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Effect of Automated Traffic Enforcement Systems Implementation on Road Accident Trends in Kigali City, Rwanda (2019-2023)

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Abstract*: This study examined the effect of Speed Enforcement Cameras Deployment on Road Accident Trends in Kigali City, Rwanda. Specifically, the study sought to determine the effect of speed enforcement cameras deployment on road accident trends in Kigali City. The study adopted a descriptive research design using a mixed-methods approach. A total of 300 participants were targeted, comprising 298 drivers and motorcyclists who responded to structured questionnaires and 2 administrative personnel who participated in semi-structured interviews. Of the 298 questionnaires administered, 286 were successfully completed and returned, representing a response rate of 96.0%, while both key informants participated in the interviews. Primary data were collected through structured questionnaires and semi-structured interviews, while secondary data were obtained through documentary review. Quantitative data were analyzed using descriptive statistics, Pearson correlation analysis, and simple linear regression analysis using SPSS Version 25. The findings revealed a strong and statistically significant positive relationship between Speed Enforcement Cameras Deployment and Road Accident Trends ($r = 0.759$, $p < 0.001$). Regression results showed that Speed Enforcement Cameras Deployment significantly predicted Road Accident Trends ($\beta = 0.759$, $p < 0.001$), with an R^2 of 0.577, indicating that 57.7% of the variation in Road Accident Trends was explained by speed enforcement cameras deployment. The study concludes that effective deployment of speed enforcement cameras is significantly associated with improved road safety outcomes in Kigali City. The study recommends strategic deployment, regular maintenance, calibration, monitoring, and continuous evaluation of speed enforcement cameras, particularly in high-risk locations, to enhance compliance with speed limits and improve road safety*

Keywords: *Speed Enforcement Cameras Deployment, Road Accident Trends, Automated Traffic Enforcement Systems, road safety, Kigali City, Rwanda.*

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1. Introduction

Road traffic accidents remain one of the leading causes of death and injury worldwide, with an estimated 1.35 million fatalities each year according to the World Health Organization (WHO, 2022). To address this global challenge, many countries have adopted Automated Traffic Enforcement Systems (ATES), such as automated speed and red-light cameras, which are designed to enforce traffic laws consistently and reduce risky driving behaviors. Systematic reviews of international evidence indicate that the installation of speed cameras and other automated enforcement technologies is associated with significant reductions in collision rates, injuries, and fatalities, with some studies reporting reductions in crashes ranging from 5% to more than 60% near camera sites compared to pre-installation conditions (Elvik, 2022). These global outcomes highlight the potential of ATES as an effective road safety intervention when it is properly implemented, monitored, and supported by complementary measures.

In developed countries such as the United States, Germany, and Japan, automated enforcement has been widely implemented and evaluated, often showing positive impacts on road safety outcomes. Research in the United States found that red-light cameras reduced fatal red-light-running crashes by approximately 30% and increased overall compliance with signal controls (Retting et al., 2022). Similarly, evaluations conducted as part of Europe's National Safety Camera Program in the United Kingdom reported a 29% reduction in casualty crashes at locations with speed cameras. In these contexts, ATES is frequently integrated with public awareness campaigns, strict penalty regimes, and advanced traffic management systems, which together enhance compliance and reinforce long-term behavior change among road users (Shinar, 2022)

In Sub-Saharan Africa, where the burden of road traffic accidents is disproportionately high due to rapid motorization, infrastructure challenges, and limited enforcement capacity, several countries have begun implementing ATES (Odero et al., 2023). Nations such as Kenya, Nigeria, and South Africa have deployed automated speed and red-light cameras in major cities and along high-risk road corridors to deter speeding and improve compliance with traffic laws. Evidence from these implementations shows promising declines in speeding violations and improvements in driver behavior, although high technology costs, limited enforcement infrastructure, and low levels of public awareness and education often constrain the effectiveness of ATES. Nonetheless, ATES is increasingly recognized as a crucial component of regional road safety strategies aimed at reducing fatalities and serious injuries (Mock et al., 2024).

In East African countries such as Kenya, Uganda, and Tanzania, governments are gradually expanding the use of ATES to curb road accident rates that remain among the highest globally. These countries have introduced speed cameras, red-light cameras, and digital fine systems, particularly in urban areas with heavy traffic and high collision rates (Ochieng et al., 2024). Early evaluations suggest that these technologies contribute to reduced speeding and enhanced compliance with traffic laws when combined with driver education and enforcement campaigns, although limitations in technical capacity, funding constraints, and uneven geographic coverage pose ongoing challenges. Overall, ATES in East Africa demonstrates promise as part of broader road safety frameworks, particularly when implementation is supported by strong institutional coordination and community engagement (Kairu & Waiganjo, 2020).

In Rwanda, the government has been proactive in implementing Automated Speed Enforcement (ASE) systems as part of a national strategy to reduce road traffic deaths and serious injury crashes. Interrupted time series analyses reveal that the introduction of ASE cameras in Rwanda was significantly associated with a substantial monthly decrease in road traffic fatalities compared with pre-implementation periods (Nkurunziza et al., 2023). Field studies further indicate that visible automated speed enforcement sites, particularly in high-traffic areas such as Kigali City, are linked to significant reductions in speed violations and average vehicle speeds relative to comparable locations without cameras, demonstrating the effectiveness of ATES in altering driver behavior and promoting compliance with traffic laws in a resource-limited setting (Uwimana & Hakizimana, 2021). Despite challenges such as maintenance costs and the need to raise public understanding of automated systems, Rwanda's experience in Kigali City provides valuable lessons on the potential of ATES to improve road safety outcomes in low- and middle-income countries (Nsengiyumva et al., 2024).

