Research on the Impacts of Automated Speed Enforcement in Rwanda to Develop Recommendations for African Countries

Self-Published Compiled Reports

Global Road Safety Facility

UKaid from the British people

Healthy People Rwanda

TIRF

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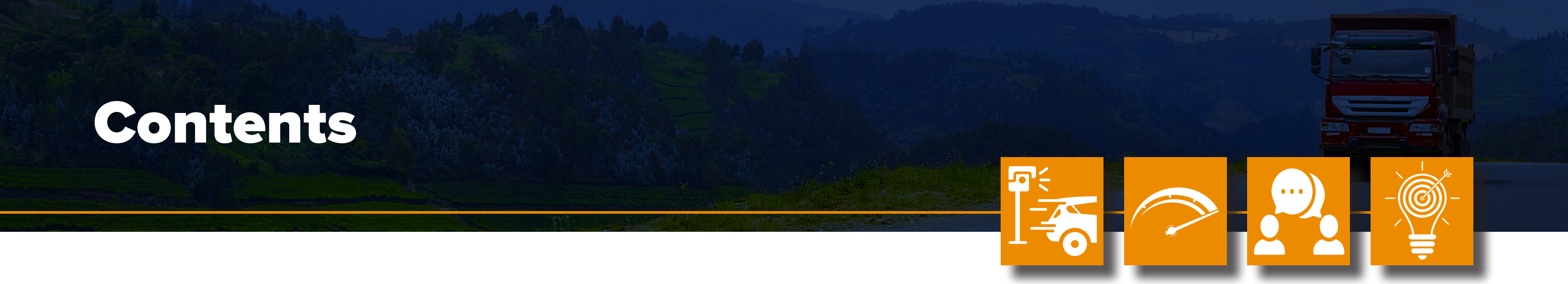

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Abbreviations and acronyms

AIC: Akaike Information Criterion
ASE: Automated Speed Enforcement
CI: Confidence Interval
COK: City of Kigali
GDP: Gross domestic product
GRSF: Global Road Safety Facility
HIC: High-income country
HPR: Healthy People Rwanda
ICT: Information Communication Technology
LMIC: Low- or middle-income country
NISR: National Institute of Statistics of Rwanda
RNEC: Rwanda National Ethics Committee
NHTSA: National Highway Traffic Safety Administration
PPP: purchasing power parity
RNP: Rwanda National Police
RRA: Rwanda Revenue Authority
RWF: Rwandan Franc
SARIMA: Seasonal Autoregressive Integrated Moving Average
TIRF: Traffic Injury Research Foundation
US: United States
USD: United States Dollar

Executive Summary

Introduction & Study Setting

Speed is one of the leading risk factors contributing to injury and death on the roads. This includes both excessive speeding, defined as when vehicles exceed the posted speed limit, and inappropriate speed, when a vehicle travels at a speed that is not suitable for the conditions (e.g., weather, traffic) but within the designated speed limit. Increases in speed result in a higher risk of crash resulting in an injury or death. It is estimated that a 1% increase in mean speed results in an increase of 4% and 3% risk in death and serious injury, respectively. Automated speed enforcement (ASE) is a critical tool to reduce speed-related crashes, injuries, and deaths. Rwanda is the first low-income country in Africa to implement a comprehensive national ASE system providing an opportunity to generate and share the lessons learned to facilitate implementation of ASE in other countries experiencing similar challenges of limited resources, a high burden of road traffic injuries and deaths, and a desire to improve road safety. Rwanda is a low-income country in East Africa with a population of 13.2 million that has made tremendous development gains in terms of poverty reduction (from 78% in 2000 to 56.5% in 2016), increasing life expectancy (from 49 in 2000 to 69 in 2020), and GDP (from $2.02 billion in 2000 to $11.07 billion in 2021). Descriptive data from annual police crash investigation reporting show mostly stable fatal crashes, an 87% decrease in serious injury crashes, a 175% increase in property damage only crashes and a 249% increase in minor injury crashes from 2019-2022. These shifts in the distribution of crash outcomes are concurrent with the ASE implementation timeline.   However, the large discrepancy between these reported data and WHO models of projected road deaths and injuries in Rwanda raise questions and inspire efforts to understand these results more clearly.

