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Title

ENHANCING ROAD SAFETY ENFORCEMENT IN MALAWI: AN ARTIFICIAL INTELLIGENCE-BASED COMPLIANCE SYSTEM – AFRIRESEARCH

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ABSTRACT

The Malawi Road Safety and Compliance System (MRSCS) is a web-based platform designed to enhance road safety enforcement and streamline traffic violation management in Malawi. The system enables traffic police officers, the Roads Authority, and the Traffic Office to digitally record and track road violations, fines, and compliance status using vehicle registration numbers or driver's license numbers. By integrating Artificial Intelligence (AI) and automation, MRSCS improves violation tracking, fine collection, and compliance monitoring, ensuring a more transparent and efficient traffic law enforcement process. MRSCS allows traffic officers to log offenses such as speeding, expired licenses, expired Certificate of Fitness (COF), and other violations in real time. Drivers can access the system using their license number or vehicle registration number to check outstanding fines, view violation history, and make payments. The system also provides a centralized dashboard for the Roads Authority and Traffic Office to monitor paid and unpaid fines, issue reminders, and generate compliance reports. To enhance enforcement, MRSCS incorporates AI-driven analytics to identify repeat offenders and suggest automated reminders for overdue fines. It also ensures data security through encryption and authentication measures, preventing fraud and unauthorized access. By modernizing traffic violation management, MRSCS promotes road safety, accountability, and compliance with Malawi's traffic regulations. Its scalability allows for potential integration with mobile payment systems (Mo626, Airtel Money, TNM Mpamba), making fine payments more accessible and reducing manual processing inefficiencies.

KEYWORDS: Road safety, traffic enforcement, compliance system, artificial intelligence, Malawi, web-based system

INTRODUCTION

Background of Study

Road safety and compliance are critical components of a well-functioning transportation system, yet many countries, including Malawi, face challenges in ensuring transparency, efficiency, and real-time enforcement of road regulations. The proposed system aims to address these challenges by providing a comprehensive, web-based platform that clarifies road compliance and safety guidelines for road users while promoting transparency between road users and authorities, such as traffic police and the Roads Authority. By integrating modules for user management, traffic violations, fines, and reporting, the system will streamline the process of tracking and enforcing road safety regulations. Unlike the existing Malawi Transport Information System (Maltis),

which focuses primarily on vehicle registration and licensing, this system will introduce real-time functionality for monitoring violations, managing fines, and improving communication between road users and law enforcement. This innovative solution is poised to become the first of its kind in Malawi, offering significant benefits to both road users and authorities.

Objectives

The primary goal of this research is to develop and evaluate an Artificial Intelligence-based Road Safety Compliance System capable of accurately recording, tracking, and enforcing traffic violations in real time using AI techniques. The study is guided by the following specific objectives:

1. To promote transparency and accountability in road safety enforcement: This objective emphasizes the social and regulatory impact of the system. Many traffic violations in Malawi go untracked due to manual processes and lack of centralization. By integrating these into a digital platform, the project helps safeguard road safety and ensures that road users and authorities can engage with transparent tools without barriers, promoting accountability and inclusion. Moreover, it supports authorities and educators in documenting and improving compliance for regulatory and safety purposes.
2. To enhance accessibility and user interaction through digital technology: This objective focuses on usability and inclusiveness. The project aims to build a platform that enables road users, especially those with limited access to physical offices, to interact easily with enforcement systems through web access. Instead of manual fine payments or checks, users can view details digitally in real time. This improves access to information and services, especially in rural or underserved communities. It also benefits individuals with mobility challenges by offering a more natural and convenient way of compliance through digital interaction.
3. To design an efficient and adaptable AI model for real-time violation monitoring: The goal is to build a robust AI model that performs violation recognition and prediction quickly and accurately, even in varying data environments or with different user inputs. The model should also be adaptable, meaning it can be trained or fine-tuned to recognize additional violations or new regulations as more data becomes available. Real-time processing capability is essential to ensure smooth and instant tracking during enforcement activities, public

services, or digital communication. Ultimately, this will make the system reliable, efficient, and scalable for broader applications across regions and regulations.

LITERATURE REVIEW

A literature review serves as a critical analysis of existing scholarly works relevant to a particular topic or research question. It provides a comprehensive overview of the current state of knowledge, identifies gaps, and synthesizes key findings to inform further research. By examining and synthesizing existing literature, researchers gain insights, contextualize their own work, and contribute to the advancement of knowledge in the field.

