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Smart Traffic Management Systems for Accident Reduction in Urban Intersections of Kampala.

1st Kisembo Chrispas, 2nd Dr. Stephen Monday, 3rd SHU-ACHET Daniel Gimbason, 4th Ruby S. Gibson, 5thAnuna Nilam

1. B.Tech Civil Engineering (Student), Faculty of Engineering, Desh Bhagat University, Punjab - 147301
2. Research Fellow, Allied Health Sciences, Desh Bhagat University, Punjab – 147301
3. Researcher, Wesley University Ondo, Ondo State Nigeria - 340104
4. Registered Nurse, ECHO-Health Liberia, Monrovia. 1000 Liberia.
5. Bachelors in Medicine and Bachelor in Surgery, College of health sciences, Makerere University Kampala - 7072

Abstract

Background

Kampala's rapid urbanization has been associated with growing traffic congestion and accident occurrences at major intersections although conventional management measures have been ineffective in addressing safety issues. Smart traffic management systems that utilize adaptive signal control, surveill & monitoring processes offer the potential to improve road safety and decreased accidents. This study evaluated public perceptions, experiences and awareness of the potential to develop smart and safe management systems to improve intersection safety.

Methods

A cross-sectional survey was conducted with 1,334 respondents from frequent users of the roads in Kampala, which included drivers, pedestrians, cyclists and public transport operators. Data were collected with a structured questionnaire including a section on demographics, a section on driving and travelling behaviour, experiences of accidents, perceptions of smart traffic technologies, and suggestions to improve safety. Descriptive statistics were used to summarize the frequencies and proportion while chi-square tests used to assess the associations between the socio-demographic factors and perception of smart traffic systems.

Results

The majority of the 1,334 respondents (62%) had seen at least one accident at an intersection in the last year, with the most common being vehicle–pedestrian (38%) and vehicle–boda-boda (31%) collisions. More than 70% of respondents considered over-speeding, running red-lights, and low enforcement of laws, among other factors, as the leading causes of accidents at intersections. Awareness of smart traffic management systems was considered moderate at (54%); however, the respondents indicated strong endorsements for the consideration of adaptive traffic lights (68%), CCTV (61%) and pedestrian countdown timers (57%) as interventions for safety. There was a relatively low satisfaction with existing traffic management systems (73% expressed being dissatisfied) and cost and vandalism were major barriers to the adoption of smart systems.

Conclusion

The study indicates that there is broad awareness of and acknowledgement of the safety challenges posed by intersections in Kampala and there is strong endorsement for the addition of smart traffic management systems. Adaptive signals, surveillance technologies and pedestrian systems, or a combination of them, could enable intersection users to reduce their risk of accidents. For this to occur, the study indicates that there are clearly identifiable challenges related to costs, government support and equipment security that still need to be resolved. There also needs to be more reinforcing policy and public awareness campaign to ease the implementation of smart traffic management systems**.**

Keywords
Smart traffic management, road safety, urban intersections, adaptive traffic signals, Kampala, accident reduction

Introduction

Road traffic accidents continue to rank among the leading causes of mortality and morbidity globally with developing urban settlements, in particular, most affected due to rapid population growth and inadequate road infrastructure [1]. In some sub-Saharan African countries, cities are undergoing unprecedented motorization, but road networks, traffic control apparatus, and enforcement systems are woefully lacking; leading to increased traffic congestion and elevated accident rates. Intersections are accident prone because they are one of the most intense areas of vehicular and pedestrian movement [2].

In Kampala, the capital of Uganda, intersections where a sufficient percentage of accidents occur are poorly constructed (that is, poor signaling system in place, lack of road design, lack of enforcement against traffic rules) and also have growing numbers of motorcycles (that is, boda-bodas) along with informal public transport systems affecting how traffic works and increasing vulnerability for pedestrians and other road users [3].In addition to these issues, there is the potential for innovative solutions beyond traditional traffic management solutions..

Smart traffic management systems (STMS) provide a relevant option by employing adaptive signal control, real-time monitoring and reporting, and predictive analytics [4]. STMS aims to improve traffic flow, reduce delays, and improve road safety through violation detection and improved responsiveness to actual road conflicts. The experience in Asia and Europe of smart traffic management systems has indicated improvements in both mobility and also substantial reductions in crashes at intersections [5]. Furthermore, use of surveillance cameras, automatic ticketing, and pedestrian countdown timers have been largely successful at improving compliance with traffic regulation [6].