1.2 Statement of the Problem

Automated Traffic Enforcement Systems (ATES), including automated speed cameras, red-light cameras, and digital monitoring systems, have emerged as key technological interventions in global road safety strategies (Henry, 2023). These systems aim to improve traffic law compliance, reduce risky driving behaviors, and ultimately decrease the frequency and severity of road accidents. ATES operates by continuously monitoring vehicle speeds, red-light compliance, and other infractions, issuing penalties automatically without reliance on manual enforcement. Their adoption aligns with international road safety frameworks such as the United Nations Decade of Action for Road Safety, which emphasizes evidence-based interventions to reduce road traffic deaths and injuries. Despite the theoretical benefits of ATES, actual impacts vary significantly across contexts due to differences in enforcement capacity, public awareness, technological infrastructure, and socio-economic environments (Wassey, 2024).

In Rwanda and more broadly in many low- and middle-income countries road traffic accidents continue to pose a serious public health and economic burden (Terry, 2023). According to the World Health Organization, road traffic crashes are among the top causes of death for persons aged 5–29 years globally, with low- and middle-income countries accounting for over 90% of fatalities despite having only about 60% of the world's vehicles (WHO, 2023). In Rwanda, road traffic injuries accounted for a significant share of injury-related hospital admissions and fatalities in recent years, with data indicating that traffic deaths per 100,000 population remain above the global average (RNP figures reported by KT Press, 2023). These fatalities strain healthcare systems, reduce productivity, and cause emotional and economic hardships for families and communities. In urban areas such as Kigali City, high traffic density and speeding have exacerbated the risk of accidents, underscoring the urgent need for effective enforcement mechanisms (Philemon, 2024).

Previous studies have examined the impacts of automated enforcement on road safety outcomes with varying results. For example, Wilson et al. (2020) and Elvik (2012) conducted global reviews indicating that automated speed and red-light cameras can significantly reduce crashes and related injuries. In developed contexts, Retting et al. (2023) found that red-light cameras in the United States were associated with notable declines in fatal red-light running crashes, while evaluations of the United Kingdom's safety camera program reported substantial reductions in casualty collisions (Elvik & Vaa, 2024). In Sub-Saharan Africa, Odero et al. (2023) documented preliminary improvements in compliance following the deployment of automated enforcement, though infrastructural limitations constrained results. Within Rwanda, interrupted time series analyses by Nkurunziza et al. (2023) and Nsengiyumva et al. (2024) demonstrated that Automated Speed Enforcement (ASE) cameras were linked to reductions in traffic fatalities, and studies by Mukabatsindi et al. (2022) and Uwimana & Hakizimana (2021) highlighted declines in speed violations in urban enforcement zones such as Kigali City.

Despite this growing body of research, important gaps remain in understanding the long-term effects and context-specific dynamics of ATES implementation in Rwanda, particularly in rapidly urbanizing districts such as Nyarugenge. Many existing studies focus on short-term impacts or broad national trends, with limited attention to localized accident patterns, compliance behavior over time, and comparative assessments between automated and traditional enforcement approaches. Moreover, there is a lack of research integrating quantitative accident data with qualitative insights from road users and enforcement agencies to explain how ATES influences behavior change. This study seeks to bridge these gaps by conducting a comprehensive analysis of road accident trends before and after ATES implementation in Kigali City, combining statistical evaluation with stakeholder perspectives to generate context-relevant evidence for policy and practice.

This study sought to achieve the following research objective:

To determine the effect of speed enforcement cameras deployment on road accident trends in Kigali City, Rwanda.

2. Literature Review

This section reviews the key concepts related to the implementation of Automated Traffic Enforcement Systems (ATES) and their effect on road accident trends. It examines the main components of ATES, including speed enforcement cameras, red-light cameras, and Automated Number Plate Recognition (ANPR) systems. It explains how these technologies function to enhance compliance with traffic regulations. The review also considers the processes involved in deploying and managing ATES, highlighting how systematic planning, coordination, and monitoring contribute to improved road safety outcomes in urban environments

2.1.1 Automated Traffic Enforcement Systems

Automated Traffic Enforcement Systems (ATES) refer to technology-driven mechanisms used to monitor, detect, and enforce compliance with traffic laws through automated processes (Chen & Ewing, 2020). These systems include speed enforcement cameras, red-light cameras, and Automated Number Plate Recognition (ANPR) systems, which capture traffic violations using cameras, sensors, and integrated data processing platforms. ATES operate continuously and objectively, reducing reliance on manual enforcement and minimizing human bias or error. By increasing the certainty of detection and enforcement, ATES influence driver behavior, enhance compliance with traffic regulations, and contribute to reductions in road accidents, injuries, and fatalities, particularly in urban and high-traffic environments (World Health Organization, 2020)

The implementation of ATES involves systematic planning, coordination, and control of activities to achieve predefined road safety objectives (Reyson, 2020). Key processes include needs assessment, selection of enforcement locations, allocation of financial and technical resources, system installation, and integration with legal and traffic management frameworks. Continuous monitoring and evaluation enable authorities to assess system effectiveness through indicators such as accident trends, violation rates, and compliance levels. Effective coordination among traffic police, transport authorities, technology providers, and the public enhances system efficiency and sustainability. When well-planned and managed, ATES serve as reliable tools for data-driven decision-making and long-term improvement of road safety outcomes (Aeron-Thomas & Hess, 2022)

2.1.2. Speed Enforcement Cameras Deployment

Speed enforcement cameras deployment refers to the planned installation and use of automated devices designed to detect and record vehicles that exceed legally prescribed speed limits (WHO, 2020). These cameras are commonly installed at locations identified as high risk based on traffic volume, crash history, pedestrian activity, and road design characteristics. Proper deployment relies on systematic assessment of road safety data to ensure that cameras are placed where speeding is a significant contributor to accidents. When strategically positioned, speed enforcement cameras increase perceived detection likelihood, thereby encouraging drivers to comply with speed limits and reducing both the frequency and severity of traffic crashes (Pilkington & Kinra, 2020).

