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Abstract

Purpose: This study aims to explore the factors influencing the performance of Intelligent Traffic Control Systems (ITCS) in Nairobi, focusing on road intersection management, traffic education, law enforcement, and evaluation, while examining how these factors interact to enhance ITCS performance.

Methodology: A pragmatist research paradigm was adopted, integrating qualitative and quantitative approaches. A mixed-methods, explanatory research design was used to provide comprehensive insights into traffic management practices, combining qualitative stakeholder interviews with quantitative survey data. The study targeted 942 traffic management stakeholders, including public service vehicle SACCO leaders, traffic police officers, county officials, and representatives from the National Transport and Safety Authority (NTSA) and the Kenya Urban Roads Authority. Data collection involved key informant interviews and structured questionnaires to capture diverse viewpoints and enhance the study's comprehensiveness.

Findings: The results reveal that traffic education positively impacts ITCS performance, emphasizing the importance of educating road users to improve traffic flow. However, road intersection engineering and law enforcement showed minimal effect on ITCS, and traffic evaluation had a negative impact on performance. This suggests that while traffic education is critical, infrastructure and enforcement need further improvement for better results.

Unique Contribution to Practice and Policy: This study offers insights into factors affecting ITCS performance and provides practical recommendations for policymakers, emphasizing the need to focus on enhancing traffic education, improving infrastructure, and optimizing law enforcement to strengthen traffic management systems in Nairobi. An integrated ap

Keywords: *Management, Road Intersection, Performance, Intelligent Traffic Control Systems*

INTRODUCTION

Efficient mobility is essential for economic growth and development, as it facilitates the movement of people and goods within and across urban areas. However, Nairobi, like many rapidly urbanizing cities, faces severe traffic congestion, leading to economic losses, environmental degradation, and reduced quality of life. Nairobi's congestion is primarily driven by increasing vehicle ownership, limited road infrastructure expansion, and ineffective traffic management systems (Agyapong & Ojo, 2018). According to the Nairobi Metropolitan Area Transport Authority (NaMATA), the city's traffic congestion costs the economy approximately KES 50 billion annually in lost productivity and increased fuel consumption. To address these challenges, the implementation of intelligent traffic control systems has been identified as a potential solution to optimize mobility, minimize delays, and improve road safety (Jayasooriya & Bandara, 2017).

Traffic congestion in Nairobi has been exacerbated by an imbalance between population growth and transportation network expansion. With Nairobi's population projected to surpass six million by 2030, congestion levels are expected to rise significantly unless sustainable interventions are implemented (Amiegbebhor, 2018). Recent studies indicate that congestion levels in the city have reached approximately 65%, with some major roads experiencing up to 90% saturation during peak hours (NaMATA, 2022). Without effective traffic management strategies, congestion will continue to lead to increased travel times, fuel consumption, and pollution, ultimately worsening urban mobility challenges (Sorensen et al., 2008). The ability of intelligent traffic control systems to address congestion in Nairobi depends on their capacity to regulate traffic at key intersections, coordinate vehicle movement, and enhance road user experiences.

Urban centers globally have long struggled with congestion, with historical records indicating traffic challenges even before the advent of modern automobiles (Falcocchio & Levinson, 2015). Cities such as 19th-century New York and 17th-century London experienced congestion due to high population densities and inadequate transportation infrastructure (Ayo-Odifiri et al., 2017). In modern times, Nairobi faces similar challenges as major global cities such as Los Angeles and Beijing, where congestion has led to significant economic losses. For instance, traffic congestion in Los Angeles resulted in an estimated cost of $305 billion in 2018, with residents spending an average of 102 hours in traffic annually (Suryani et al., 2019; Vencataya et al., 2018). Nairobi's traffic situation is equally dire, with commuters spending an average of 62 minutes in traffic daily, leading to an estimated annual economic loss of 2% of Kenya's GDP (Kenya Urban Roads Authority [KURA], 2021). The primary causes of congestion in Nairobi include inadequate road networks, uncoordinated urban planning, and inefficient public transport systems.

African cities, including Nairobi, Lagos, Cairo, and Johannesburg, have been increasingly affected by traffic congestion due to poor infrastructure, ineffective traffic regulation enforcement, and inadequate public transit systems (Agyapong & Ojo, 2018). In Nairobi, unregulated public transport systems, poor traffic discipline, and limited road capacity contribute to severe congestion, impacting economic productivity and air quality (Raheem et al., 2015). To address these challenges, the Nairobi County Government, in collaboration with transport agencies, has proposed various interventions, including the implementation of the Bus Rapid Transit (BRT) system, expansion of road networks, and adoption of intelligent traffic control technologies (Ezeibe et al., 2019). However, many of these strategies are still in their early stages and have yet to yield significant improvements. Given the rapid urbanization and increasing demand for efficient transport solutions, further research is needed to explore innovative approaches to traffic congestion management in Nairobi, ensuring sustainable urban mobility.