Figure 5 | Number of Annual Road Fatal Crashes in Rwanda | 2015 - 2022

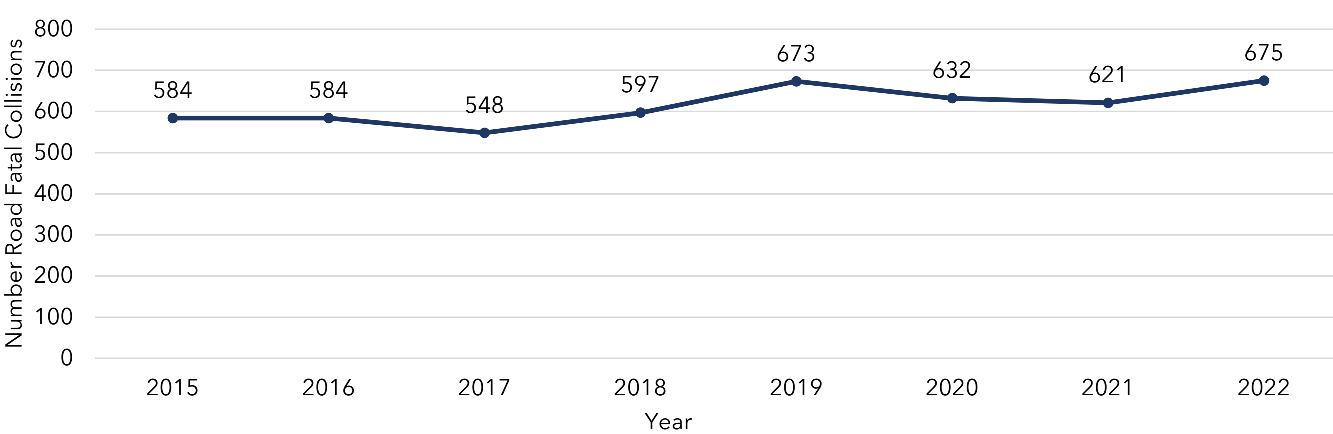


Figure 6 | Number of Annual Serious Injury Crashes in Rwanda | 2015 - 2022

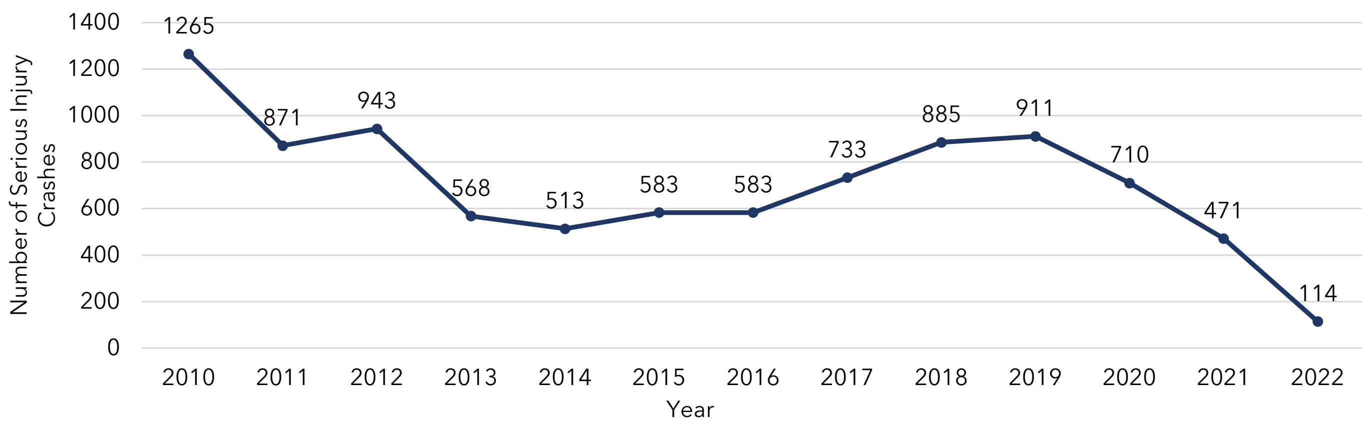


Figure 7 | Number of Annual Road Minor Injury Crashes in Rwanda | 2015 - 2022

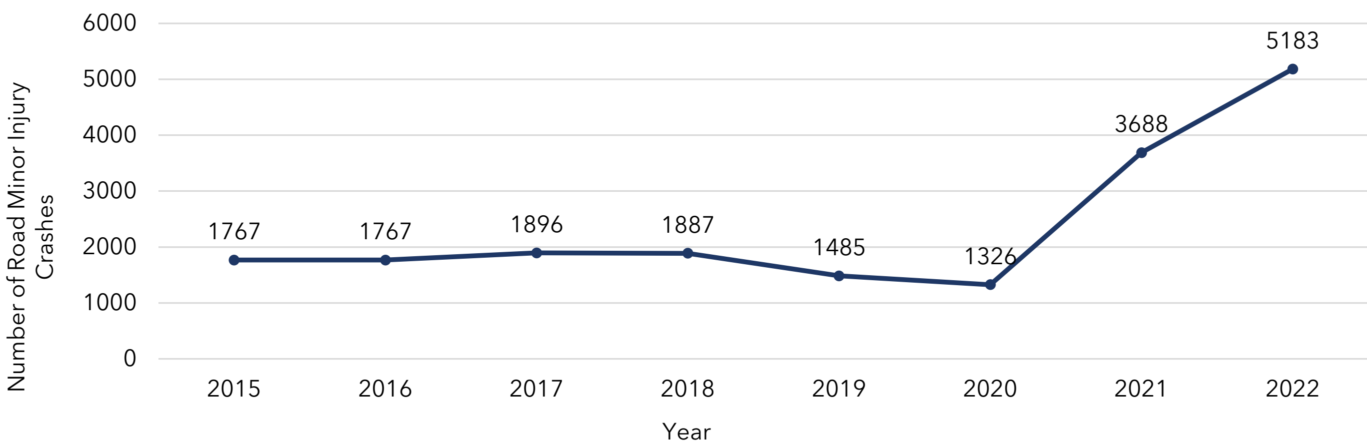
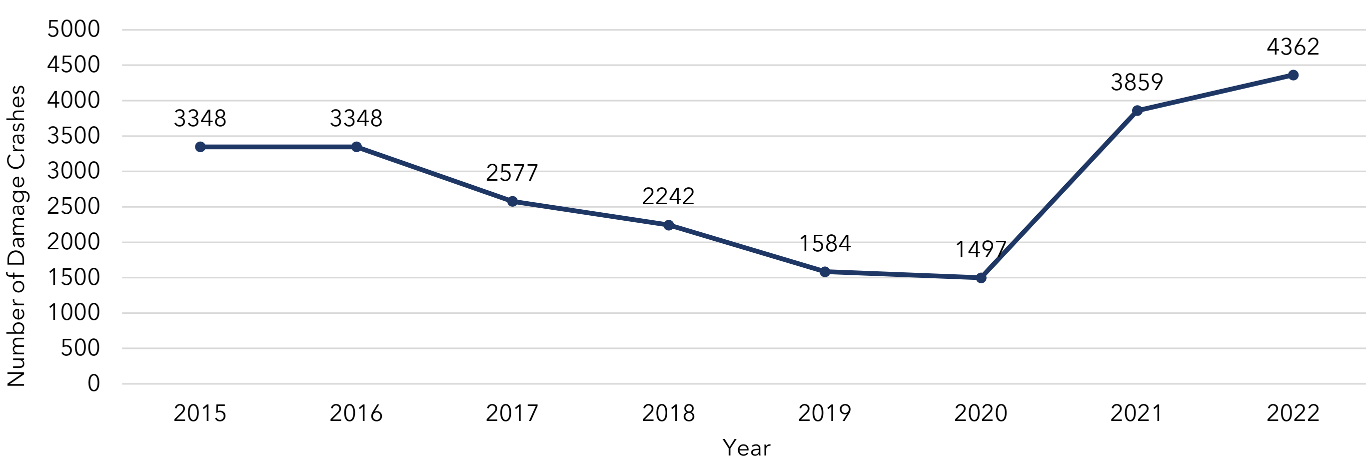


Figure 8 | Number of Annual Damage Crashes in Rwanda | 2015 - 2022



Study Objective & Components

To the best of our knowledge, no studies have assessed national automated speed enforcement implementation in any African nor low-income country. To fill this critical gap, we aimed to 1) describe the implementation of an ASE system, 2) conduct an experiment to assess the effect of cameras on speed outcomes, 3) measure the public's experience, views, and perceptions on ASE and road safety in Rwanda, and 4) investigate the effect of ASE tools, including cameras and other road safety measures such as campaigns, in reducing fatal, injury, and property damage collisions then synthesized our findings and the literature to provide broadly transferable recommendations for other Low and Middle-Income (LMIC) African Countries.

1. **The national adoption and scale up of automated speed enforcement in Rwanda: an approach to guide implementation** | Using structured key informant interviews (7 interviewees), focus group discussions (8 participants) and participatory feedback (several high-ranking police) we conducted a qualitative study with stakeholders involved in the ASE program to 1) map and describe the planning and implementation process of ASE; 2) document perceived successes and areas for improvement. We adapted questions from a study conducted by the United States National Highway Traffic Safety Administration (NHTSA) to the Rwandan context and attempted to fill in gaps with the focus group discussion. Under optimal conditions our empirical methodology would have captured all data to lower the risk of bias, but these feedback sessions proved invaluable. And verified that most information we collected initially was correct. Rwanda's ASE program began with RNP engagement in foreign study visits to learn about different types of ASE programs in ~2017. Scoping and implementation studies were done in partnership with the selected vendor and used retrospective crash data and police experience to locate >1,000 blackspots associated with over speeding, severe injuries, and deaths. Prospective speed data were assessed at certain blackspots to validate assumptions and the availability of infrastructure needed to operate ASE was determined. Some actions were taken prior to implementation such as assuring that speed limit signs preceded any ASE cameras (considered a surrogate for specific ASE warning signs), setting conditions of penalties for speeding, and some public sensitization efforts. In July 2019 one mobile and five fixed cameras were installed and activated as a pilot and to raise public awareness.

Figure 1 | Examples of a functioning ASE system

Scale up began in January 2021 with four more cameras and continued gradually until September 2021 when 106 ASE cameras were installed with another bolus between January-March 2022 of 98 cameras. As of May 2023, more than 400 cameras are actively in use including unidirectional and bidirectional overt fixed cameras, covert mobile, trailers,

Intersection/redlight and enforcement patrol vehicle lightbar cameras. Each ASE has ~5 km of paved road before the next camera, though this varies greatly between urban and rural areas given blackspot-targeted locations and varied locations of mobile ASE. When vehicles are within view and detected to travel >10% over the speed limit approaching or passing the ASE cameras photograph and autodetect the vehicle plate numbers (front or rear) that are crossmatched to the identification database and within minutes to hours an SMS is sent to the registered owner of the vehicle notifying of the penalty, fine and payment terms (detailed later). Rwanda's ASE program leverages existing digital platforms and databases that link vehicle registration with national identification numbers, mobile phone numbers and associated cashless payment systems. These services coalesce in the online government service portal Irembo, on which one can check for and remedy unpaid ASE penalties. A reminder SMS is sent when a penalty is due and when the fines have increased for non-payment. Social media, especially Twitter, is commonly used by the public to raise complaints and contest improper violations they received, and the police will respond as requested. The RNP have also designated phone lines, emails and offices that handle such concerns and can provide doubtful offenders with photographic evidence for verification or re-assignment in the case of errors. Upon noting a high rate of failure to pay the RNP instituted random checkpoints that caused substantial traffic jams as each vehicle was stopped for a manual check before release, causing many public complaints. Technology provided a solution to this problem through positioning an enforcement lightbar patrol vehicle to survey passing vehicles during peak traffic hours ~500 km prior to police officers who are notified of approaching vehicles with unpaid violations that are targeted for stopping while other traffic continues to flow. Similarly, public complaints have produced changes to speed limit thresholds and additional sensitization campaigns. Collected revenue is distributed to the government treasury for flexible use as needed to fund programming. We believe that our efforts to engage ASE stakeholders in the process of mapping decision points, motivations, and actors relative to design and implementation has the potential to improve both this program and others in the long term, empowering individuals to ask important questions and critically evaluate the planning and implementation decisions.