The deployment process also involves coordination of technical installation, operational procedures, and enforcement mechanisms to ensure coordinating technical installation, operational procedures, and enforcement mechanisms to ensure the consistent and reliable functioning of the cameras (Wangui, 2022). Ongoing system monitoring and maintenance are essential to sustain accuracy and public confidence in enforcement outcomes. In addition, continuous analysis of speed and accident data enables authorities to evaluate effectiveness and make informed adjustments where necessary. Public information and awareness initiatives further enhance compliance by ensuring that drivers understand the purpose of speed enforcement cameras as safety tools rather than revenue-generating instruments. Empirical studies consistently show that well-deployed speed enforcement cameras lead to significant reductions in speeding behavior, road traffic injuries, and fatalities, particularly in urban settings (Elvik et al., 2023).

2.1.3. Road Accident Trends

Road accident trends refer to the patterns, frequency, and severity of traffic-related incidents over a specific period within a defined area (Khayesi, & Heda, 2023). These trends provide crucial information about the occurrence, distribution, and underlying causes of road accidents, enabling authorities, policymakers, urban planners, and traffic management agencies to identify high-risk locations, vulnerable road users, and common contributing factors. Analyzing these trends involves examining accident counts, fatalities, injuries, collision types, time of occurrence, and associated factors such as speeding, reckless driving, traffic violations, vehicle condition, and road infrastructure quality. Understanding road accident trends is essential for designing effective preventive interventions, improving traffic safety strategies, and allocating resources efficiently to areas with the highest risk (Peden et al., 2024).

In urban areas such as Kigali City, road accident trends are influenced by multiple factors, including rapid urbanization, rising vehicle ownership, high population density, inadequate road infrastructure, and inconsistent adherence to traffic regulations (Afukaar, 2023). Over the years, the district has experienced an increase in road crashes, particularly at busy intersections, pedestrian crossings, and major arterial roads, underscoring the need for targeted interventions. Monitoring accident trends over time allows traffic authorities to evaluate the effectiveness of traffic management strategies and law enforcement measures, including the introduction of Automated Traffic Enforcement Systems (ATES). By analyzing pre- and post-implementation data, authorities can determine how interventions such as speed enforcement cameras, red-light cameras, and ANPR systems contribute to reductions in accident frequency, severity, and associated fatalities (Olabode, 2023).

Continuous analysis of road accident trends also supports evidence-based decision-making, enabling policymakers and enforcement agencies to prioritize high-risk zones, optimize the placement of traffic control devices, and develop targeted safety campaigns (Stephenson, 2023). It enables early identification of emerging risk patterns, such as the effects of increased vehicle speeds during peak hours or the correlation between non-compliance with traffic signals and intersection collisions. Furthermore, trend analysis provides valuable feedback for public education programs, helping road users understand the consequences of unsafe driving practices and promoting a culture of traffic safety. By systematically examining these trends, stakeholders can implement proactive measures that reduce accidents, save lives, and improve the overall efficiency of urban transport systems in Kigali City (Ewing, 2020).

2.2 Theoretical Review

This study was anchored on Deterrence Theory, which explains how the likelihood of detection and punishment can influence individuals' decisions to comply with established rules and regulations. The theory is rooted in classical criminology and was initially associated with Cesare Beccaria's work On Crimes and Punishments in 1764. It assumes that individuals consider the potential consequences of their actions and are less likely to engage in unlawful behavior when the expected costs of violating rules outweigh the perceived benefits (Piquero et al., 2021). Over time, the theory has been applied to traffic safety to explain how enforcement mechanisms can influence drivers' compliance with traffic regulations (Kleck, 2021).

The theory emphasizes three major elements of deterrence: certainty, severity, and celerity of punishment. Certainty refers to the likelihood that a violation will be detected, severity concerns the seriousness of the punishment imposed, while celerity refers to the promptness with which punishment follows a violation (Kleck & Barnes, 2023). In traffic safety, drivers are more likely to comply with speed limits, traffic signals, and other road regulations when they perceive that violations will be detected and followed by appropriate sanctions. Thus, effective enforcement can discourage risky driving behaviors and promote greater compliance with traffic regulations (Nagin, 2023).

The theory was particularly relevant to this study because Automated Traffic Enforcement Systems (ATES) increase the likelihood and efficiency of detecting traffic violations. Speed enforcement cameras, red-light cameras, and Automated Number Plate Recognition (ANPR) systems enable traffic violations to be identified and recorded through automated processes, increasing drivers' perceived certainty of detection (Terry & Wang, 2020). This may discourage speeding, red-light violations, and other unsafe driving practices, thereby contributing to improved road safety and reduced road accidents. Therefore, Deterrence Theory provided a suitable foundation for examining how the implementation of ATES influences road accident trends in Kigali City, Rwanda (Bunley, 2021).

2.3 Empirical Review

The empirical review examines previous studies and evidence related to the effect of Automated Traffic Enforcement Systems (ATES) on road accident trends. It provides insights into the effectiveness of speed enforcement cameras, red-light camera integration, and Automated Number Plate Recognition (ANPR) systems across different contexts, including global, developed, African, East African, and Rwandan settings. By analyzing prior research findings, this section identifies patterns, outcomes, and gaps that inform the current study on road safety interventions in the Kigali City. The review highlights methodologies, key findings, and recommendations from prior studies while underscoring areas requiring further research, particularly in low- and middle-income urban environments.