Problem Statement

Traffic congestion remains a critical urban challenge, particularly at road intersections where vehicular flow is most restricted. In Nairobi County, one of Africa's fastest-growing urban centers, congestion at major intersections leads to severe delays, increased fuel consumption, and heightened pollution levels, negatively impacting urban mobility (Agyapong & Ojo, 2018). While various measures such as road expansions, traffic signal installations, and manual traffic control by police officers have been implemented, congestion persists, largely due to inefficiencies in intersection management. Conventional traffic signals and roundabouts in Nairobi often lack adaptive capabilities, failing to respond dynamically to fluctuating traffic volumes, which exacerbates delays and reduces overall transport efficiency (Raheem et al., 2015).

The adoption of ITCS in Nairobi has been proposed as a solution to mitigate congestion by leveraging real-time data, automated signal coordination, and adaptive traffic algorithms (Suryani et al., 2019). However, the effectiveness of these systems remains inconsistent due to various challenges in intersection management. Key gaps include inadequate synchronization of ITCS with existing infrastructure, unreliable power supply leading to frequent system disruptions, and limited integration of sensor-based vehicle detection technologies (Toan, 2019; Vencataya et al., 2018). Moreover, manual traffic interventions by police officers often override automated controls, reducing the efficiency of ITCS and leading to unpredictable traffic patterns. Despite global evidence supporting the potential of ITCS in optimizing traffic flow, the extent to which intersection-specific challenges hinder their performance in Nairobi remains insufficiently explored.

Without addressing these gaps, the full potential of ITCS cannot be realized, resulting in continued inefficiencies in urban mobility. A critical examination of how intersection management strategies such as adaptive traffic signals, sensor-based vehicle detection, and intersection design modifications impact the performance of ITCS is essential (Falcocchio & Levinson, 2015). If left unaddressed, poor intersection management will continue to undermine urban transport efficiency, leading to economic losses, decreased productivity, and worsening air quality in Nairobi. Therefore, this study seeks to investigate the intersection-specific factors affecting the operational efficiency of ITCS in Nairobi County, providing insights that can inform evidence-based policy decisions and infrastructure investments to enhance urban transportation.

Theoretical Review

Concurrent Engineering Theory

The concurrent engineering theory, advanced by Rosenblatt and Watson (1991), emphasizes the simultaneous integration of various disciplines and processes rather than a sequential approach. In regards to managing road intersections, this theory highlights the importance of real-time collaboration among key traffic management stakeholders, including traffic engineers, law enforcement agencies, urban planners, policymakers, and transport system evaluators so as to enhance the performance of ITCS. Unlike traditional traffic management approaches that address road infrastructure, enforcement, and system optimization in isolation, concurrent engineering advocates for an integrated and synchronized approach that improves traffic flow, safety, and system adaptability (Faskin, & Henshaw, 2017).

This theory is particularly relevant to Nairobi's traffic challenges, where inefficient intersection management remains a major contributor to congestion. Nairobi's road network suffers from uncoordinated traffic signals, frequent manual overrides by traffic police, and inconsistent enforcement of traffic regulations. For instance, major intersections such as those along Thika Road, Uhuru Highway, and Jogoo Road experience severe congestion due to a lack of real-time coordination between traffic lights, enforcement agencies, and road users. Concurrent engineering provides a strategic framework for addressing these inefficiencies by ensuring that intersection engineering, traffic enforcement, traffic education, and system evaluation are treated as interconnected components rather than isolated functions.

Trough application of concurrent engineering principles, ITCS in Nairobi can be designed and implemented through a holistic, collaborative approach. For example, real-time traffic data collected from sensors at intersections can be directly integrated into adaptive signal control systems while simultaneously informing law enforcement on areas requiring immediate intervention. Similarly, traffic education campaigns can be tailored based on system performance evaluations, ensuring that drivers, pedestrians, and public transport operators are aware of and adhere to ITCS guidelines. Moreover, Nairobi's traffic control agencies, such as the Nairobi Metropolitan Area Transport Authority (NaMATA, 2022). and the Kenya Urban Roads Authority (KURA), can work together to ensure that traffic engineering improvements, such as intersection redesigns and dedicated bus lanes, are reinforced by smart enforcement measures like automated violation detection.

Through fostering proactive, real-time collaboration and data-driven decision-making, concurrent engineering enhances ITCS performance, leading to improved road safety, reduced congestion, and optimized urban transport efficiency. As a result, this theory underscores the need for an integrated, multidisciplinary approach to traffic intersection management in Nairobi, ensuring that all stakeholders contribute collectively to a sustainable and efficient urban mobility system.