Figure 12 | SMS Text Messages

Sunday 10:35PM

Traffic Fine
Fine # | [redacted]
Offense | Non respect of traffic lights
Location | [redacted]
Kinuga
Fees to be paid | 25,000 RWF
Plate No | [redacted]
Issue Date | 07-05-2023
Pay Before | 10-05-2023
Late fees apply after the due date.
Go to https://bit.l/RNPfines or dial *909# to pay.

Sun, Feb 19 3:06 PM

Traffic Fine
Fine # | [redacted]
Speed | 67 km/h
Location | [redacted]
Rukiril
Fees to be paid | 25,000 RWF
Plate No | [redacted]
Issue Date | 19-02-2023
Pay Before | 22-02-2023
Late fees apply after the due date.
Go to https://bit.l/RNPfines or dial *909# to pay.

Your application for | TRAFFIC FINES with billing number
[redacted]
was successfully paid. You can track your application with the followiwng details! Application number |
[redacted]
Fees paid | 25,000 RWF

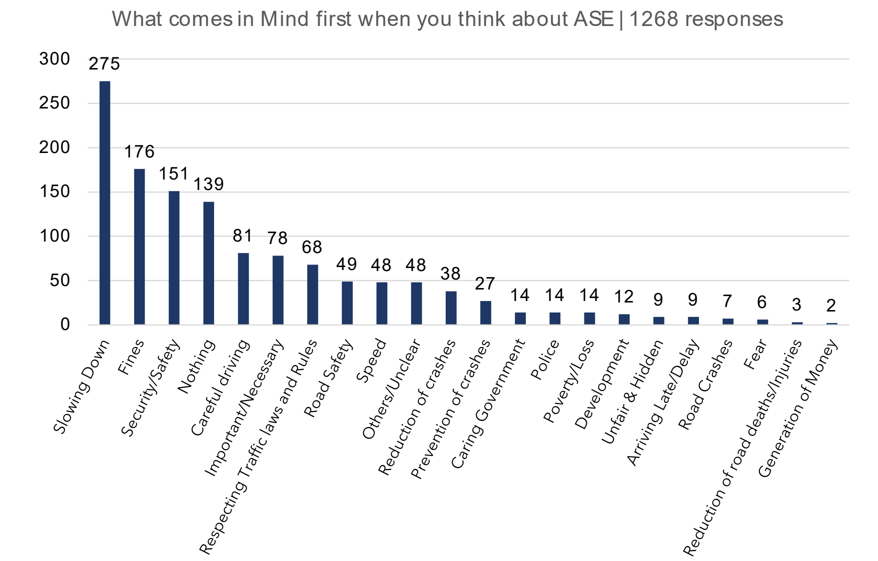
2. **A Cross-sectional with controls Study of the Impact of Automated Speed Enforcement on Motorist Speeds and Speeding Violations in Rwanda** | We measured the effect of overt speed cameras (exposed site, called 'case' herein) versus no camera (i.e., only a hidden speed collection device, control site) on speeding outcomes including the mean speed, the number of official violations (defined as equal to or above 10% of the set speed limit), and any speed limit violations (defined as going above the designated speed limit) on national roads. There was a significant decrease in mean speeds for all vehicles and each vehicle type in case (overt camera) versus no camera locations, indicating that ASE may be positively affecting road user behaviour and leading to decreased speeds in these localized areas. Despite limitations, our findings are consistent with other literature. Given the limitations of this study, we would recommend that other studies assess the impact of ASE with more rigorous study designs. Specifically, we would recommend studies include an assessment of the effects spatially and temporally. We would highly

Figure 20 | Data collection site examples

recommend that speed, crash, and injury data is collected prior to implementation of ASE to establish baseline trends. Relatedly, we would recommend the use of geospatial data on crashes and injuries to understand if mean speeds, number of violations, and number of vehicles exceeding the speed limit affects road safety outcomes in LMICs.

3. **A National Survey to Understand the Public Perception of Automated Speed Enforcement and Road Safety in Rwanda** | Informed by the ASE implementation study findings we designed a cross-sectional study of a nationally representative sample of Rwandans using quantitative surveys with two simple qualitative questions, conducted via in person interviews, to gain insight into the perceptions of people and road users on ASE and road safety. Most road users agree that speed cameras and the delivery of citations are fair, and they confirm the importance of ASE as a tool for improving public safety. We suspect this is a sign of country development, trust of leadership and a government that works for the people. This study provides critical information as it shares the public insights into the first national scale up of ASE in an African, low-income country. Such insights are critical for addressing a research gap in understanding the implementation and the public perceptions of such programs in LMICs and in Africa. Additionally, this study generated a rich data set for local policy makers and the Rwanda National Police to consider in their work and/or to serve as a baseline by which the impact of interventions that may change public knowledge, attitudes and practices can be evaluated.

Figure 25 | First thoughts of participants about ASE



4. **An Interrupted Time Series Analysis of the Impact of Automated Speed Enforcement on Road Traffic Crashes, Injuries and Deaths in Rwanda from 2010-2022** | We used police reported crash frequencies and outcomes to check if the positive descriptive trends observed during the period of ASE implementation could be clearly associated with implementation of the technology. Unfortunately, the limitations of the data sources make it impossible to draw empiric conclusions about these. We suspect that paper data collection then transfer to a digital database, manually de-aggregating the crash data to the district and monthly level, and our lack of a source of true exposure data to understand how many people are using the roads that these crashes occurred on all contributed to our lack of robust findings. We include the full methods and results as an appendix to share the attempted methods and challenges we encountered; however, this exercise had deep value despite its limitations. This was the first opportunity to identify conflict points between the top priorities of researchers (accurate and complete data needed to optimize analyses) and the police (the safety and security of the Rwandan people). Recognition is a necessary first step in mitigation and resolution of conflict, and despite differing orders of priorities both the research team and the police share the goal of improving the safety of Rwandan roads to prevent death, disability, and economic losses.

Synthesized Recommendations & Conclusion

Finally, we present the challenges we experienced and endeavoured to overcome as researchers in addition to the findings of our studies in the context of international ASE literature and guidelines. This is best considered as a follow up publication to the "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement" used as a Rwandan case study in which to consider design and implementation strategies relevant to other African countries. Our assessments of Rwanda's specific readiness based on our retrospective findings include notable achievements like substantial political support for ASE, strong regulatory and enforcement frameworks that promote vehicular registration, and linking national identification to a unique mobile phone number that facilitates real-time, digital feedback to vehicle owners of an over-speeding infraction. We created a "Checklist for ASE program design, implementation, maintenance and evaluation" that outlines activities within four sections: 1) program preparation and coordination, 2) program design steps, 3) program implementation steps, and 4) program maintenance and evaluation. In addition to this checklist, we provide cross-cutting recommendations for Rwanda, other countries implementing ASE, and researchers evaluating ASE in similar contexts. The following themes are detailed in the full reports:

- Co-production and collaboration with in-country partners is essential.
- High-quality data systems need to be developed, maintained, and used for rigorous research.
- Research should be conducted more frequently to determine the most effective implementation strategies and road user perceptions.
- Data on baseline speeds, traffic, and road safety indicators is necessary to understand the impact of ASE.
- Road users should be included and given adequate information about ASE implementation.
- ASE should not be seen as the silver bullet to solving all road safety issues.