2.3.1 Speed Enforcement Cameras Deployment and Road Accident Trends

Globally, the deployment of speed enforcement cameras has been widely studied as a road safety intervention that reduces traffic crashes, injuries, and fatalities. A notable study by Wilson et al. (2020) conducted a systematic meta-analysis that combined before-and-after camera crash data with matched control sites across multiple countries, including the United Kingdom, Canada, and Sweden. The analysis found that installation of speed enforcement cameras was associated with an average reduction of 20% in all reported crashes, 35% in injury crashes, and 42% in fatal crashes at camera sites compared with control locations. The authors concluded that automated speed enforcement is one of the most effective traffic enforcement measures for reducing both the frequency and severity of road accidents. They recommended that authorities combine speed cameras with other safety measures, such as improved signage and public awareness campaigns, to maximize impact. However, the global evidence also highlights a gap in understanding of how speed cameras perform in low- and middle-income urban environments, where road user behavior and enforcement capacity differ significantly from those in high-income contexts.

In developed countries, speed enforcement cameras have demonstrated measurable impacts on road accident trends. Jonson and Mannering (2024) conducted a longitudinal before-after study with empirical Bayes adjustments in 150 cameras-equipped urban road sections in the United States over a five-year period. The study found that speed cameras were associated with a 25% decrease in injury crashes and a 30% reduction in speed-related collisions, after controlling for traffic volume and regression-to-the-mean effects. The authors concluded that regular enforcement via automated cameras significantly enhances compliance with speed limits and reduces crash rates. They recommended scaling up automated enforcement along key urban corridors and ensuring maintenance of cameras for effectiveness. Nevertheless, these findings are less generalizable to contexts with different road-user patterns and enforcement challenges, indicating a research gap in urban African settings such as Kigali City, where such longitudinal analyses are scarce.

In Africa, empirical evidence on speed enforcement cameras has begun to emerge, demonstrating promising yet context-specific results. An observational study by Abubakar (2021) in Accra, Ghana used a cross-sectional traffic speed and crash analysis before and after camera deployment at ten high-risk locations. The study found that speed cameras contributed to a 17% reduction in total crashes and a 22% reduction in serious-injury crashes within one year of implementation. The authors concluded that automated enforcement can enhance road safety outcomes in African cities but emphasized that complementary interventions such as driver education and consistent penalty enforcement are required to sustain compliance. The study recommended increased public engagement and infrastructure upgrades around camera sites. However, the research did not assess long-term accident trends beyond one year, revealing a gap in understanding sustained impacts of speed cameras over longer timeframes in the African urban context.

In the East African region, speed enforcement camera deployment has shown positive effects on road safety, but it faces unique implementation challenges. A quasi-experimental study in Kampala, Uganda by Mugisha et al. (2022) used pre- and post-camera installation crash data with time series analysis to evaluate road accident trends over a three-year period. The findings indicated that speed cameras were associated with a 16% reduction in fatal crashes and a 20% reduction in serious-injury crashes on major urban roads. The authors concluded that automated speed enforcement contributed to improved compliance with speed limits and reduced traffic trauma. They recommended expanding camera coverage, ensuring reliable power and data systems, and integrating enforcement with public awareness programs. However, the study noted limitations in assessing changes in driver behavior and highlighted a research gap in linking enforcement interventions to broader socioeconomic factors, such as vehicle mix and pedestrian exposure, in East African cities.

In Rwanda, empirical research on automated speed cameras has begun to produce evidence of road safety benefits. Nkurunziza et al. (2023) conducted an interrupted time-series analysis using five years of quarterly crash and enforcement data before and after the introduction of speed cameras in Kigali. The study found that the deployment of speed-enforcement cameras was associated with a 28% reduction in road-traffic fatalities and a 23% decrease in serious-injury accidents in monitored zones compared with the pre-camera period. The authors concluded that automated speed enforcement played a significant role in improving road safety outcomes in urban areas and recommended further strengthening of enforcement and public education. Nevertheless, this research focused primarily on Kigali at the district-aggregate level, leaving a gap in localized assessments of specific high-risk areas, such as Kigali City, where road user behavior, traffic mix, and enforcement dynamics may differ.

3. Methodology

This study employed a quantitative research approach complemented by qualitative data to examine the effect of Automated Traffic Enforcement Systems (ATES) implementation on road accident trends in Kigali City, Rwanda. The quantitative approach was adopted because it enabled the collection and statistical analysis of numerical data concerning the implementation of ATES and road accident trends, while the qualitative approach provided contextual information on the effectiveness, challenges, and operational experiences associated with ATES implementation. The integration of quantitative and qualitative data provided a comprehensive understanding of the contribution of Automated Traffic Enforcement Systems to road safety in Kigali City.

The study adopted a descriptive research design combining quantitative and qualitative approaches. According to Kothari (2019), a research design provides a systematic framework that guides the collection, analysis, and interpretation of data. The descriptive design was appropriate because it enabled the researcher to describe the implementation of Automated Traffic Enforcement Systems and examine its relationship with road accident trends without manipulating the study variables. The quantitative component focused on respondents' perceptions and experiences regarding ATES and changes in road accident trends, while the qualitative component provided insights from administrative personnel concerning the implementation and effectiveness of ATES.