Routine Activity Theory

The routine activity theory, introduced by Cohen and Felson (1979), suggests that crime and rule-breaking behavior occur when three factors align: a motivated offender, an accessible target, and the absence of capable guardianship. When applied to road intersection management and the performance of ITCS, this theory underscores the importance of traffic enforcement, monitoring systems, and road infrastructure in deterring violations and enhancing safety. In Nairobi, traffic congestion and frequent violations at major intersections are exacerbated by poor enforcement, inadequate monitoring, and infrastructure gaps. For example, intersections such as Nyayo Roundabout, Globe Roundabout, and Mombasa Road frequently experience reckless driving, lane indiscipline, and unauthorized pedestrian crossings, often due to weak enforcement and inadequate surveillance (NaMATA, 2022).. By integrating routine activity theory into ITCS, authorities can mitigate these challenges by strengthening monitoring mechanisms, improving real-time enforcement, and enhancing intersection design to minimize risky behavior.

One effective intervention is the use of automated surveillance and real-time traffic monitoring. Nairobi has piloted the installation of traffic cameras at critical junctions, such as Kenyatta Avenue and Thika Road, to detect and penalize violations, reducing the likelihood of reckless driving. Moreover, the introduction of Intelligent Traffic Lights under the Nairobi Integrated Urban Development Master Plan (NIUPLAN) has sought to regulate traffic flow more efficiently, minimizing congestion and reducing driver impatience that often leads to violations (Kariuki, 2021). Beyond automation, physical intersection improvements play a crucial role in crime prevention within traffic systems. Well-designed intersections that integrate clear road signs, optimized signal operations, and designated pedestrian crossings minimize opportunities for rule-breaking. For example, the redesign of the Haile Selassie-Uhuru Highway intersection incorporated pedestrian footbridges and clearly marked lanes to discourage jaywalking and illegal turns.

Furthermore, the presence of both human and automated enforcement mechanisms strengthens traffic compliance. Strategic deployment of traffic officers at high-risk intersections, coupled with smart traffic cameras, serves as a deterrent against reckless driving, reducing the chances of road offenses. Nairobi's recent enforcement of electronic ticketing for traffic violations further aligns with this approach by ensuring offenders face immediate penalties, reinforcing compliance. Through incorporating routine activity theory into ITCS, Nairobi can create a structured, deterrence-based system that enhances compliance, minimizes accidents, and contributes to a safer urban mobility framework. This theory highlights the need for a comprehensive approach that combines technology, infrastructure improvements, and active enforcement to create an efficient and rule-abiding urban transport network.

Stakeholder Theory

The Stakeholder Theory, developed by Freeman (1984), asserts that organizations must consider the interests of all key stakeholders to achieve long-term success. When applied to road intersection management and the performance of Intelligent Traffic Control Systems (ITCS), this theory highlights the importance of collaboration among engineers, law enforcement agencies, policymakers, commuters, urban planners, and public transport operators. A well-functioning ITCS requires input from multiple stakeholders to ensure infrastructure development, enforcement measures, and public awareness initiatives align with the needs and expectations of different groups.

In Nairobi, various stakeholders play integral roles in traffic management. For instance, the NaMATA is responsible for urban mobility planning, while the Kenya Urban Roads Authority (KURA) oversees road infrastructure development, ensuring that intersections accommodate increasing traffic demands. Traffic police officers, under the National Police Service, enforce road rules, while the Nairobi City County Government regulates public transport operators such as matatus, which significantly impact congestion at intersections. Effective coordination among these entities is essential for improving ITCS performance and intersection efficiency.

A practical example of stakeholder collaboration in Nairobi is the Green Park Bus Terminal project, designed to decongest the Central Business District (CBD) by relocating long-distance public service vehicles to designated terminals outside the city center. This initiative required cooperation between NaMATA, KURA, the Nairobi County Government, and matatu operators to ensure smooth implementation (NaMATA, 2022). However, delays and resistance from stakeholders particularly matatu owners, demonstrated the challenges of inadequate stakeholder engagement. A better application of stakeholder theory in such projects would

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involve earlier consultation, transparent policymaking, and incorporating feedback from affected groups to improve acceptance and effectiveness.

Another example is the installation of intelligent traffic lights along major Nairobi roads such as Haile Selassie Avenue, Kenyatta Avenue, and University Way (Kariuki, 2021). Engineers from KURA and the Nairobi City County worked together to implement smart signal systems, but initial challenges arose due to power outages and poor enforcement, leading to continued reliance on manual traffic control. This highlights the need for greater coordination between power supply agencies , law enforcement, and traffic management authorities to ensure uninterrupted ITCS functionality.