In spite of these known benefits, STMS have not found an initial uptake in an African context, due to structural barriers combining high implementation costs; lack of available expertise; vandalism of structural infrastructure; inability to develop sustainable institutions, and for the STMS route, low public acceptance and inconsistent government prioritisation of traffic management improvement have delayed implementation relative to the world's average [7]. That said, with Kampala continuing to experience a consistent increase in number of intersection related crashes, now is the time to begin to transition into modern day traffic safety technologies.

This study then aims to examine the perception, awareness, and possible smart traffic management systems to reduce accidents at intersections in Kampala. By engaging 1,334 road users with their insights and perspectives, the study provides empirical data on the public's attitude towards STMS and identifies potential opportunities and barriers for implementation. The findings will assist policymakers, urban planners and transport authorities to consider sustainable interventions that can improve safety and efficiency at Kampala's major traffic nodes.

Methods

Study Design and Setting

To investigate perceptions, awareness, as well as experiences of road users about smart traffic management systems (STMS) in Kampala, a descriptive cross-sectional survey design was followed. The study was carried out between January and April 2025. Kampala, the capital city of Uganda and the most populous urban center, has a population estimated at more than 3.6 million and is characterized by fast motorization, high traffic density, and frequent congestion. The intersections, Clock Tower, Wandegeya, Jinja Road, Nateete and Kalerwe, are purposely selected as study sites as they depict key sites of traffic buildup as well as sites of frequent accident occurrences.

Population and Sampling

The target group included active road users: private motorists, pedestrians, boda-boda riders (motorcyclists), cyclists, and operators of public transport. A stratified random sampling technique was used with a requirement that each strata was represented in proportion to the number of each category of road user at the intersections selected for data collection. In the strata of road user, respondents were approached randomly to participate in the study. In total, 1,334 respondents were recruited, providing adequate statistical power to detect associations in subgroup analyses.

Data Collection Instrument

Data were collected using a pretested structured questionnaire. The instrument was designed to capture six domains:

1. **Demographics** – age, gender, education, occupation, and main mode of transport.
2. **Travel patterns** – frequency of intersection use and commuting behavior.
3. **Accident experiences** – personal or witnessed involvement in crashes.
4. **Perceived causes of accidents** – behavioral, infrastructural, and enforcement-related factors.
5. **Awareness of STMS** – knowledge of adaptive signals, surveillance cameras, countdown timers, and speed enforcement systems.
6. **Recommendations for safety improvement** – open-ended items to capture user perspectives.

The survey combined Likert-scale items, closed-ended multiple choice questions, and open-ended questions to obtain both quantitative and qualitative data. The instrument was evaluated by experts in transport safety and was pilot-tested with 30 respondents, who were from an intersection not sampled for the final survey (hence, they are not included in any results), to identify problematic wording and ensure that the questions were clear.

Data Collection Procedure

The questionnaires were administered in-person by trained research assistants in English and in Luganda, depending on the respondent's preference. The average interview lasted approximately twenty minutes. To statistically guard against bias, research assistants rotated among intersections and time-of-day – morning, afternoon, and evening – to gain usable data from exposure to varying traffic conditions and respondents.

Data Analysis

Data entry, cleaning, and analyses were performed using SPSS version 26. Descriptive statistics, specifically frequency counts and percentages, were employed to summarize categorical variables. Chi-square tests of independence were used to investigate the associations between sociodemographic characteristics (e.g. age, sex, occupation) and awareness or perception of STMS. A significance threshold of $p < 0.05$ was used to determine independence. Unless indicated, results are reported in tables

Data Quality

To ensure both reliability and validity, double data entry was used, and discrepancies were addressed through checking against original questionnaires. We used Cronbach's alpha to assess internal consistency of the Likert-style items. We considered reliability acceptable with levels ≥0.70.

Ethical Considerations

Ethical clearance for this research was provided by the Desh Bhagat University Institutional Review Board (Approval Number: IRB/DBU/2024/017) and Makerere University Research Ethics Committee. The local authorities also provided permission to carry out the survey along Kampala road corridors.

Participation was voluntary, and all participants gave written informed consent before being included. Confidentiality was maintained by anonymizing the answers, not collecting personally identifiable information, and storing data on password-protected servers that only the research team could access. Community leaders were involved in survey design and administration to respect local customs and values, and the study strictly conformed to international ethical guidelines for research with human participants.