The target population comprised road users and administrative personnel directly involved in road safety and the implementation and monitoring of Automated Traffic Enforcement Systems in Kigali City. Specifically, the population consisted of 765 licensed drivers, 433 registered motorcyclists, and 11 administrative personnel, giving a total target population of 1,209 respondents. Drivers and motorcyclists were included because they are directly exposed to automated traffic enforcement measures, while administrative personnel were included because of their direct involvement in the management, monitoring, and operation of ATES.

Using Yamane's (1967) formula at a 5% margin of error, a sample size of 300 respondents was determined from the target population of 1,209. The sample comprised 190 drivers, 108 motorcyclists, and 2 administrative personnel. Random sampling was used to select drivers and motorcyclists, while purposive sampling was used to select administrative personnel who had relevant knowledge and experience concerning the implementation and management of Automated Traffic Enforcement Systems. This combination of sampling techniques ensured that the study obtained information from both road users and personnel directly involved in ATES implementation. The study determined a total sample size of 300 participants. Of these, 298 participants comprising drivers and motorcyclists were selected to respond to structured questionnaires, while 2 administrative personnel were purposively selected to participate in semi-structured interviews. Thus, the total sample consisted of 300 participants.

Both primary and secondary data were collected to achieve the objective of the study. Primary data were obtained through structured questionnaires administered to drivers and motorcyclists and semi-structured interviews conducted with administrative personnel involved in the implementation and monitoring of ATES. The questionnaire collected information concerning respondents' awareness, perceptions, experiences, and views regarding Automated Traffic Enforcement Systems and road accident trends. Interviews provided qualitative information on ATES implementation, operational challenges, enforcement practices, system coordination, and perceived effectiveness. Secondary data were obtained through documentary review of government reports, traffic accident records, Rwanda National Police records, transport authority documents, published research, policy documents, and other relevant sources concerning ATES and road safety in Kigali City.

The research instruments comprised a structured questionnaire, a semi-structured interview guide, and a documentary review guide. The questionnaire consisted of closed-ended items measured using a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. It was organized into sections covering respondents' demographic characteristics, Automated Traffic Enforcement Systems, and road accident trends. The ATES section covered its major components, namely speed enforcement cameras, red-light cameras, and Automated Number Plate Recognition (ANPR) systems. These components were treated as dimensions of the single ATES variable rather than as separate independent variables. The interview guide was used with administrative personnel to obtain detailed information concerning the implementation, operation, effectiveness, and challenges of ATES.

The validity and reliability of the research instruments were established before the main data collection exercise. Content validity was assessed through consultation with traffic enforcement experts and administrative personnel familiar with ATES operations in Kigali City. The experts reviewed the instruments to determine whether the items adequately covered the main study variable, Automated Traffic Enforcement Systems, and its dimensions, including speed enforcement cameras, red-light cameras, and ANPR systems, as well as road accident trends. Construct validity was further supported by aligning the questionnaire and interview questions with the study objective and conceptual framework. A pilot study was also conducted to identify unclear or ambiguous items and improve the instruments before the main data collection.

Reliability was assessed through a pilot study involving 30 respondents, representing 10% of the total sample. The pilot participants included drivers, motorcyclists, and administrative personnel who were not included in the main study. The pilot data were analyzed using SPSS Version 25 to determine the internal consistency of the questionnaire items using Cronbach's Alpha coefficient. The reliability coefficients were 0.864 for Speed Enforcement Cameras Deployment, 0.817 for Red-Light Cameras Integration, 0.845 for ANPR Systems, and 0.801 for Road Accident Trends, with an overall reliability coefficient of 0.832. Since all coefficients exceeded the recommended threshold of 0.70, the research instrument was considered reliable for the main study.

The collected quantitative data were coded, cleaned, and analyzed using the Statistical Package for the Social Sciences (SPSS) Version 25. For the analysis of the study objective, Speed Enforcement Cameras Deployment was treated as the independent variable, while Road Accident Trends was treated as the dependent variable. Pearson correlation analysis was used to establish the strength and direction of the relationship between Speed Enforcement Cameras Deployment and Road Accident Trends. Simple linear regression analysis was then conducted to determine the extent to which Speed Enforcement Cameras Deployment explained variations in Road Accident Trends. The R-squared value was used to determine the proportion of variation in Road Accident Trends explained by Speed Enforcement Cameras Deployment, while ANOVA was used to assess the overall significance of the regression model. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize respondents' demographic characteristics and their perceptions regarding Speed Enforcement Cameras Deployment and Road Accident Trends.

Qualitative interview data were analyzed using thematic analysis. The analysis involved familiarization with the interview responses, coding the information into relevant categories, and identifying recurring themes concerning the implementation and effectiveness of Automated Traffic Enforcement Systems. Particular attention was given to themes related to system effectiveness, operational challenges, public compliance, system coordination, and recommendations for improving ATES implementation. The qualitative findings were then compared with the quantitative findings to provide contextual explanations and strengthen the interpretation of the study results.

Ethical principles were observed throughout the study. Participation was voluntary, and respondents were informed about the purpose and procedures of the study before providing informed consent. Participants were also informed of their right to withdraw from the study at any time without negative consequences. Confidentiality and privacy were maintained by protecting respondents' personal information and ensuring that names and other identifying information were not disclosed in the analysis or reporting. The information collected was used solely for academic purposes. Permission was obtained from the relevant traffic and administrative authorities before data collection commenced, and the study adhered to the principles of non-maleficence, beneficence, justice, integrity, and respect for participants.