Moreover, urban planners and road users play a vital role in improving ITCS effectiveness. Public participation in road design projects, such as the expansion of Ngong Road and the Nairobi Expressway, has allowed stakeholders to provide input on accessibility and pedestrian safety (KURA, 2024). Feedback from commuters has led to modifications, such as adding pedestrian crossings and footbridges to enhance road user experience and reduce accidents at intersections. By integrating stakeholder theory into traffic management and ITCS development, Nairobi can foster a more inclusive, well-regulated, and participatory approach to urban mobility. Ensuring transparent governance, active stakeholder involvement, and continuous dialogue between agencies and the public can lead to more effective, sustainable, and widely accepted traffic control solutions.

Empirical Review

Studies on road intersection engineering emphasize the crucial role of infrastructure in regulating traffic flow and reducing congestion. Saleh et al. (2017) and Nugmanova et al. (2019) both examined how specific engineering interventions impacted congestion, though their findings diverged due to contextual differences. Saleh et al. (2017) found that while the construction of flyovers at busy intersections in Indonesia was intended to ease congestion, it paradoxically increased traffic load due to induced demand. Conversely, Nugmanova et al. (2019) demonstrated that the Big Almaty Ring Road in Kazakhstan successfully alleviated congestion by redirecting transit traffic away from city centers, showcasing the importance of strategic planning in infrastructure projects. Wanjala (2020) provided further insight into infrastructure inefficiencies in Nairobi, identifying issues such as inadequate pavements and poor signage along Tom Mboya Street, which contributed to traffic congestion. These findings suggest that while engineering solutions are essential for traffic management, their effectiveness depends on comprehensive urban planning, proper execution, and continuous assessment.

Moreover, the integration of technology into road infrastructure has been explored as a means of enhancing traffic efficiency. Yan and Wu (2014) and Sandu (2013) emphasized the role of intelligent traffic systems, including variable message signs and automated road signage, in improving driver compliance and optimizing traffic movement. These studies collectively suggest that while infrastructure development remains a core aspect of traffic management, incorporating smart technologies and adaptive traffic control measures can significantly enhance road intersection efficiency.

Traffic law enforcement has been widely studied as a mechanism for controlling traffic violations and improving overall road safety. Pérez et al. (2007) provided empirical evidence that speed camera surveillance significantly reduced accidents and congestion in urban areas by deterring reckless driving. However, Mphela (2011) found that punitive enforcement

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strategies had minimal impact on reducing road fatalities in Botswana, indicating that enforcement alone is insufficient without complementary measures such as education and infrastructure improvements. Musau (2015) examined Kenya's national roads and concluded that weak enforcement mechanisms contributed to increased congestion and accidents, reinforcing the need for a more structured and efficient enforcement framework.

Rosenfeld (2019) further highlighted that in developed countries, the success of traffic law enforcement relied on consistency and technological integration, such as automated ticketing and real-time monitoring. These findings underscore a key gap in developing countries like Kenya, where enforcement is often irregular and resource-constrained. While strict enforcement mechanisms have proven effective in some contexts, their long-term impact depends on their adaptability, fairness, and integration with broader traffic management strategies.

Education and awareness initiatives have been identified as key drivers of improved road user behavior and traffic efficiency. Uwadiegwu (2013) and Olumide and Owoaje (2016) argued that public education campaigns play a critical role in reducing congestion by promoting responsible driving habits. Their studies suggested that well-designed awareness programs can lead to better compliance with traffic regulations, particularly among commercial drivers and public transport operators. Topolšek et al. (2019) provided further evidence by demonstrating that participation in structured traffic safety programs significantly reduced violations and accidents, reinforcing the value of long-term behavioral interventions.

However, some studies question the sustainability of these effects. Sami et al. (2013) argued that while education can lead to short-term improvements in driving behavior and congestion reduction, its long-term impact is contingent on reinforcement mechanisms such as continuous training and stricter policy enforcement. Similarly, Olumide and Owoaje (2016) noted that the benefits of education campaigns tend to diminish over time without sustained engagement from policymakers and law enforcement agencies. These findings suggest that while education remains a vital component of traffic management, its effectiveness is maximized when combined with enforcement and infrastructural improvements.

Kariuki (2021) probed the potential of implementing smart traffic control systems in Nairobi using Internet of Things (IoT) technologies. The study highlights the persistent traffic congestion in Nairobi and proposes an IoT-driven solution that integrates real-time data collection, adaptive signal control, and intelligent monitoring to enhance traffic flow. The research examined the feasibility of deploying IoT-enabled sensors, automated traffic lights, and centralized traffic management systems to improve road intersection efficiency. Through a case study analysis, the study identified challenges such as high implementation costs, infrastructure limitations, and data security concerns. However, the findings suggest that a well-integrated IoT-based traffic control system could significantly enhance mobility, reduce delays, and improve road safety.