These studies have produced novel and valuable information about a national ASE program in an African low-income country. Describing the design and implementation processes of ASE, verifying a localized decrease in measured vehicle speeds associated with overt ASE, and detailing the public perceptions of Rwandan ASE generated new knowledge and built a foundation for future growth. We are cognizant of the limited results this research can confidently generate, and further study with more comprehensive data will surely improve the understanding of ASE impacts in Rwanda and other African countries. Specifically, there is potential to compare our findings with the North African, lower-middle income country of Morocco that has a much greater land mass than Rwanda and a longer history with ASE. Additionally, the lack of road use exposure data uncovered in this research can be an effective driver of change to improve data quality and quantity that will support future studies. Rwanda is not unique in our data limitations, contributing to the generally low road safety research productivity across African LMICs. This ASE evaluation, the challenges to road safety research, and the recommendations generated from the overall experience could form the basis for a continental working group that generates African solutions to the problems of road safety in Africa. One such solution may be broader incorporation of ASE programs into national road safety strategies in African countries. We hope that posterity will find this report to be an African road safety case study in humility and effective methods to catalyse rapid development and research quality improvement. If realized, the impacts of this research on the impacts of ASE in Rwanda to develop recommendations for African countries could contribute exponentially greater value than originally anticipated at the launch of this project.

Proposed Guide for Determining Readiness for ASE Checklist Table Adapted to Rwandan Findings

Issues to consider	Minimum requirements	Assessed ASE Readiness of Rwanda Per Stakeholder Accounts
Political	Do decision makers understand the road safety benefits of managing speeds?	Policy makers, most commonly in the police instigated ASE as it fell in line with several national priorities including a recognized need to reduce crashes, injuries, and road deaths.
	Do decision makers accept the value of AE and is there sufficient political acceptance to introduce an AE program?	Shared purpose and vision within the government is common in Rwanda and it seems that ASE was no exception
	Is there appreciation of the potential income for Government (which could be used for further road safety improvements)?	Income generation potential is appreciated though funds are centralized with the national treasury. There is also recognition of accessory cost savings through task shifting to use police human resources more efficiently.
Legislation and policy decisions that may be legislated	Does legislation identify which agency/ agencies have responsibility for various parts of the AE system?	We know that a coalition of stakeholder agencies worked on ASE, and standard legislative procedures were said to apply, the precise composition and designation of specific responsibilities is less clear.
	Do you have approval to use camera equipment type (type approval)?	It is not clear if specific legislation dictates ASE equipment type approval or if the stakeholder coalition simply confers with the supplier/consultant and reaches a consensus decision on ASE type.
	Is there a legal process to identify the vehicle and the driver? to prosecute an offender?	Rwanda uses registered owner onus to determine responsibility for the speeding offense, the plate identifies the registered owner. If offenders do not pay by the deadlines the fines are increased and eventually the vehicle will be stopped at a checkpoint and removed from the roads until the fine has been paid. Additional prosecution processes were not elaborated.
	Do organisations that need access to ASE generated data; driver licensing data; and vehicle registration data have the legal right to access it?	Respondents were clear. Different government agencies work cooperatively in pursuit of their shared vision to improve the safety of the roads and contain the costs of doing so through ASE. Thus, data can be accessed readily from within these agencies
	Are there data security policies and protocols to: secure roadside data capture and transfer? secure storage and use? prevent unauthorised access?	We collected few responses to directly address data security issues though it was mentioned that the police own and manage all the data.
	Is there a policy relating to cameras being fit for purpose (e.g., to operate effectively in the environment where they'll be used such as will they operate in extreme heat, cold or humidity?	Infrastructure limitations were acknowledged as a challenge during design and implementation of ASE in Rwanda, but cameras could be modified to operate on battery power when electricity was not available at the deployment site.
	Are registration plates generally clearly visible at high speeds or in low light?)	License plates in Rwanda are standardized in their color, shape, size and mounting on the front and rear of the vehicle. Cameras have a flash available to improve lighting.

Issues to consider	Minimum requirements	Assessed ASE Readiness of Rwanda Per Stakeholder Accounts
Organizational & Funding Issues	Is there government funding to develop and sustain an AE program, or a partnership with private sector through which government funding is not necessary?	Both sources of stable funding were available at the genesis of ASE in Rwanda.
	Is there sufficient offence processing capacity to deal with volume of infringements within a reasonable time?	The time to issue the offence was not commented on but there was also no indication that insufficient capacity to send notices in a reasonable time was one of the problems.
	Is the infringement notice processing system compatible with and able to process notices generated by the intended automated technology?	Most of the offences are processed automatically through the SMS to the vehicles registered owner and ability to pay the fine online through the Irembo online portal after standard accuracy checks.
Site Selection and Camera Installation	Do all camera sites allow for accurate speed detection and readable images to be collected? (consider position in relation to rising/setting sun; roadside barriers, change of speed limits for certain times of day e.g. school zones)	Camera sites were chosen based on known clusters of crashes, injuries, and death hotspots on roads. Other reasons for selecting a location were based on availability of necessary infrastructure (e.g., internet/data, electricity), prior research on road design, and recommendations by stakeholders and other agencies. Two large surveys were undertaken to understand suitable locations.
	Do all camera sites allow for safe operation and maintenance?	Vitronic provided valuable feedback based on their experience implementing cameras in other countries. Thus, it's implied that camera accuracy, safe operation/ maintenance and field of vision were accounted for in site selection, but specific comment was not made.
	Are cameras mounted such that the mounting does not contribute to inaccurate speed recording or data capture?	It is unclear how common erroneous citations are issued but this was mentioned as a challenge.
Camera maintenance & calibration	Is there a protocol and appropriate resources for maintenance and calibration of cameras?	Eastern Ventures regularly calibrates and maintains these cameras per their contract.
Unique identification of vehicle from an image (vehicle registration / identification)	Is there a reasonable proportion of all vehicles registered and correctly displaying ASE-readable vehicle registration plates that uniquely identify that vehicle?	Respondents did not comment on proportions of unregistered vehicles on the roads, police report very few.
	Is legislation in place that compels vehicle registration plates to be correctly positioned so that they can be detected by a speed camera, unobscured and legible that deters drivers from attempting to evade speed camera detection?	Per legislation, police enforce the legal requirement for vehicles to be registered and properly outfitted with a plate on the rear and front bumpers in standardized locations to promote visibility. Accordingly, a visible plate is flash-enabled camera readable.
Linking vehicle to owner and contacting the owner when an infringement is issued	Is there a reasonable proportion of vehicle registration records that accurately reflect the rightful owner? Does legislation and enforcement support this?	It's unclear how commonly erroneous registration records occur but they were reported as a problem. There is legislation regarding this, but it may not be commonly enforced as it can take months for formal change in ownership of vehicles to complete processing.
	Is there a system to enable linkage of a detected vehicle to the vehicle owner?	Linkage between a vehicle and the registered owner is accomplished through national identification cards and/ or passports, the same document is required for vehicle registration and obtaining a mobile phone number, thus assuring that contact is simple.