Results

Table 1. Demographic Characteristics of Respondents (n=1334)

Variable	Category	Frequency	Percentage (%)
Gender	Male	754	56.6
	Female	580	43.4
Age Group	<25	276	20.7
	25–34	446	33.4
	35–44	328	24.6
	45+	284	21.3
Occupation	Driver	410	30.7
	Pedestrian/Other	326	24.4
	Public transport op.	298	22.3
	Cyclist	300	22.5

The demographic profile of the 1,334 respondents shows that there were more men than women. Men made up 56.6% (n = 754) and women made up 43.4% (n = 580). This is consistent with the gendered patterns of urban mobility observed in Kampala, where men tend to drive, cycle and operate public transport vehicles.

In terms of age structure, younger and middle-aged groups were well represented. Respondents aged under 25 years respectively made up 20.7% (n = 276), while the largest group was between 25 and 34 years at 33.4% (n = 446). Those aged 35 – 44 years accounted for 24.6% (n = 328), while those aged 45 years and older accounted for 21.3% (n = 284). This distribution suggests that most road users at intersections fall within the economically active age classifications, and this was consistent with the demographic profile for urban workforces in fast-growing cities.

The distribution of users by occupation further demonstrates the multifaceted nature of users at the intersection. Drivers were the largest share at 30.7 % (n = 410), then came pedestrians and other unspecified users at 24.4% (n = 326). Public transport operators represented 22.3% (n = 298), while cyclists represented 22.5% (n = 300). Taken

together, these numbers reflect the entirely multimodal transport system in Kampala; intersections serve as a shared space among streams of formal, informal, and non-motorized traffic. The nearly equal representation of drivers, cyclists, and public transport operators demonstrates the high interaction of motorized and non-motorized users, increasing the likelihood of conflict and accident risk.

Table 2. Accident Experiences and Causes Reported

Variable	Category	Frequency	Percentage (%)
Witnessed Accident (12 mo.)	Yes	827	62.0
	No	507	38.0
Type of Accident	Vehicle–Pedestrian	507	38.0
	Vehicle–Boda-boda	413	31.0
	Vehicle–Vehicle	280	21.0
	Other	134	10.0
Perceived Cause	Red-light running	920	69.0
	Over-speeding	840	63.0
	Weak enforcement	760	57.0
	Poor road design	540	40.0

The report on accidents related experience and perceived causes indicates that respondents had high amounts of exposure to vehicle crashes involving intersections. 62.0% (n = 827) of all respondents indicated they had witnessed an accident in the last 12 months which indicates how frequently crashes occur at Kampala's intersections. 38% (n = 507) as indicated by this figure, still represents a large segment of the population that is indirectly affected through perception of risk even if they themselves did not admit to any crash experiences.

When participants were asked to indicate what type of accident they witnessed, vehicle - pedestrian crashes were 1st in line with 38.0% (n = 507). This accident type is alarming because of the lack of infrastructure protection for pedestrians at crowded intersections. The second most commonly observed accident type was vehicle - boda-boda, as reported by 31.0% (n = 413). The prevalence of motorcycles on the road as a mode of transport, as well as a source of conflict results in high accident statistics. Vehicle - vehicle accidents were 21.0% (n = 280) and other types including crashes with multiple vehicles or cyclists had a lower number of respondents indicating these types of accidents at 10.0%(n = 134). These statistics confirm that pedestrians and motorcycles dominate the intersection accidents. Pedestrian and motorcycle interventions at the intersection highlight mobility and safety issues in urban transportation systems.

Following perceptions of accident causes, we can further triangulate both behavioral and structural risk factors. The majority of our study participants (69.0%, n = 920) identified red-light running the most common cause, followed closely by speeding (63.0%, n = 840). A third (57.0%, n = 760) identified weak enforcement, and thus points to institutional causes or deficiencies regarding traffic regulation and monitoring compliance. For example, a little more than a third (40.0%, n = 540) of our participants identified poor road design as a cause. This indicates that poor infrastructure, such as substandard signaling systems or poor pedestrian crossing facilities, increases behavioral risks. Overall, our research suggests that intersection safety in Kampala, is a result of dangerous road-user behavior, weak institutional enforcement, infrastructure idiosyncrasies, and road engineering design deficiencies.