Munene (2017) examined the effectiveness of traffic management strategies employed by traffic police in Nairobi County, focusing on measures such as manual traffic control, enforcement, roadblocks, and public awareness campaigns. The study found that while these strategies contributed to improved compliance with traffic laws, their overall impact was limited by challenges such as corruption, inadequate staffing, poor infrastructure, and a lack of technological support. The research emphasized that sustainable traffic management required the integration of ITCS alongside traditional enforcement methods. To enhance efficiency, the study recommended investing in automated traffic management solutions, strengthening officer training programs, and implementing stricter anti-corruption policies to optimize traffic flow and reduce congestion in Nairobi.

The Kenya Urban Roads Authority (KURA) (2024) reported on the ongoing upgrade of Nairobi's traffic management system, focusing on the implementation of Intelligent Transport Systems (ITS) to enhance urban mobility. The project aimed to modernize 25 key intersections by integrating vehicle detection systems, adaptive traffic signals, variable message signs, surveillance cameras, and a centralized Traffic Management Centre (TMC). The study highlighted the expected benefits, including reduced congestion, improved traffic flow, enhanced road safety, and lower vehicle emissions. However, it also acknowledged challenges such as financial constraints, system maintenance, and the need for inter-agency coordination. The report emphasized the importance of sustained investment in ITS infrastructure and stakeholder collaboration to ensure long-term effectiveness in managing Nairobi's traffic.

Despite the extensive research on traffic management strategies, several gaps remain. First, while studies have explored the role of infrastructure, enforcement, and education independently, there is limited research on their combined effects within an integrated ITCS framework. Second, existing research on enforcement is predominantly focused on punitive measures, yet there is limited analysis on the role of incentives and positive reinforcement in traffic compliance. Lastly, most studies on education campaigns focus on short-term behavioral changes, with little exploration of sustained impact assessments.

METHODOLOGY

This research adopted a pragmatist research paradigm, which integrates both qualitative and quantitative approaches to provide a comprehensive understanding of the complex relationships among key variables. Rooted in the practical application of research findings, pragmatism emphasizes deriving actionable solutions that are relevant to real-world issues. To achieve this, a mixed-methods and explanatory research design was implemented, facilitating a thorough examination of the research problem. By combining qualitative insights from stakeholder interviews with quantitative data from structured surveys, the study ensures a well-rounded investigation of traffic management practices, offering both in-depth analysis and broad generalizability. The design also supports comparative analysis across different stakeholder groups, allowing for meaningful insights that can be applied to a wider population.The study focused on a target population of 942 traffic management stakeholders, consisting of 621 leaders of public service vehicle SACCOs, 200 traffic police officers, 100 city county traffic officials, eight officials from Nairobi County's Public Works and Transport sector, seven representatives from the National Transport and Safety Authority (NTSA), and six members of the Kenya Urban Roads Authority. This diverse sample ensures a broad range of perspectives on traffic management issues. Primary data collection was conducted through key informant interviews and structured questionnaires, chosen to capture both expert knowledge and a diverse array of viewpoints, thereby enhancing the study's comprehensiveness in understanding the traffic management landscape in Nairobi.

Measurement of Variables

The measurement of variables was systematically designed to align with the context of the study. The independent variable, management of road intersections, was operationalized through four key dimensions: intersection engineering, traffic enforcement, traffic education, and traffic evaluation. These dimensions represent distinct aspects of intersection management,

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including the design and engineering of physical infrastructure, the effectiveness of traffic law enforcement, the role of educational initiatives in promoting road safety, and the ongoing evaluation and monitoring of traffic operations. Each dimension is measured using specific indicators that capture its contribution to the overall efficacy of intersection management.

The dependent variable, the performance of ITCS, was measured through a set of indicators that reflect the multifaceted nature of traffic system efficiency. These include customer satisfaction, which provides insight into user perceptions of system effectiveness; ownership, which denotes the level of public and institutional investment in the ITCS; cost efficiency, which evaluates the system's financial sustainability and resource utilization; traffic flow, which measures the smoothness and speed of traffic movement; travel time, which gauges reductions in commute durations; and pedestrian control, which assesses the system's ability to manage pedestrian traffic. These comprehensive indicators offer a nuanced evaluation of ITCS performance, facilitating a detailed analysis of how various factors influence the system's overall success in managing urban traffic.