Issues to consider	Minimum requirements	Assessed ASE Readiness of Rwanda Per Stakeholder Accounts
Delivering enforcement notice to relevant offender (investigation/ adjudication)	Is there a system by which the owner can be contacted to receive the infringement notice?	When speeding citations are issued the legal process begins with an SMS to the registered vehicle owner who is responsible for paying the fine. Failure to pay can result in compounding penalties and removal of the vehicle from the road until fines are paid.
	Is there a process to identify the offending driver if not the owner?	The registered owner is responsible for identifying and assuring the actual offending driver pays the fine.
System to manage offense contestability	Is there a process to allow a driver accused of speeding to legally challenge the offense?	Yes, there were some comments about the options: "There is an email we give them to send local complaints, they can write on Twitter and Facebook, they can call us, they can go to the office in person wherever they like."
Process to ensure penalty is applied and managing repeat offenders	Is there a process by which non-payment of penalty can be followed up and resolved?	· The police ensure that payment is made through routine checks of all passing vehicles and stopping those with unpaid penalties, vehicles may be confiscated if the fines are too high, repeat offenders are discouraged currently only by too many fines.
Penalties for speeding are appropriate	Are the penalties for speeding sufficient to deter speeding?	Interestingly, respondents did not share an opinion about the appropriate magnitude of the penalty fine, it has been static for many years prior to ASE.
	Do penalties increase in severity as the speed detected increases?	Yes, by an absolute threshold the penalty fine increases, it will also increase if it is not paid by the deadline. The ASE uses 10% over the speed limit as the threshold for issuing a violation. There is no indication of further increases.
	Penalties can be too high, generating Police reluctance to apply them. Is this risk managed?	It is not clear if the penalties are too high such that police decline to issue them nor if measures are in place to manage this risk besides general corruption deterrence.
	Is there a mechanism for applying a penalty for falsely accepting responsibility for the offence (e.g., fraudulent use of demerit points belonging to another person)?	Repeat offenders were not reported to suffer extraordinary consequences such as revocation of a driver's license. Because there are no demerit points falsely accepting an offense is not likely to occur commonly
Evaluation to show road safety improvements	Is there a plan to evaluate the safety outcomes of the AE system? Is there funding for evaluation?	Police report improvements in crash, injury, and road death rates attributable to ASE but other than reporting the totals temporally in relation to ASE deployment. We are unaware of any specific impact evaluations besides this study with funding from the GRSF.
	Will baseline speed and crash data be collected for this evaluation?	Rwandan cameras are only activated to record after the speed limit is exceeded, so exposure data are not routinely collected to establish a baseline. Pre-ASE crash data are available on the level of districts but not for specific locations to show the impacts around the camera sites in particular.

Checklist for ASE program design, implementation, maintenance, and evaluation

In 2017 Rwanda began the process of adding Automated Speed Enforcement (ASE) to efforts intended to reduce road traffic crashes, injuries and deaths. As of April 2023, over 400 ASE devices have been installed across the country. Detailed in "Research on the Impacts of Automated Speed Enforcement (ASE) in Rwanda to Develop Recommendations for African Countries," the recent World Bank supported project led by Healthy People Rwanda and the Traffic Injury Research Foundation, evidence indicates that ASE can be an important road safety tool.

The disproportionate burden of road traffic crash death and disability on the African continent demands an urgent, effective response. While ASE can be expensive to implement, the benefits of lives saved, and economic loss avoided may outweigh the costs. To our knowledge, Rwanda is the first African Lower Income Country to have implemented a comprehensive, national ASE program.

Research has the greatest value when applied to solve problems, so our team created this checklist that we hope will support other African countries to design, implement, maintain and evaluate the impacts of their own ASE programs. We designed this guide based on the lessons learned in the past year researching Rwandan ASE and through review of international guidelines.

ASE Program Preparation & Coordination

- ☑ Evaluate the quality and quantity of your available crash data – without data to understand a problem it is impossible to understand the effectiveness of interventions to solve that problem
    - ☑ Understand the concept of risk and need for exposure data – 25 road deaths occur at two different blackspots in one month. Blackspot 1 had 10,000 vehicles drive through it during that month, Blackspot 2 had 100,000 vehicles drive through; are the two blackspots equivalent?
    - ☑ The Africa Transport program created a free guide that can help "Road Safety Data in Africa: A Proposed Minimum Set of Road Safety Indicators for Data Collection, Analysis, and Reporting"
- ☑ Consult the guidance "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement" and follow the checklist to make sure you are prepared to succeed when you launch your ASE program.

ASE Program Design Steps

- ☑ Consider your available digital (internet, electricity) and physical (roadside barriers) infrastructure to determine the best options for ASE hardware
  - ☑ Road strips can detect speed when driven over, video can determine speed and capture evidence of the offender identity, data can be physically downloaded from ASE each week or dynamically transmitted by internet, etc
- ☑ Interview different hardware and software vendors based on your level of readiness, infrastructure constraints, human resources available for the ASE program, contracts offered and many more – the relationship with your vendor can greatly impact ASE program success
- ☑ Establish a reasonable violation fine structure, suitable payment system, method to check that fines have been paid, convenient procedures for payment or to contest a violation (e.g. linking vehicle plate, identification and mobile phone numbers)
- ☑ Choose a threshold over the speed limit that when exceeded will trigger issuing a violation being issued, 10% of the speed limit is used in Rwanda.
- ☑ Secure funding for your ASE program apart from the revenue generated by violation fines. If your program is optimally successful speeding will decrease and so will fines collected.

ASE Program Implementation Steps

- ☑ Sensitize the public early and continuously by many different avenues, involve the media and use social media, explain the connection between speed and injuries/deaths and how the ASE will work
- ☑ Begin with a pilot of ASE at a variety of types of locations and evaluate your findings carefully to understand what works and what challenges you will face during scale up
  - ☑ Consider each site carefully and surrounding roads to anticipate potential spillover and what the impacts might be if it occurs
- ☑ Design your evaluation and maintenance plans during the implementation phase to make sure you are considering the data you will need to evaluate the impacts.
- ☑ Keep detailed records of the timing, locations of installation, reason to install at that site
- ☑ standardize your reporting of the built environment at each site of installation, controls and potential spillover sites you will evaluate

ASE Program Maintenance & Evaluation

- ☑ Start early and do regular monitoring and evaluation (M&E) of the program from all the different angles that can all be impacted or provide your exposure data
  - ☑ Violations issued
  - ☑ Road traffic crashes and spectrum of outcomes
    - ☑ Property damage
    - ☑ Minor injury

        - ☑ Moderate injury
        - ☑ Severe injury
        - ☑ Deaths
        - ☑ Use injury data from the health system and police records
    - ☑ Exposure data from vehicle quantity, kilometers traveled, density, 85% speeds
        - ☑ Telecom or satellite data may be useful
        - ☑ Manual stand counts at regular intervals
    - ☑ Survey the public to understand experiences and perceptions, share the findings of all evaluations to build support for the program
- ☑ Other road safety measures are still effective and should not be neglected
- ☑ Establish a regular calibration system and plan for handling emergency problems like system malfunctions
- ☑ This can be negotiated within the vendor contract

Introduction

The burden of road traffic injuries and deaths is substantial and growing. Annually, road traffic crashes result in 50 million injuries and 1.35 million deaths globally. An estimated 90% of deaths occur in low- and middle-income countries (LMICs) (1, 2). Road traffic injury is the leading cause of death for people 5-29 years of age (2). Per World Health Organization models, Rwanda has one of the highest road traffic fatality rates at 29.7 per 100,000 people, over three times as high as the average of 8.3 deaths per 100,000 in high income countries (3, 4). In 2016, there were an estimated 53,025 serious injuries. Economic losses associated with fatalities and serious injuries are about $854 million (10.1% of the gross domestic product [GDP])(1).

Speed is one of the leading risk factors contributing to injury and death on the roads. This includes both excessive speeding, defined as when vehicles exceed the posted speed limit, and inappropriate speed, when a vehicle travels at a speed that is not suitable for the conditions (e.g., weather, traffic) but within the designated speed limit (5). Increases in speed result in a higher risk of crash resulting in an injury or death. It is estimated that a 1% increase in mean speed results in an increase of 4% and 3% risk in death and serious injury, respectively (3). Automated speed enforcement (ASE) is a critical tool to reduce speed-related crashes, injuries, and deaths. ASE involves the use of speed cameras, which can be fixed or mobile, operated with or without a police officer, and overt (clearly visible) or covert (hidden) (6).

In a recent systematic review of 26 randomized controlled trials or controlled before-after studies aiming to assess the impact of speed enforcement detection devices, all but one found an absolute reduction in average speed after introducing ASE (6). Further, all studies found a reduction in road traffic crashes and injuries. Of the seven studies which assess fatal crashes, ASE led to reductions ranging from 14-58% (6). Impacts may be even greater for specific road users; one study in France found significant decreases (20%) in total crashes resulting in injuries and deaths and even higher decreases among motorcyclists (39%) (7). Beyond reductions of adverse road safety outcomes, studies have demonstrated economic benefits of introducing ASE (4, 13). Economic benefits come from crash cost reductions of £2.2-4.3 million ($2.55-4.97 USD) annually. A recent study from New York City indicated that the 140 existing cameras would result in a cost savings of $1.2 billion USD over the lifetime of current residents (8). Of note, most studies are conducted in high-income countries (HICs). This trend of limited research is consistent with macro-level research trends; it is estimated that less than 10% of the total road safety research takes place in LMICs, despite more than 90% of road traffic injuries and deaths taking place in these countries whose vehicle park consists of a relatively small proportion of vehicles (9).