4. Results and Discussion

This section presents the findings of the study on the effect of Automated Traffic Enforcement Systems (ATES) implementation on road accident trends in Kigali City, Rwanda. The findings were obtained from questionnaires administered to drivers and motorcyclists and interviews conducted with key informants involved in the implementation and monitoring of ATES. Quantitative data were analyzed using the Statistical Package for the Social Sciences (SPSS) Version 25 through descriptive statistics, Pearson correlation, and multiple regression analysis. Qualitative information obtained from the Project Manager and SPIU Staff was analyzed thematically and used to complement the quantitative findings. The presentation and discussion of findings were guided by the study objective concerning the speed enforcement cameras deployment

4.1 Results

4.1.1 Response Rate

The response rate presents the number of questionnaires distributed and returned, together with the key informants who participated in the interviews. The results are presented in Table 1:

Table 1: Response Rate

Data Collection Instrument	Target Respondents	Administered/Interviewed	Response	Response Rate (%)
Questionnaire	Drivers and Motorcyclists	298	286	96
Interview	Key Informants	2	2	100
Total		**300**	**288**	**96.0**

Source: Field Data (2026)

The total of 300 respondents were targeted for the study. Of these, 298 questionnaires were administered to drivers and motorcyclists operating in Kigali City, while two key informants, comprising one Project Manager and one SPIU Staff member, were interviewed. Out of the 298 questionnaires distributed, 286 were successfully completed and returned, representing a questionnaire response rate of 96.0%, while 12 questionnaires were not returned, representing 4.0%. The two purposively selected key informants participated fully in the interviews.

The response rate was considered adequate for the analysis because the large proportion of returned questionnaires provided sufficient information for statistical analysis and interpretation. The interviews further enriched the quantitative findings by providing information on the implementation process, operational experiences, coordination mechanisms, and challenges associated with ATES. The combination of questionnaire and interview data therefore provided a broader understanding of the implementation of Automated Traffic Enforcement Systems and its contribution to road safety in Kigali City.

4.1.2 Descriptive Statistics of Speed Enforcement Cameras Deployment

The first objective of the study sought to examine the effect of speed enforcement cameras deployment on road accident trends in Kigali City, Rwanda. Respondents were requested to indicate their level of agreement with statements measuring the deployment and effectiveness of speed enforcement cameras. The statements focused on the strategic placement of cameras, reduction of speeding behaviour, compliance with speed limits, fairness of enforcement, and the contribution of speed enforcement cameras to road safety. These indicators were adopted because they reflect the key dimensions of speed enforcement cameras deployment examined in this study. The findings are presented in Table 2.

Table 2: Descriptive Statistics on Speed Enforcement Cameras Deployment

Statements	N	Mean	Std.
Speed enforcement cameras are installed in areas with high accident risks.	286	4.36	0.71
Speed enforcement cameras have reduced speeding among drivers.	286	4.28	0.76
The presence of speed enforcement cameras has increased compliance with speed limits.	286	4.32	0.73
Speed enforcement cameras operate consistently and fairly.	286	4.14	0.82
Speed enforcement cameras have contributed to reducing road accidents in Kigali City.	286	4.41	0.68
Overall Mean		**4.30**	**0.74**

Source: Field Data (2026)

The findings presented in Table 4.7 indicate that respondents expressed positive perceptions regarding the deployment of speed enforcement cameras in Kigali City, with an overall mean of 4.30 and a standard deviation of 0.74. The high overall mean demonstrates that respondents generally agreed that speed enforcement cameras have played a significant role in improving compliance with traffic regulations and reducing road accidents. The relatively low standard deviation further indicates consistency in respondents' opinions, suggesting that most participants shared similar views regarding the effectiveness of speed enforcement cameras.

Among the statements assessed, respondents recorded the highest level of agreement with the statement that speed enforcement cameras have contributed to reducing road accidents in Kigali City (Mean = 4.41, SD = 0.68). This finding implies that respondents perceived automated speed enforcement as an effective intervention to enhance road safety by discouraging excessive speeding, a leading cause of road traffic accidents. The low standard deviation indicates a high level of consensus among respondents concerning the positive contribution of speed enforcement cameras to accident reduction.

Respondents also strongly agreed that speed enforcement cameras are installed in areas with high accident risks (Mean = 4.36, SD = 0.71). This suggests that respondents believed the authorities strategically deployed the cameras in locations where speeding had previously contributed to frequent crashes. Appropriate placement of enforcement cameras increases their effectiveness because they target areas with greater safety concerns and encourage motorists to maintain safe driving speeds. The findings further reveal that respondents agreed that the presence of speed enforcement cameras has increased compliance with speed limits (Mean = 4.32, SD = 0.73) and that speed enforcement cameras have reduced speeding among drivers (Mean = 4.28, SD = 0.76). These results indicate that the implementation of automated enforcement has positively influenced driver behaviour by increasing adherence to speed regulations. The perception that violations are continuously monitored appears to have encouraged motorists to drive more cautiously, thereby reducing risky driving behaviour associated with excessive speed.

Although speed enforcement cameras operate consistently and fairly, they recorded the lowest mean score (Mean = 4.14, SD = 0.82), yet respondents still agreed with the statement. The relatively higher standard deviation suggests slight variations in respondents' perceptions regarding the consistency and fairness of the enforcement process. Such differences may be attributed to individual experiences with automated enforcement or varying levels of awareness regarding how the technology operates. Nevertheless, the mean score remained substantially above the neutral point, indicating that respondents generally considered the system to be reliable and objective.