Data Analysis and Presentation

Data analysis in this study was conducted using both qualitative and quantitative methods to provide a comprehensive understanding of the relationships between the variables under investigation. Qualitative data from key informant interviews were analyzed thematically, identifying key patterns, trends, and insights related to traffic management practices, while quantitative data from structured questionnaires were analyzed using statistical techniques such as descriptive statistics, correlation analysis, and regression analysis. The descriptive statistics provided a summary of the demographic characteristics of the sample, while correlation analysis was employed to explore the relationships between the management of road intersections and ITCS performance. Regression analysis was used to determine the strength and direction of these relationships, offering a deeper understanding of the factors that influence the effectiveness of the Intelligent Traffic Control System. The results were then presented through tables, charts, and graphs to enhance clarity and support a clear interpretation of the findings.

FINDINGS

This section of the research paper presents diagnostic, descriptive, and inferential statistical analyses. Descriptive statistics provide a summary of the key characteristics of the variables, while inferential analysis explores relationships between variables through regression techniques.

Descriptive Statistics

This section provides an overview of the initial data analysis, focusing on the attributes and relationships of individual variables. It examines each variable separately, detailing key statistical measures such as central tendency, variability, and distribution trends. Furthermore, it detects any anomalies or outliers that could impact the study's overall conclusions.

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Table 1: Descriptive Statistics

Variable	Mean	Standard Deviation
Road intersection engineering	2.92	1.42
Traffic education	2.44	0.97
Traffic law enforcement	2.74	0.99
Traffic evaluation	2.44	0.61
Performance of ITCS	2.84	1.17

Table 1 presents the descriptive statistics for key variables associated with the management of road intersections and the performance of ITCS. The mean values indicate the average ratings for each variable, with road intersection engineering recording the highest mean score (2.92), suggesting that this aspect is relatively more developed or prioritized. Traffic law enforcement follows with a mean of 2.74, indicating a moderate level of enforcement effectiveness. Performance of ITCS has a mean of 2.84, reflecting a fairly positive assessment of its functionality. However, traffic education and traffic evaluation both have the lowest mean scores (2.44), highlighting possible gaps in awareness initiatives and systematic assessment of traffic management.

The standard deviation values reveal the extent of variability in responses. Road intersection engineering exhibits the highest variability (1.42), indicating diverse perceptions among respondents regarding its effectiveness. Performance of ITCS also shows considerable variation (1.17), suggesting differing experiences with the system's efficiency. In contrast, traffic evaluation has the lowest standard deviation (0.61), reflecting greater consensus in respondents' views on its implementation. Traffic education (0.97) and traffic law enforcement (0.99) demonstrate moderate variability, indicating some consistency in opinions. These findings suggest that while road intersection engineering and ITCS performance are relatively well-rated, improvements in traffic education and evaluation are necessary to enhance overall traffic management effectiveness.

Regression Results

The analysis presented in Table 2 explores the relationship between the management of road intersections and the performance of the Intelligent Traffic Control System (ITCS). By examining key factors such as road intersection engineering, traffic education, traffic law enforcement, and traffic evaluation, the study assesses how these variables collectively impact the efficiency and effectiveness of ITCS in managing urban traffic. The following sections outline the statistical findings from the regression analysis, providing insights into the significance of each variable and its contribution to ITCS performance.

Table 2: Estimation Results

Model Statistics	Value
R	0.479
R Square	0.229
Adjusted R Square	0.216
Standard Error of the Estimate	3.375
F-Statistic	17.332
Significance (p-value)	0.001

ANOVA Results					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	789.696	4	197.424	17.332	0.001
Residual	2654.052	233	11.391		
Total	**3443.748**	**237**			

Regression Coefficients					
	(Unstandardized)		**(Standardized)**	**t**	**p**
	B	**Std. Error**	**Beta**		
(Constant)	**39.932**	**5.542**	**-**	**7.21**	**0.001**
Road Intersection Engineering	-0.004	0.064	-0.004	-0.06	0.951
Traffic Education	0.318	0.051	0.372	6.23	0.001
Traffic Law Enforcement	-0.005	0.099	-0.003	-0.05	0.960
Traffic Evaluation	-0.627	0.153	-0.283	-4.10	0.001

Table 2 presents the results of the regression analysis examining the relationship between the management of road intersections and the performance of the Intelligent Traffic Control System (ITCS). The model statistics show that the regression model is statistically significant, $F = 17.332$, $p < 0.001$, with an R^2 value of 0.229. This indicates that approximately 22.9% of the variance in ITCS performance is explained by the independent variables included in the model.

The regression coefficients reveal that traffic education significantly predicts ITCS performance ($\beta = 0.372$, SE = 0.051, t = 6.23, $p < 0.05$), suggesting that efforts in traffic education positively contribute to the performance of ITCS. On the other hand, road intersection engineering ($\beta = -0.004$, SE = 0.064, t = -0.06, $p > 0.05$) and traffic law enforcement ($\beta = -0.003$, SE = 0.099, t = -0.05, $p > 0.05$) show no significant effect on ITCS performance. This indicates that while traffic education is a key factor in improving ITCS performance, the engineering of road intersections and law enforcement do not have a meaningful impact in this model. Additionally, traffic evaluation has a significant negative effect on ITCS performance ($\beta = -0.283$, SE = 0.153, t = -4.10, $p < 0.05$), suggesting that increasing traffic evaluation activities may negatively influence the performance of the ITCS.