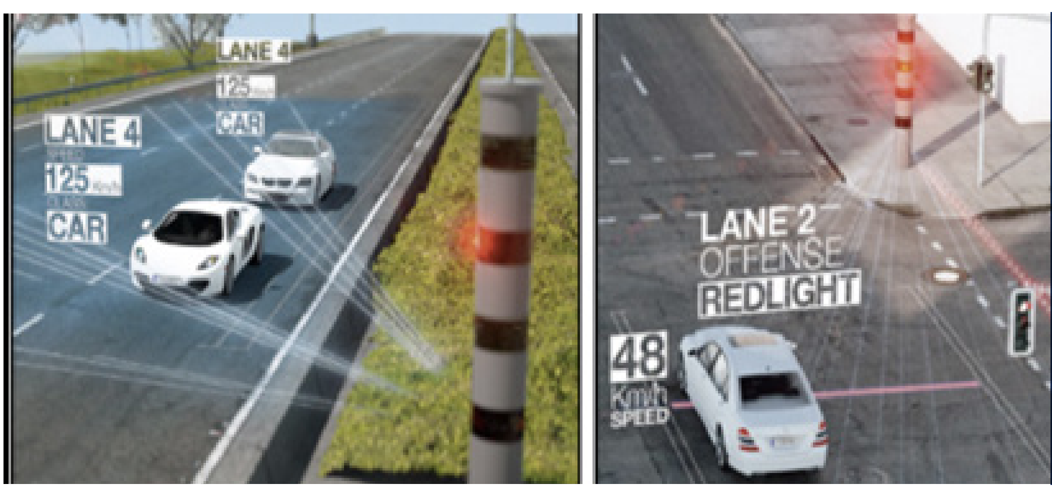


Figure 1 | Examples of a functioning ASE system

Beyond the positive impacts, ASE cameras offer several advantages over traditional speed enforcement approaches, including their ability to detect high rates of violations; their ability to operate where traffic stops are not feasible or safe; and their fair and equal approach to violations (10). Further, ASE programs are efficient, they allow traffic police to engage in other tasks while maintaining surveillance of road user behaviors otherwise done in person. Figure 1 shows examples of ASE systems.

In the most recent Global Status Report on Road Safety (2018), most surveyed countries (90 of 157) employed automated methods for managing speed (3). However, only 30 of these countries self-reported their speed enforcement measures as 'good', indicating opportunities for improvement and potential gaps in understanding best practices for implementing ASE. This, along with persistent trends of limited road safety research in LMICs, is a major concern for efforts to reduce adverse road safety outcomes.

In 2020, the Global Road Safety Facility (GRSF) and Global Road Safety Partnership (GRSP) published a document, titled "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement" (11). This document aims to assist jurisdictions with determining levels of readiness for ASE, including the legal and operational components. Additional objectives include to identify the value of ASE for reducing injuries and deaths, issues and criteria before implementing ASE, steps to take to achieve readiness, and issues to improve existing systems. This guide inspired our interest in developing an ASE implementation toolkit to be used as a follow-up for use once readiness has been determined. Rwanda is the first low-income country in Africa to implement a comprehensive national ASE system (shown in Figure 2), providing an opportunity to generate and share the lessons learned to facilitate implementation of ASE in other countries experiencing similar challenges of limited resources, a high burden of road traffic injuries and deaths, and a desire to improve road safety.

Figure 2 | News article describing ASE systems in Rwanda

Pan Butamire
Thursday, June 16, 2022

You'll find her by the roadside or in the median of a double carriageway and, motorist or other road user, she'll be wide-eyed, watching you. Over-speed and she'll send you a penalty note. If somehow she doesn't, check on Irembo platform or punch in at *127# on your mobile. Miscreant road users, she is your dread.

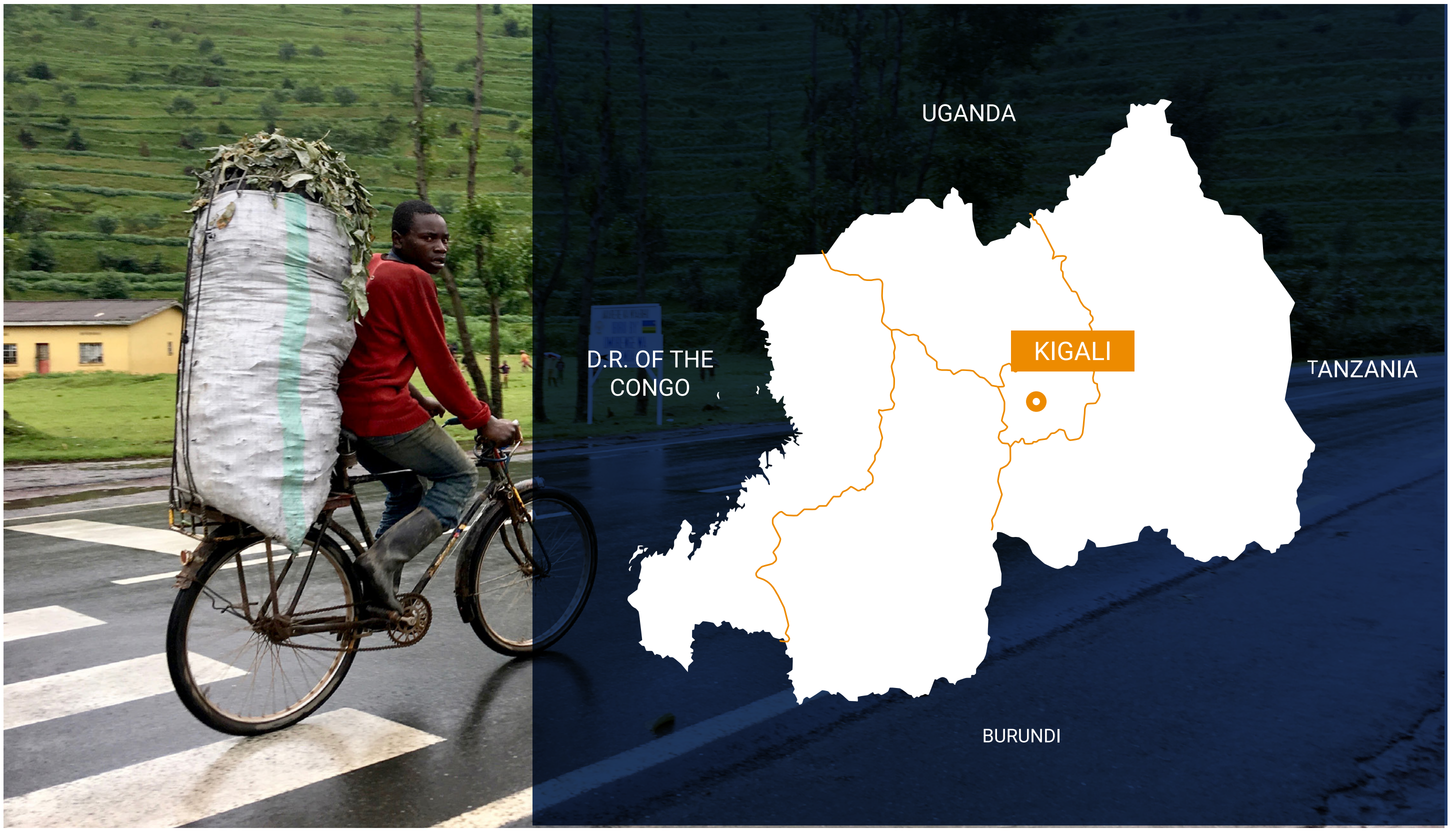
Meet 'Sophia', the speed camera that many in advanced countries have for long taken for granted but that was alien to Rwanda until a few years ago. She is here to check your speed, your respect for traffic signs, zebra-crossing lines, keeping to the right lanes and correctly entering intersections. Pedestrian, follow road rules or get a roasting also.