The qualitative findings obtained from the interviews further supported the quantitative results. The Project Manager explained that speed enforcement cameras were deployed after comprehensive road safety assessments identified locations with persistent speeding violations and high accident rates. According to the respondent: *"The deployment of speed enforcement cameras was guided by accident statistics and traffic risk assessments. Cameras were installed in locations where speeding had become a major contributor to road crashes. Since implementation, compliance with speed limits has improved considerably, and the number of speeding-related accidents has gradually declined."*

Similarly, the SPIU Staff member explained that automated speed enforcement has strengthened monitoring and improved the consistency of traffic regulation enforcement. The respondent stated:*"Unlike manual* *enforcement, the automated system operates continuously without interruption. Drivers are aware that speeding violations are detected automatically, which has encouraged greater compliance with speed limits and improved overall road discipline."*

The interview findings complement the quantitative results by demonstrating that the deployment of speed enforcement cameras has strengthened traffic law enforcement, enhanced driver compliance, and improved road safety in Kigali City.

The findings of the present study corroborate those reported by Wilson et al. (2020), who established that the deployment of speed enforcement cameras significantly reduced road crashes, injuries, and fatalities by discouraging speeding behaviour. Their meta-analysis concluded that automated speed enforcement remains one of the most effective road safety interventions because it increases compliance with speed regulations and reduces risky driving practices.

The results also mirror the observations of Jonson and Mannering (2024), who found that regular enforcement using automated speed cameras contributed to substantial reductions in injury crashes and speed-related collisions. Their study demonstrated that continuous automated monitoring encouraged drivers to observe posted speed limits, thereby improving overall traffic safety. Similarly, the findings lend further support to the work of Abubakar (2021), who reported that speed enforcement cameras reduced total crashes and serious injury crashes in Accra, Ghana. The author emphasized that automated enforcement technologies improve compliance with traffic regulations, particularly when complemented by public awareness campaigns and consistent enforcement mechanisms. Comparable findings were reported by Mugisha et al. (2022) in Uganda, who observed that speed enforcement cameras contributed to reductions in fatal crashes and serious traffic injuries through improved compliance with speed limits.

The findings can be interpreted through the Deterrence Theory, which posits that individuals are more likely to comply with established rules when they perceive a high probability of detection and punishment for violations. The positive perceptions regarding speed enforcement cameras suggest that automated monitoring has increased the certainty of detecting speeding offenses, thereby encouraging drivers to comply with prescribed speed limits. As a result, risky driving behaviours have declined, contributing to improvements in road safety.

4.1.3 Correlation Analysis

The findings of the correlations between the independent variables and the dependent variable are summarized and presented in Table 3. The Pearson correlation coefficient was used to determine the strength and direction of the relationships between Speed Enforcement Cameras Deployment, Red-Light Cameras Integration, Automated Number Plate Recognition (ANPR) Systems, and Road Accident Trends in Kigali City:

Table 3: Correlation between independent variable and dependent variable

		Speed Enforcement Cameras Deployment	**Road Accident Trends**
Speed Enforcement Cameras Deployment	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	286	
Road Accident Trends	Pearson Correlation	.759**	1
	Sig. (2-tailed)	.000	
	N	286	286

Source: Field data, 2026

The findings in Table 3 indicate a strong positive and statistically significant relationship between Speed Enforcement Cameras Deployment and Road Accident Trends, with a Pearson correlation coefficient of $r = 0.759$ and a significance level of $p = 0.000$. Since the p-value is less than 0.05, the relationship is statistically significant. This indicates that improvements in the deployment of speed enforcement cameras are associated with improvements in road accident trends in Kigali City. The strong positive correlation suggests that the increased deployment and effective operation of speed enforcement cameras are associated with improved road safety outcomes. The findings imply that speed enforcement cameras may discourage speeding, increase compliance with speed limits, and consequently contribute to reducing road accidents in Kigali City. Therefore, the results provide preliminary evidence of a significant relationship between this dimension of Automated Traffic Enforcement Systems and road accident trends.

4.1.4 Regression Analysis

The analysis aimed to determine the extent to which Speed Enforcement Cameras Deployment contributes to variations in Road Accident Trends in Kigali City. Simple linear regression analysis was conducted to determine the predictive effect of Speed Enforcement Cameras Deployment on Road Accident Trends. The results of the model summary are presented in Table 4.

Table 4. Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.759[a]	.577	.575	.33568

a. Predictors: (Constant), Speed Enforcement Cameras Deployment

The regression results indicate a strong and statistically significant positive relationship between Speed Enforcement Cameras Deployment and Road Accident Trends ($\beta = 0.759$, $p < 0.001$). The positive coefficient indicates that higher levels of speed enforcement camera deployment are associated with more favorable road accident trends, as reflected by respondents' reported improvements in road safety, compliance with speed limits, and reduction in accidents. The R^2 value of 0.577 indicates that 57.7% of the variation in the Road Accident Trends score is explained by Speed Enforcement Cameras Deployment. Therefore, the findings suggest that effective deployment of speed enforcement cameras is significantly associated with improved road safety outcomes in Kigali City.

Table 5. ANOVA Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	43.616	1	43.616	387.080	.000[b]
	Residual	32.001	284	.113		
	Total	75.617	285			

a. Dependent Variable: Road Accident Trends (Y)

b. Predictors: (Constant), Speed Enforcement Cameras Deployment

The ANOVA results presented in Table 5 indicate that the simple linear regression model was statistically significant, $F(1, 284) = 387.080$, $p < 0.001$. Since the significance value is less than the 0.05 level of significance, the null hypothesis that the regression model does not significantly predict Road Accident Trends is rejected. This finding indicates that Speed Enforcement Cameras Deployment significantly contributes to explaining variations in Road Accident Trends in Kigali City. Therefore, the regression model provides a statistically significant prediction of Road Accident Trends based on Speed Enforcement Cameras Deployment.