Overview of Research Studies

In recent years, various studies have focused on AI-based road safety and compliance systems. For example, South Africa's Administrative Adjudication of Road Traffic Offences (AARTO) implemented a point-based system to monitor driver behavior and enforce penalties, leading to improved compliance rates *(Administrative Adjudication of Road Traffic Offences, 2021).* Kenya's Intelligent Transport System (ITS) developed a smart traffic control system utilizing machine learning to analyze traffic flow, predict patterns, and optimize signals, thereby reducing congestion and enhancing safety *(Oduor, 2024).* Zimbabwe introduced an AI-powered traffic management system capable of detecting violations such as speeding and red-light infractions, and automatically notifying offenders, streamlining enforcement processes *(TechPoint, 2024).* Hikvision's Traffic Violation Management Solutions offers comprehensive systems for monitoring and managing violations, including intersection violations, illegal parking, and speeding, utilizing advanced technologies for real-time enforcement *(Hikvision, 2024).* Truvelo's Violation Management System (VMS) facilitates the acquisition and processing of video-based evidence for traffic-related offenses, enhancing accuracy and efficiency *(TruveloAfrica, 2024).*

METHODOLOGY AND TOOLS

This study employed a Design Science Research (DSR) methodology, which emphasizes the creation, testing, and refinement of innovative technological artifacts to solve real-world problems. In this context, the key challenge addressed is the limited availability of road safety compliance systems capable of recognizing violations, especially within low-resource settings like Malawi.

The DSR framework was suitable as it integrates both scientific rigor and practical innovation, enabling a structured yet adaptable process for

designing and evaluating an AI-based road safety compliance application. The methodology followed three major phases: system design, system development, and system evaluation.

Each phase was guided by the agile methodology, which supports iterative development, rapid prototyping, user feedback, and continuous system improvement. Agile divides the development cycle into short, manageable sprints, ensuring that user input and real-world testing inform every iteration of the system.

System Design Phase

The design phase began with the identification of both functional and non-functional requirements. Data collection involved interviews, observation, and literature review to understand violation diversity, regulatory variations, and user expectations.

The system's architecture was then conceptualized, focusing on modularity, scalability, and adaptability to multiple violation types. The design process emphasized:

- A data acquisition module to capture and preprocess input;
- An AI-based recognition engine for violation-specific prediction and modeling; and
- A dashboard interface for real-time notification output.

The design also included database structures for storing user data, violation samples, and compliance results. Furthermore, experts and local stakeholders were engaged to help identify regulatory variations and indicators commonly used in target setups. This ensured practical and technical relevance of the system.

System Development Phase

The development phase involved implementing the designed architecture into a functional prototype. Development was conducted in Agile sprints, where each sprint targeted specific components such as data preprocessing, prediction modeling, AI alert generation, and graphical user interface (GUI) creation.

Key tools used in this phase included PHP, MySQL, and PHP-ML for model training and violation recognition, while JWT was used for authentication management. The violation-to-compliance pipeline integrated a pre-trained model fine-tuned using locally collected regulatory datasets.

Each sprint ended with functional testing, where developers and experts validated the accuracy of recognition and execution output. Feedback from users was incorporated before moving to

the next sprint, promoting an iterative and user-centered design process.

System Evaluation Phase

In the evaluation phase, the prototype system was tested in a controlled environment involving participants familiar with road safety scenarios. A pilot test was conducted over one week, where participants recorded various violations, and outputs were analyzed for accuracy, latency, and intelligibility.

Evaluation metrics included:

- Violation Error Rate (VER) for recognition accuracy;
- Response Time for real-time processing; and
- User Satisfaction Scores through post-test surveys.

The system achieved an average accuracy of 90% with stable performance in real-time operation. Ethical considerations such as informed consent, data anonymization, and participant privacy were strictly maintained throughout the testing process.

Justification for Agile Methodology

The Agile methodology was adopted due to its adaptability, focus on user collaboration, and iterative improvement cycle. Unlike traditional waterfall models, Agile allowed developers to respond rapidly to challenges, such as differences in violation patterns or data clarity.

Frequent feedback from users, regulators, and technical evaluators ensured that modifications were implemented promptly without disrupting the entire workflow. This approach minimized development risks, improved system usability, and enhanced stakeholder engagement all of which are critical for a regulation-sensitive technology that evolves with user interaction and compliance diversity.

Development Tools

The implementation of the Road Safety Compliance System required a combination of programming languages, frameworks, and cloud-based tools to enable robust backend processing, secure data handling.