She supplements the work of police which has other technology-enabled tools that multi-task like closed-circuit television that may include video cameras, display screens, recording equipment, others. There are also speed guns (out of fashion now?) and mobile speed cameras.

Source | New Times

Study Setting

All portions of this study were conducted by Healthy People Rwanda (HPR), a non-profit registered in Rwanda, and the Traffic Injury Research Foundation (TIRF), an organization based in Canada with funding support from the World Bank. We began in January 2022 with the development of research tools and application for ethical clearance. Prospective data collection took place between May 2022 and March 2023 and was performed by HPR. Rwanda is a low-income country in East Africa with a population of 13.2 million and a GDP on purchasing power parity (PPP) per capita of $2,440 USD (12). In recent decades, Rwanda has made tremendous development gains in terms of poverty reduction (from 78% in 2000 to 56.5% in 2016), increasing life expectancy (from 49 in 2000 to 69 in 2020), GDP (from $2.02 billion in 2000 to $11.07 billion in 2021), and access to



electricity (from 6.2% in 2000 to 46.6% in 2020) (13). The ASE program is a government project managed by the Rwanda National Police through a partnership with Eastern Ventures (a local Special Purpose Vehicle) and Vitronic, a German company with a subsidiary in the United Arab Emirates. A multi-million-dollar deal was signed in February 2020 to install 500 speed cameras from Vitronic (14).

Descriptive data from annual police crash investigation reporting as displayed above show that serious injury crashes dropped profoundly (911 to 114, an 87% decrease of 797 crashes) without an explanation such as a change in serious injury definitions or data anomalies between 2019-2022. We also see a dramatic spike in the number of property damage only collisions (1,584 to 4,362, a 175% increase of 2,778 crashes) and minor injury crashes (1,485 to 5,183, a 249% increase of 3,698 crashes). The incidence of cumulative road traffic injuries (minor, serious and deaths) jumped from 34.9/100,000 in 2019 to 84.4/100,000 population in 2022. The incidence of annual road deaths initially decreased from 2010 to 2011 but experienced an increasing trend with slight fluctuations until 2022. Rwanda reported 7,835 road deaths over 13 years (an average of 603 deaths per year), resulting in an average of 5.43 annual deaths per 100,000 people from 2010 to 2022. These shifts in the distribution of crash outcomes between 2019-2022 are concurrent with the ASE implementation timeline. However, the large discrepancy between these reported data and WHO models of projected road deaths and injuries inspires more questions and attempts to uncover additional data to understand the significance of these results.

Figure 3 | Incidence of Annual Road Deaths per 100,000 people in Rwanda | 2010 - 2020

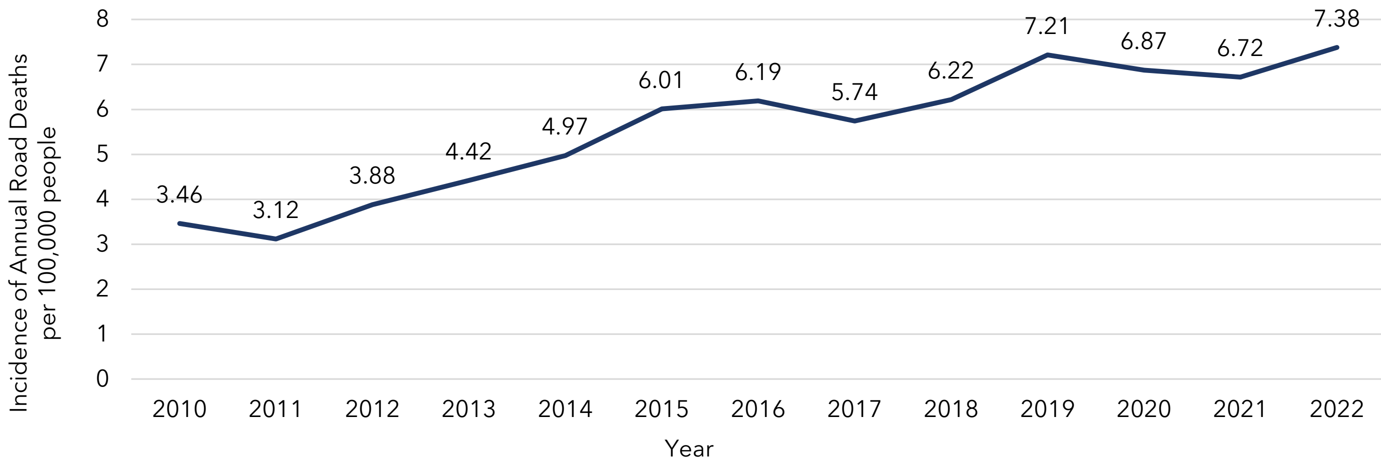


Figure 4 | Incidence of Annual Road Injuries per 100,000 people in Rwanda | 2010 - 2020