Table 6. Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.812	.150		5.426	.000
	Speed Enforcement Cameras Deployment	.864	.044	.759	19.674	.000

a. Dependent Variable: Road Accident Trends (Y)

The regression coefficients presented in Table 6 indicate that Speed Enforcement Cameras Deployment has a positive and statistically significant effect on Road Accident Trends in Kigali City. The standardized regression coefficient ($\beta = 0.759$) shows a strong positive contribution of Speed Enforcement Cameras Deployment to Road Accident Trends, while the significance value ($p = 0.000$) is below the 0.05 threshold. The t-value of 19.674 further confirms the statistical significance of the predictor. The unstandardized coefficient ($B = 0.864$) indicates that a one-unit increase in Speed Enforcement Cameras Deployment is associated with a 0.864-unit increase in the Road Accident Trends score, holding other factors constant. The constant of 0.812 indicates the expected value of Road Accident Trends when Speed Enforcement Cameras Deployment is zero. Therefore, the findings provide evidence that Speed Enforcement Cameras Deployment significantly contributes to road safety outcomes in Kigali City. Since $p = 0.000 < 0.05$, the null hypothesis stating that Speed Enforcement Cameras Deployment has no statistically significant effect on Road Accident Trends in Kigali City is rejected

4.2 Discussion of Findings

This section discusses the findings of the study by relating the descriptive statistics, correlation analysis, and regression analysis to the study objective, the underlying theoretical framework, and previous empirical studies. The discussion focuses specifically on the effect of Speed Enforcement Cameras Deployment on Road Accident Trends in Kigali City, Rwanda.

The descriptive findings showed that respondents generally had positive perceptions regarding the deployment of speed enforcement cameras in Kigali City. Respondents agreed that the cameras are installed in high-risk accident areas, reduce speeding among drivers, increase compliance with speed limits, operate consistently and fairly, and contribute to reducing road accidents. These findings suggest that speed enforcement cameras have become an important mechanism for strengthening traffic regulation and promoting road safety in Kigali City.

The correlation analysis established a strong positive and statistically significant relationship between Speed Enforcement Cameras Deployment and Road Accident Trends. This finding indicates that improvements in the deployment and operation of speed enforcement cameras are associated with favourable changes in road accident trends. The relationship suggests that automated monitoring increases drivers' awareness of enforcement and encourages compliance with speed limits, thereby contributing to improved road safety outcomes.

The regression analysis further established that Speed Enforcement Cameras Deployment significantly contributes to Road Accident Trends in Kigali City. The regression model demonstrated that the predictor explains a substantial proportion of the variation in road accident trends, while the ANOVA results confirmed that the model is statistically significant. The regression coefficient further demonstrated that Speed Enforcement Cameras Deployment is a significant predictor of Road Accident Trends. These findings provide statistical evidence that the deployment of speed enforcement cameras plays an important role in improving road safety in Kigali City.

The findings are consistent with Deterrence Theory, which explains that individuals are more likely to comply with established rules when they perceive a high probability of detection and punishment. In this study, speed enforcement cameras increase the certainty that speeding violations will be detected and recorded. This can discourage drivers from exceeding prescribed speed limits and encourage safer driving behaviour. Therefore, the findings support the theoretical argument that automated enforcement can influence road-user behaviour through increased certainty of detection.

The findings are also consistent with previous empirical studies. Wilson et al. (2020) found that speed enforcement cameras significantly reduce road crashes, injuries, and fatalities by discouraging speeding behaviour. Similarly, Jonson and Mannering (2024) established that automated speed enforcement contributes to reductions in injury crashes and speed-related collisions. Abubakar (2021) reported that speed enforcement cameras reduced total crashes and serious-injury crashes in Accra, Ghana, while Mugisha et al. (2022) found that speed cameras contributed to reductions in fatal crashes and serious traffic injuries in Uganda. These findings support the present study's conclusion that speed enforcement cameras can contribute to improved road safety.

The qualitative findings further support the quantitative results. The Project Manager explained that speed enforcement cameras were deployed based on accident statistics and traffic risk assessments, particularly in locations where speeding was a major contributor to road crashes. The SPIU Staff member also indicated that continuous automated monitoring has encouraged drivers to comply with speed limits and improved overall road discipline. These views provide additional contextual support for the statistical findings concerning the contribution of speed enforcement cameras to road safety.

5. Conclusion and Recommendations

5.1 Conclusion

The study concludes that Speed Enforcement Cameras Deployment has a statistically significant positive effect on Road Accident Trends in Kigali City, Rwanda. The findings from the descriptive analysis, Pearson correlation, and simple linear regression demonstrate that effective deployment of speed enforcement cameras is associated with improved road safety outcomes. The regression results further indicate that Speed Enforcement Cameras Deployment explains a substantial proportion of the variation in Road Accident Trends. Therefore, strengthening the strategic deployment, operation, and maintenance of speed enforcement cameras can contribute to improved compliance with speed limits and enhanced road safety in Kigali City.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. The Rwanda National Police and relevant road safety authorities should strengthen the strategic deployment and maintenance of speed enforcement cameras in high-risk locations and areas with frequent speeding violations. Regular monitoring, maintenance, and calibration should be undertaken to ensure that the cameras operate accurately and consistently. In addition, traffic authorities should continuously evaluate camera performance using road accident and traffic violation data to identify areas requiring improved enforcement coverage.
2. The relevant traffic authorities should strengthen the integration and effective operation of ANPR systems to improve vehicle identification, traffic monitoring, and timely enforcement of traffic violations. This would enhance the capacity of ATES to detect violations and encourage greater compliance with traffic regulations.
3. The Rwanda National Police and other road safety stakeholders should improve the integration and management of ATES component especially speed enforcement cameras. Regular evaluation of system performance, public awareness, and coordination among responsible institutions should be strengthened to maximize the contribution of ATES to reducing road accidents in Kigali City.

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