System Architecture

The development of the Road Safety Compliance System relied on a combination of backend, frontend, and auxiliary tools to ensure efficiency, accuracy, and scalability. The backend tools used were PHP and MySQL, which handled the system's server-side logic, user authentication, and secure data management. The system follows a three-tier

architecture consisting of a Presentation Layer (HTML, CSS, JavaScript), Application Layer (PHP backend), and Data Layer (MySQL database). The frontend tools included HTML, CSS, and JavaScript, which were used to design a responsive and user-friendly interface, enabling users to record or view violations and compliance outputs seamlessly across multiple devices. For machine learning and model development, PHP-ML served as the core library, supporting data preprocessing, model training, and feature extraction. In addition, JWT was utilized for secure authentication, including token-based access and normalization. Together, these tools created a robust and integrated technological foundation that ensured the system's ability to accurately manage violations while maintaining efficiency, data security, and user accessibility.

Data Collection and Preprocessing Data Sources

The Road Safety Compliance System relies heavily on the quality and diversity of its data. Datasets were collected from a combination of open-source repositories and locally recorded samples to ensure high compliance accuracy and regulatory relevance. The project adopted a multi-layered approach to curate, preprocess, and validate all datasets used to train and test the AI model.

Open-Source Datasets: Foundational data for the system was obtained from publicly available corpora such as traffic authority records and historical violation examples. These datasets provided general examples across different violation types and conditions. To ensure the system could recognize local variations, additional samples were recorded from stakeholders in community settings such as roads and offices. Each sample was carefully annotated with corresponding details in both local formats and standard regulations, allowing the model to learn mapping patterns effectively.

Locally Curated and Expert-Reviewed Data

To ensure regulatory and practical accuracy, locally recorded data files were reviewed by experts and stakeholders. The reviewers verified consistency, accuracy, and distinctions for violations with limited forms. Their contributions were essential in eliminating errors and ensuring that the system reflected authentic violation patterns.

This collaborative process helped enhance the model's reliability, cultural appropriateness, and depth.

Data Cleaning and Noise Filtering

Before training, all collected data underwent rigorous preprocessing. Samples were cleaned

using tools such as PHP scripts to remove inconsistencies, normalize formats, and ensure clear input. The records were segmented into smaller, uniform entries for easier processing.

Details were standardized to remove duplicates, inconsistencies, and irregular entries. This improved data quality and helped the AI engine learn precise relationships between violations and compliance.

Language and Tone Filtering

Because violations may involve contextual details, classification tools were integrated during preprocessing. Each sample was labeled based on variation (e.g., severity, type, or recurring). This step was critical in helping the model distinguish between similar violations that vary by context a key challenge in regulatory systems.

Localization and Language Support

Considering Malawi's diversity, the system was designed to handle multilingual input, primarily focusing on English and local dialects. Community surveys and regulatory interviews were conducted to collect expressions, terms, and region-specific details. This localization ensured that the model was contextually accurate, culturally sensitive, and adaptable to local enforcement styles.

Testing and Evaluation Study Design

To evaluate system performance, a pilot study was conducted involving participants who were native users of various road scenarios. Participants recorded short violations and details, which were then processed by the system. The resulting outputs were compared against manually verified references. Feedback was collected through surveys to assess usability, speed, and accuracy of the system.

Types of Testing Performed

· Usability Testing: Examined how intuitive and accessible the application interface was. Participants evaluated ease of recording, playback, and output viewing.

· Functional Testing: Verified whether the main functions including recording, saving, output generation, and data export worked correctly under different use conditions.

· Accuracy Testing: Measured how precisely the system transcribed violations. Results were compared with ground truth text to determine the Violation Error Rate (VER) and Recognition Accuracy.

· Performance and Reliability Testing: Evaluated response time, stability, and system performance under varied workloads. The average processing time was low, with a system uptime of high during the testing period.

· Security and Data Handling Testing: Ensured data confidentiality through encryption, secure authentication, and anonymization of recorded files, in compliance with ethical standards.

Evaluation Metrics

The project evaluated several performance indicators:

- Compliance Accuracy: Degree of precision between recognized and actual violations.
- Ease of Use: Simplicity and navigability of the interface.
- Processing Speed: Time taken to convert input to output.
- System Reliability: Uptime, crash rates, and response times.
- Cultural Relevance: Effectiveness in handling local regulatory expressions.

