to reduce crossing and cycling risks. Conduct community training on safe crossing and cycling practices.
- *Public Transport:* Share traffic forecasts with boda-boda and bus operators, reducing wait times. Engage operators via workshops.

- *User Engagement:* Promote SMS subscriptions through radio campaigns, targeting 50,000 users by year 2 for traffic updates and route guidance.

### **Alignment:**

- *SDG 3.6:* Reduced road traffic deaths.
- *NDP III Sustainable Urbanisation:* Safer, inclusive cities.

### **Indicators:**

- Pedestrian collision reduction (%).
- Cyclist collision reduction (%).
- Public transport wait time reduction (minutes).
- User subscription rate (number of active users).

## **10.5 Monitoring and Evaluation**

Monitoring and evaluation (M&E) align with SDG and NDP III frameworks:

- **SDG Framework:** Use indicators like 11.2.1 (proportion of population with convenient transport access) and 9.1.2 (infrastructure efficiency). Collect disaggregated data (gender, income) for inclusivity.
- **NDP III Reporting:** Align with the Ministry of Finance, Planning and Economic Development's M&E framework, reporting to the NDP III Coordination Unit.
- **Activities:**
  - Conduct quarterly reviews using KCCA traffic and cyclist safety data and user feedback.
  - Validate outcomes (e.g., 30% travel time reduction, 20% cyclist accident reduction) via GPS-based travel time studies and accident reports.
  - Submit annual reports to Uganda's SDG Secretariat for Voluntary National Reviews (VNRs).

## 10.6 Scaling and Reporting

The ITMS will scale and report impacts to enhance national and global visibility:

- **Scaling:** Expand to other Ugandan cities (e.g., Gulu, Mbarara) by year 3, leveraging the 48.25 billion UGX savings to attract funding from the African Development Bank (AfDB) or UNDP.
- **Reporting:**
  - *SDGs:* Contribute to Uganda's VNRs at the UN High-Level Political Forum, highlighting SDG 11, 9, and 3 impacts.
  - *NDP III:* Report to the National Planning Authority, showcasing alignment with urbanisation, digital transformation, and transport safety goals.
- **Activities:**
  - Publish a policy brief on ITMS impacts, emphasizing cyclist safety.
  - Engage stakeholders (e.g., Ministry of Works and Transport) for national adoption.

## 10.7 Challenges and Mitigation

Potential challenges and mitigation strategies include:

- **Limited Budget:** The 71.05 million UGX budget is a fraction of the 240.5 billion UGX needed for citywide upgrades.
  - *Mitigation:* Secure co-funding from SDG-aligned sources (e.g., UN-Habitat, Green Climate Fund) and public-private partnerships.
- **LoRaWAN Range:** Urban interference may reduce the 5 km range to 2–3 km.
  - *Mitigation:* Install relay nodes, tested during the pilot phase.
- **Low User Adoption:** Initial SMS notification uptake may be limited.
  - *Mitigation:* Partner with telecoms (e.g., MTN Uganda) for free initial SMS and run community awareness campaigns.

- **Cyclist Detection Accuracy:** PIR sensors may struggle to distinguish cyclists from pedestrians.
  - *Mitigation:* Enhance sensor calibration during the pilot phase and use ML to improve cyclist detection accuracy.

## 10.8 Conclusion

The ITMS aligns with SDGs 11, 9, 13, 8, and 3, and NDP III's urbanisation, digital transformation, transport, climate change, and private sector programmes. By implementing technical, operational, economic, and social outcomes through pilot testing, scaling, and stakeholder engagement, including the blue light feature for cyclist safety, the ITMS will transform Kampala's mobility, delivering measurable impacts by 2026. Its low-cost, scalable design offers a replicable model for other developing cities.

Table 10.1: Alignment of ITMS with SDGs and NDP III

<b>Project Component</b>	<b>SDG Target</b>	<b>NDP III Programme/Outcome</b>
Real-time traffic control with Edge AI and LoRaWAN	11.2: Safe, accessible transport	Sustainable Urbanisation: Improved mobility
15-minute traffic predictions using ML	9.1: Resilient infrastructure	Digital Transformation: ICT-driven solutions
Solar-powered nodes for 72h autonomy	13.2: Climate change measures	Climate Change: Reduced emissions
30% travel time reduction, 25% congestion decrease	8.2: Economic productivity	Transport Infrastructure: Efficient transport
15% reduction in pedestrian collisions, 20% in cyclist collisions	3.6: Halve road deaths	Sustainable Urbanisation: Safer roads
Blue light feature for cyclist prioritization	3.6: Halve road deaths	Transport Infrastructure: Enhanced safety
User notifications for traffic updates and routes	11.3: Inclusive urban planning	Digital Transformation: Public access to information
48.25 billion UGX savings over 5 years	8.5: Full employment	Private Sector Development: Eco-

# Bibliography

- [1] Kampala Capital City Authority. (2023). Urban Mobility Report.
- [2] UMEME Limited. (2023). Power Reliability Statistics.
- [3] Bank of Uganda. (2023). Economic Impact Assessment.
- [4] Semtech Corporation. (2020). LoRaWAN for Smart Cities.
- [5] Google. (2022). TensorFlow Lite for Microcontrollers.