Discussion

The estimation results provide valuable insights into the factors influencing the performance of the Intelligent Traffic Control System (ITCS). Traffic education emerged as a significant positive predictor of ITCS performance ($\beta = 0.372$, $p < 0.05$), reinforcing the role of education in shaping road users' behavior and improving traffic management. This finding aligns with studies by Uwadiegwu (2013) and Olumide and Owoaje (2016), who highlight that education and awareness campaigns lead to safer driving habits, reduced congestion, and overall improved traffic flow. Additionally, Topolšek et al. (2019) found that participation in traffic safety programs significantly reduced violations and accidents, supporting the idea that education plays a critical role in improving ITCS performance. These results suggest that increasing investment in traffic education programs, particularly through structured driver training and public awareness campaigns, could enhance ITCS efficiency by promoting compliance with traffic rules and reducing erratic driving behavior.

In contrast, road intersection engineering (β = -0.004, $p > 0.05$) and traffic law enforcement (β = -0.003, $p > 0.05$) showed no significant relationship with ITCS performance. These findings contradict prior research, such as Saleh et al. (2017) and Nugmanova et al. (2019), which underscore the role of engineering solutions—such as flyovers, ring roads, and optimized signalization in alleviating congestion. One possible explanation for this discrepancy is that while infrastructure improvements are crucial, their direct impact on ITCS performance may be contingent on the quality of implementation and integration with complementary measures. For instance, if engineering solutions are poorly designed, inadequately maintained, or lack synchronization with real-time traffic control systems, their effectiveness in improving traffic flow may be diminished.

Similarly, the insignificant effect of traffic law enforcement contrasts with Pérez et al. (2007) and Musau (2015), who found that strict enforcement mechanisms, such as speed cameras and routine patrols, reduced accidents and congestion. The lack of statistical significance in this study may be due to inconsistencies in enforcement, where penalties for violations are not stringent enough or are unevenly applied. Additionally, weak institutional capacity and corruption in traffic law enforcement, as highlighted by Rosenfeld (2019), could undermine its effectiveness. Another possible factor is that enforcement alone may not be sufficient unless coupled with public education and infrastructural improvements that facilitate compliance.

The study also found a significant negative relationship between traffic evaluation and ITCS performance (β = -0.283, $p < 0.05$), a counterintuitive result that suggests overemphasis on evaluation processes may hinder system efficiency. Previous studies generally advocate for continuous monitoring and assessment as a means to enhance traffic management; however, excessive or poorly structured evaluations might divert resources from operational improvements. For example, if evaluations focus more on bureaucratic reporting rather than actionable insights, they may lead to inefficiencies and delays in implementing necessary adjustments. This finding indicates a need to balance evaluation efforts with practical interventions that directly improve system functionality.

Several factors could explain the differences between this study's findings and existing literature. First, the adequacy and quality of engineering measures in the study area should be considered. If existing road infrastructure is outdated, underfunded, or poorly integrated with ITCS components, it may not yield measurable improvements in system performance. Second, confounding factors such as uncoordinated traffic management policies, fluctuating traffic volumes, and socio-economic conditions may have diluted the effects of infrastructure and law enforcement. Third, limitations in data collection such as sample size, geographical coverage, or measurement techniques may have influenced statistical outcomes.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Based on the findings of this study, traffic education emerged as a significant factor in enhancing the performance of the ITCS. The results suggest that initiatives aimed at improving road users' behavior through education may contribute to optimizing traffic flow and system efficiency. With promotion of better driving practices and raising awareness about safe road usage, traffic education could help reduce congestion and accidents, thereby enhancing ITCS effectiveness. This finding aligns with previous studies emphasizing the role of education and awareness campaigns in traffic management. However, the extent to which these results can be generalized may depend on factors such as the specific context of implementation, the quality of educational programs, and the level of public engagement. Policymakers and traffic management authorities should therefore consider traffic education as a key component of broader strategies for improving ITCS performance while tailoring interventions to local conditions.

In contrast, road intersection engineering and traffic law enforcement did not exhibit a significant direct impact on ITCS performance in this study. While these elements are widely recognized as essential components of traffic management, their direct influence on ITCS may be contingent on factors such as infrastructure quality, enforcement consistency, and integration with other traffic control measures. The findings suggest that investment in infrastructure and law enforcement alone may not be sufficient to enhance ITCS performance unless supported by complementary strategies. Nonetheless, it is important to interpret these results cautiously, as variations in implementation and enforcement mechanisms across different contexts may affect outcomes.