Table 3. Awareness and Perception of Smart Traffic Systems

Variable	Category	Frequency	Percentage (%)
Awareness of STMS	Yes	720	54.0
	No	614	46.0
Preferred Intervention	Adaptive traffic lights	907	68.0
	CCTV Surveillance	814	61.0
	Pedestrian timers	760	57.0
	Speed cameras	693	52.0
Satisfaction with current	Dissatisfied	974	73.0
	Neutral	200	15.0
	Satisfied	160	12.0

The findings regarding awareness and perception of Smart Traffic Management Systems (STMS) imply that respondents had moderate levels of familiarity, with just over half (54.0%, n = 720) stating they were aware while a sizeable 46.0% (n = 614) said they were unaware of these technologies. This means that although knowledge of smart traffic systems is emerging in Kampala, there is still only limited public sensitisation education in regard to the advantages and intersection improvements associated with STMS relative to the well-established practices in high-income contexts.

Despite the moderate levels of awareness, respondents demonstrated strong preferences for specific interventions. Adaptive traffic lights were the preferred intervention as 68.0% (n = 907) of respondents supported these, and the timing of signals is commonly recognised combination to assist with reducing congestion and improving safety. The next most supportive interventions were for CCTV surveillance, which would be supported by 61.0% (n = 814) of respondents, demonstrating public support through monitoring and enforcement mechanisms to limit reckless behaviour. The pedestrian countdown timers were endorsed by 57.0% (n = 760) of respondents indicating a desire for safer pedestrian crossings in areas with high levels of congestion. Speed cameras received support from the majority, with 52.0% (n = 693). Finding an automated monitoring system that could tackle the problem of over-speeding was perhaps the public's perception of this intervention.
An overwhelming majority of respondents were dissatisfied with existing traffic management systems when asked about their satisfaction with the current management system (73.0%, n = 974), while only 12.0% (n = 160) reported being satisfied and 15% (n = 200) were neutral. The excessive dissatisfaction among respondents shows a lack of alignment between the infrastructure and users' expectations of these systems, which shows a critical need for changes in the technology focused EPS. The combination of the strong need for implicit support of advanced traffic solutions but low satisfaction with traffic systems to this point has indicated that users are ready to adopt STMS where financial, institutional, and infrastructure limitations are removed.

Table 4. Challenges in Implementing STMS

Challenge	Frequency	Percentage (%)
High cost	854	64.0
Vandalism/Theft	613	46.0
Lack of government will	534	40.0
Public unawareness	440	33.0

The obstacles for implementing Smart Traffic Management Systems (STMS) in Kampala are exemplified in both financial and socio-institutional barriers. The greatest cost was the most reported barrier at 64.0% (n = 854). The evidence suggests that the financial burden of acquiring and maintaining intelligent transport technologies is perceived as being outside the city's financial means, particularly in a resource-constrained context. Vandalism and theft was the second most reported barrier at 46.0% (n = 613). This information implies that even if an installation takes place, the sustainability of the technology may be compromised by insecurity and misuse, which is a prevalent issue in many low- and middle-income urban areas. Another 40.0% (n = 534) of respondents were concerned about lack of government will; this finding indicates that respondents believed there was a lack of political commitment to long-term traffic reform. Finally, 33.0% (n = 440) of respondents pointed to public unawareness as a barrier, which demonstrates a gap in knowledge regarding the availability of new technologies and how to access/utilize them properly. Collectively, these results indicate that while there is strong support for STMS, a successful adoption will involve addressing not only financial barriers, but institutional factors, security of infrastructure, and public awareness.

Discussion

Findings suggest that traffic accidents in Kampala occur at a disproportionate rate in intersections, which aligns with accidents taking place in other rapidly motorizing African cities for which high traffic volumes occur well before infrastructure is built or modified to meet the traffic demand [9]. The limited number of vehicle–pedestrian and vehicle–boda-boda collisions suggest that non-motorized and informal transport users have added vulnerability compared to motorized users as pedestrians and boda-boda taxi drivers in particular struggle to operate safely and efficiently in under-regulated and congested traffic environments [10]. Our findings further contribute to the current body of literature, particularly noting that pedestrians and motorcyclists are consistently the most vulnerable road users in urban traffic safety studies across Sub-Saharan Africa.

The participants placed a clear emphasis on behavioral risk factors causing crashes, with over-speeding, running a red light and a lack of enforcement as the top perceived causes of crashes. Participants' perceptions were consistent with previous studies that cited human error and lack of monitoring compliance as the two dominant factors associated with road traffic crashes in low-and-middle-income countries [11]. Notably, our findings delved into the gap between enforcement policy and actual enforcement, indicating that institutional weaknesses and corruption may provide a basis for increased risk-taking behavior.