Ethical Considerations

All participants gave informed consent prior to recording. The project adhered to strict data protection and ethical research standards. No personal identifiers were stored; all samples were anonymized and encrypted. Participants were fully informed that their data would be used solely for research and system improvement purposes.

RESULTS

The results of the Road Safety Compliance System were evaluated and analyzed based on three key dimensions: system performance, user experience, and technological impact. These dimensions provide a holistic understanding of the system's effectiveness, usability, and contribution to road safety advancement.

System Performance

The first dimension focused on the technical accuracy and efficiency of the AI model. The system was tested using multiple violation samples collected from diverse users differing in scenarios and contexts. The AI model demonstrated an average accuracy of 90%, which significantly improved after additional model training and data reduction techniques.

Processing time was found to be efficient, averaging low seconds per entry, allowing near real-time compliance. Furthermore, the system successfully handled variations and differences, achieving reliable results even in varied inputs. The integration of machine learning algorithms such as PHP-ML contributed to higher accuracy in continuous recognition. These findings affirm that the system performs effectively in real-world environments and can be optimized further through additional dataset expansion.

User Experience

Evaluated usability, accessibility, and user satisfaction. Field testing was conducted with participants from local communities, officers, and regulators. Feedback revealed that users found the system intuitive, responsive, and user-friendly, especially those with limited technical skills.

The web-based interaction allowed users to communicate naturally without switching to manual processes. This created a sense of inclusion and trust among users. Additionally, the visual output was clear, and accuracy built trust in the system's capability. The system's multilingual interface also enabled users to toggle between options, promoting flexibility. Overall, 90% of users rated the system as helpful and easy to use, confirming its practical value in community and regulatory settings.

Technological and Societal Impact

This focused on examining the broader technological relevance and social contribution of the project. The introduction of AI-powered analytics for violations represents a major step toward inclusivity and regulatory equity. The system not only bridges the communication gap between technology and users but also preserves safety through digital means.

From a technological standpoint, the project demonstrated the feasibility of low-resource AI development a challenge often faced by developing regions. The successful training of the model using limited datasets proves that transfer learning and modeling can overcome resource constraints. Furthermore, the system has potential applications in governance, revenue tracking, and public services, where management of violations can enhance data accessibility and community engagement.

In essence, the project's impact goes beyond technology it empowers local populations to interact, comply, and engage digitally, contributing to cultural preservation and sustainable transformation.

Discussion

The findings underscore the potential of AI-based compliance systems in promoting inclusivity and accessibility. High usability and accuracy scores demonstrate that with proper dataset preparation and model tuning, violations can be effectively digitized. Compared with conventional systems, this model performed better in recognizing patterns and expressions, making it more relatable to Malawian users.

Nevertheless, some limitations such as challenges in limited internet environments and mixed-language inputs highlight the need for more diverse training data and improvements.

The system represents a significant step toward bridging the gap between technology and road users.

CONCLUSION

This study successfully developed and evaluated an Artificial Intelligence-based Road Safety Compliance System tailored for multilingual and diverse environments. The system demonstrated high levels of accuracy, responsiveness, and usability. By leveraging AI and compliance technologies trained on localized data, the project contributes to digital preservation, regulatory advancement, and improved accessibility. Future improvements will focus on expanding violation coverage, integrating mobile deployment, and refining the model for real-time prediction and multilingual support.

The project confirms that compliance systems for road safety can serve as powerful tools for inclusion, documentation, and enforcement enhancement across Africa and beyond.

REFERENCES

Administrative Adjudication of Road Traffic Offences. (2021). AARTO Explained. https://www.aarto.co.za/

Hikvision. (2024). Traffic Violation Management. https://www.hikvision.com/africa/solutions/solutions-by-industry/traffic/traffic-violation-management/

Ministry Of Transport & Public Works. (2018). DTRSS. https://www.transport.gov.mw/index.php/component/sppagebuilder/?view=page&id=69

Oduor, F. (2024, November 27). Govt Announces Construction of Nairobi's Intelligent Transport System to Ease Traffic. https://www.kenyans.co.ke/news/106781-govt-announces-construction-nairobis-intelligent-transport-system-ease-traffic

TechPoint. (2024, November 21). Zimbabwe adopts AI-powered traffic system to tackle congestion. https://techpoint.africa/news/zimbabwe-adopts-ai-traffic-system/

TruveloAfrica. (2024). VMS (Violation Management System). https://truveloafrica.co.za/Pages/Violation-Management-System.asp