Furthermore, the study found a significant negative relationship between traffic evaluation and ITCS performance, indicating that excessive or poorly managed evaluations might lead to inefficiencies. This does not suggest that evaluation processes are inherently detrimental but rather underscores the importance of a balanced approach. Overemphasis on assessment without corresponding operational improvements may divert resources away from practical interventions. Future research could explore the mechanisms through which evaluation practices influence traffic management efficiency, considering contextual factors such as resource allocation and policy execution.

While these findings offer valuable insights, certain limitations should be acknowledged. First, the study was conducted within a specific context, and the results may not be directly generalizable to other regions with different traffic conditions, infrastructure, and regulatory environments. Second, potential confounding factors, such as variations in enforcement intensity, road design standards, and public attitudes toward traffic regulations, may have influenced the outcomes. Third, the study relied on available data, which, despite rigorous analysis, may not fully capture the complexities of traffic management dynamics. Future studies could address these limitations by incorporating a broader dataset, exploring longitudinal trends, and assessing the interactive effects of multiple traffic management strategies.

Recommendations

Based on the findings of this study, several key policy and strategic recommendations can be made to enhance the effectiveness of Intelligent Traffic Control Systems (ITCS). These recommendations focus on traffic education, infrastructure investment, enforcement enhancement, and evaluation optimization, ensuring a comprehensive and actionable approach. One of the most critical recommendations is to strengthen traffic education programs. The study found that traffic education significantly improves ITCS performance by fostering responsible road user behavior. To maximize its impact, policymakers should expand public awareness campaigns through digital platforms, television, radio, and social media. These campaigns should target not only drivers but also pedestrians and cyclists, ensuring that all road users are well-informed about traffic safety. Additionally, integrating road safety education into school curricula would help instill responsible road usage habits from an early age. The Ministry of Education, in collaboration with traffic management authorities, should develop structured learning modules on road safety and traffic laws. Furthermore, driver training programs should be enhanced by incorporating mandatory refresher courses and simulation-based training that focuses on accident prevention and ITCS functionality. Private sector involvement should also be encouraged, with transport companies and ride-hailing services required to provide periodic traffic safety training for their drivers.

While road intersection engineering did not show a significant direct impact on ITCS performance in this study, infrastructure remains a foundational element in traffic management. Poorly designed intersections and outdated road networks can limit ITCS efficiency, leading to congestion and delays. Policymakers should prioritize investments in smart road infrastructure, such as adaptive traffic control systems, real-time traffic signal synchronization, and variable message signs to enhance traffic flow. Redesigning high-congestion intersections through the construction of roundabouts, flyovers, and additional lanes where necessary should also be considered. To ensure sustainable funding, public-private partnerships (PPPs) could be leveraged to support infrastructure development while reducing the burden on public finances. Additionally, conducting periodic traffic flow assessments would help identify problematic areas requiring urgent intervention.

Another key area for improvement is enhancing traffic law enforcement to promote better compliance with traffic regulations. The study found that traffic law enforcement did not significantly impact ITCS performance, which may indicate inconsistencies in enforcement measures. To address this, authorities should deploy automated enforcement technologies such as speed cameras, red-light cameras, and AI-based traffic monitoring systems to ensure continuous and impartial enforcement. Increasing on-ground traffic patrols at high-risk intersections and accident-prone areas using data-driven approaches can further enhance compliance. Additionally, strengthening penalty mechanisms, such as introducing a progressive fine system where repeat offenders face higher penalties and mandatory retraining programs, could serve as a deterrent to traffic violations. Encouraging public participation through mobile applications that allow citizens to report traffic violations in real time would also promote accountability and support enforcement efforts.

Finally, optimizing traffic evaluation processes is necessary to support ITCS efficiency. The study found a significant negative relationship between traffic evaluation and ITCS performance, suggesting that excessive or poorly managed evaluations may disrupt system operations. To address this, authorities should implement targeted traffic evaluations focused on high-impact areas rather than conducting broad, resource-intensive assessments. Using AI-driven predictive analytics to assess traffic patterns and identify problem areas could reduce the need for excessive manual evaluations. Moreover, balancing evaluation activities with operational efficiency is crucial to ensuring that assessments do not interfere with real-time traffic management. Through refining traffic evaluation processes, authorities can ensure that ITCS remains effective without unnecessary disruptions. A coordinated and integrated approach combining traffic education, strategic infrastructure investment, enhanced enforcement, and optimized evaluation processes will significantly improve the effectiveness of ITCS. Through implementation of these evidence-based recommendations, policymakers and traffic management authorities can create a more efficient, safe, and sustainable urban traffic system.

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