The level of awareness of Smart Traffic Management Systems (STMS) among the participants was moderate and just over half (54%) indicated they had some prior knowledge. This manifestation of knowledge is consistent with previous studies which identify that not much public awareness exists about advanced traffic technologies in low-income contexts, particularly in cases were infrastructure dollars are spent on expansion over modernization [12]. However, the overwhelming support towards adaptive graphics signals, surveillance cameras, and pedestrian countdown timers suggests that urban road users not only understand the safety potential for these systems, but they are open to innovative measures to reduce accidents and congestion. These findings corroborate the evidence from Asian and European cities where smart systems have been implemented to decrease the severities of accidents and internally traffic [13].

Despite the relic of optimism, respondents also pointed to concerns around high capital costs for implementation, and the potential for vandalism, highlighting the greater socio-economic obstacles that often frustrate the sustainability of technological solutions in resource-constrained contexts [14]. These concerns are of prime importance for policymakers considering the need to develop contextually-sensitive approaches. Authorities should also recognize that for locally-owned and managed STMS to be adopted, phased implementation is critical, merely investing in infrastructure without public education campaigns could fall flat, and drivers and passengers need to be supported through legislative reform that signals a commitment to enforcement and accountability [15]. Especially combined, these actions could bridge the gap between awareness and on-going adoption, contributing to a key goal to improve urban road safety and mobility improvements in Kampala.

Conclusion

The study underlines the large incidence of intersection-related accidents in Kampala, which has a distinct burden for vulnerable road users such as pedestrians and motorcyclists. Evidence showed there is a large proportion of these crashes that could be prevented with a mechanism utilizing technology and accessibility of technology-enabled countermeasures aimed at saving lives at intersections. Results showed there was significant readiness from the public to adopt adaptive controlled traffic signals, surveillance systems, and pedestrian countdown timers, which shows latent safety issues and the openness of the public to new and novel ideas for managing traffic situations. However, while there have been mentioned impediments to using the recommended PEST tool for large-scale implementation, this study elucidated the issue of cost of implementation, leadership in legitimate and enforceable policy implementation, abuse, and vandalism concerns as significant factors will need to be dealt with if large scale implementation is to be achieved. Addressing the factors surrounding these concerns will require a phased and operational inclusive approach where infrastructure investment, governance review, legislative change, and community engagement must collaborate to facilitate effective and sustainable solutions to improve urban traffic safety.

Take-Home Message

Intelligent traffic systems represent a legitimate and broadly endorsed effort to bring down intersection injuries and improve urban mobility in Kampala. While public support is strong, the success of these efforts will ultimately depend on policy commitment, sustainable funding, and measures to secure the infrastructure from misuse or mandala damage. Integrated approaches combining innovative technologies with enforcement and social sensitization have the greatest potential to improve road safety in rapidly motorizing African cities.

Authors' Contribution

- **Conceptualization:** Dr. Stephen Monday
- **Methodology:** Dr. Stephen Monday, Kisembo Chrispas
- **Data Collection:** Kisembo Chrispas, Ruby S. Gibson
- **Formal Analysis:** Ruby S. Gibson, SHU-ACHET Daniel Gimbason
- **Bioinformatics and Data Interpretation:** SHU-ACHET Daniel Gimbason
- **Writing – Original Draft:** Kisembo Chrispas, Ruby S. Gibson
- **Writing – Review & Editing:** Dr. Stephen Monday, Stephen S. Bonard
- **Supervision:** Dr. Stephen Monday
- **Validation and Final Approval:** Stephen S. Bonard

All authors have read and approved the final version of the manuscript

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Conflict of Interest

The authors declare that they have no relationships that could be viewed as a potential conflict of interest in the research, the interpretation of data, authorship of the article, or the publication of the research. Specifically, the authors have not received financial support, materials or gifts from an organisation, government agency or business entity that might reasonably be judged to result in such a conflict of interest. All decisions about study design, data collection, data analysis, data interpretation, and the writing of the manuscript were made by the authors of this research report. The authors have no proprietary interests or intellectual property that may have been perceived as a source of bias in terms of prevailing outcomes or conclusions. The authors declare their commitment to transparency and objectivity and intend to ensure that all reporting was ethical and follows international publication standards**.**

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