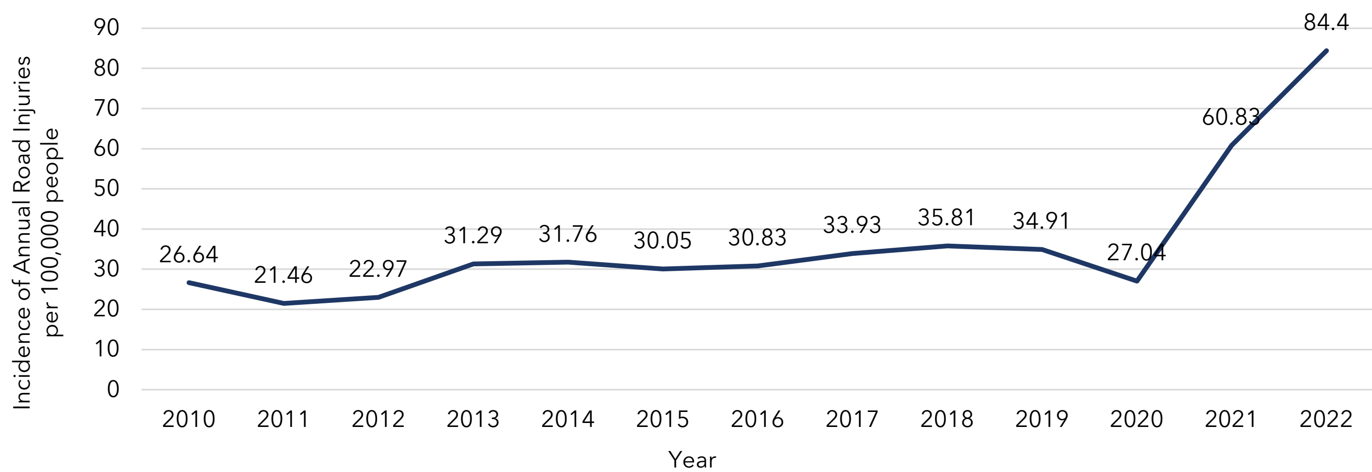


Figure 5 | Number of Annual Road Fatal Crashes in Rwanda | 2015 - 2022

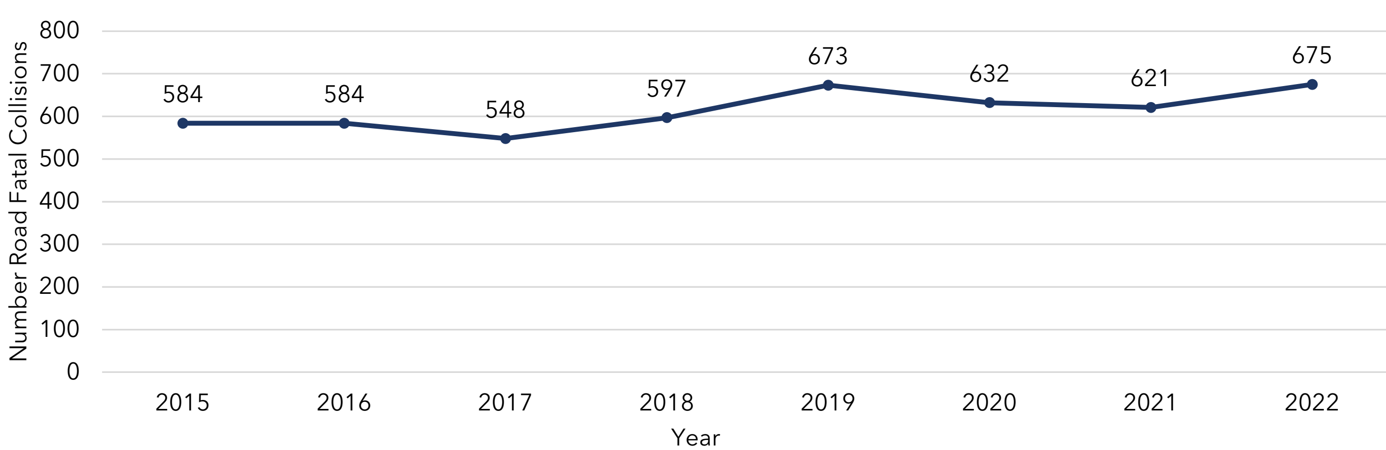


Figure 6 | Number of Annual Serious Injury Crashes in Rwanda | 2015 - 2022

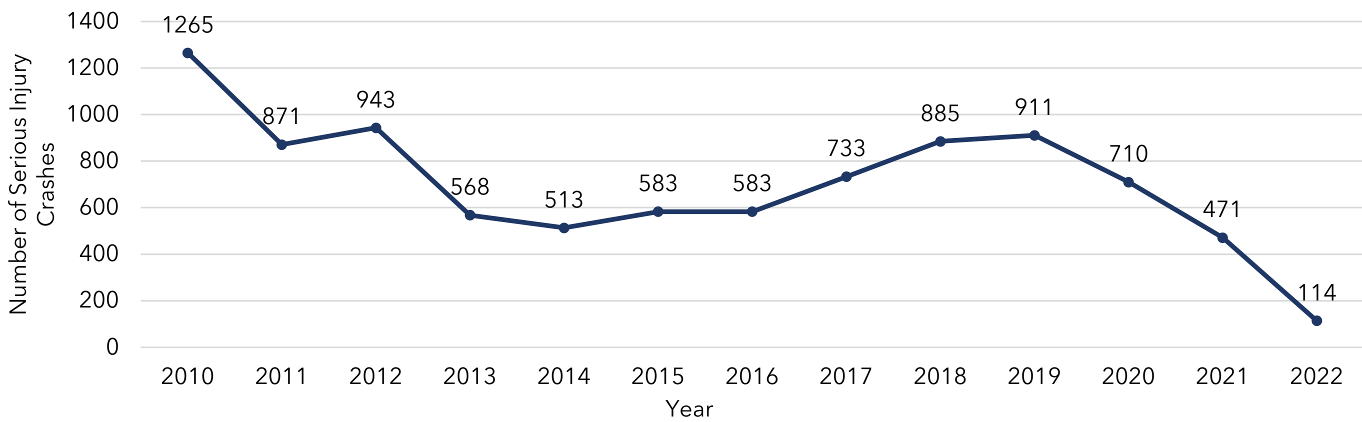


Figure 7 | Number of Annual Road Minor Injury Crashes in Rwanda | 2015 - 2022

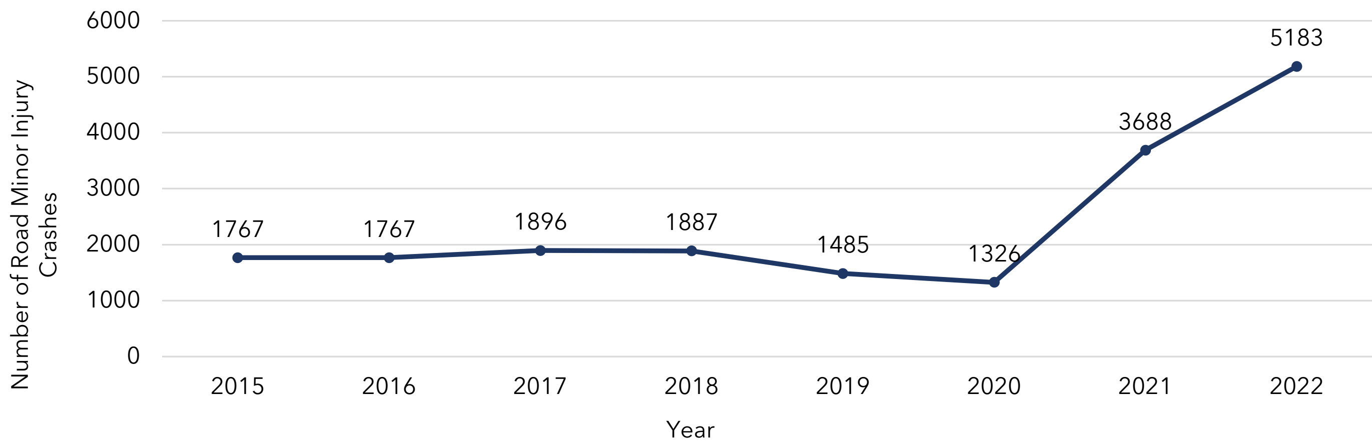
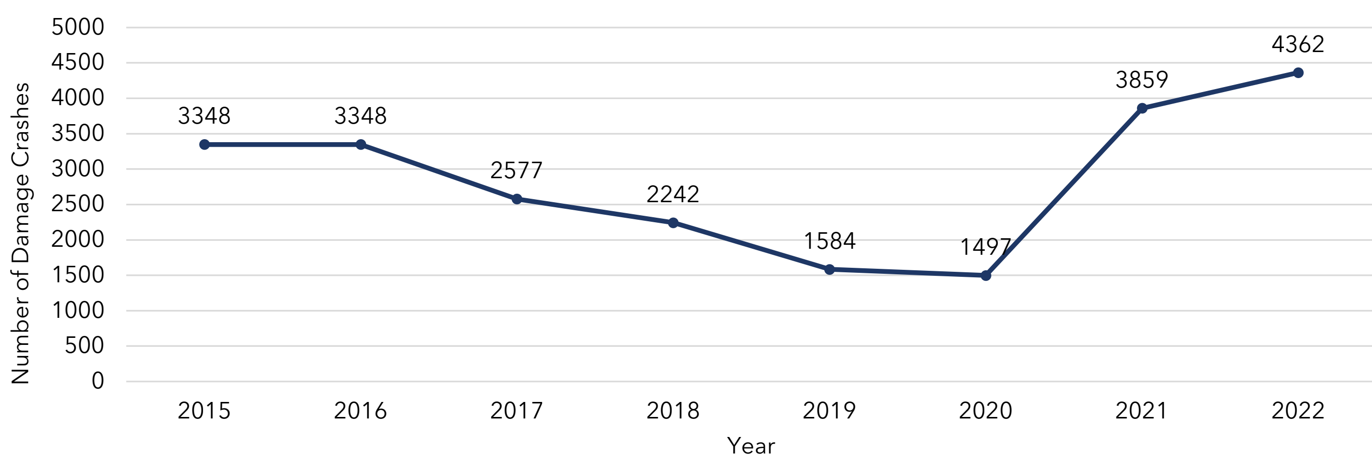


Figure 8 | Number of Annual Damage Crashes in Rwanda | 2015 - 2022



Overall Study Objective

To the best of our knowledge, no studies have assessed national automated speed enforcement implementation in any African nor low-income country. To fill this critical gap, we aimed to (i) describe the implementation of an ASE system, (ii) investigate the effect of ASE tools, including cameras and other road safety measures such as campaigns, in reducing fatal, injury, and property damage collisions, (iii) conduct an experiment to assess the effect of cameras on speed outcomes, and (iv) measure the public's experience, views, and perceptions on ASE and road safety in Rwanda to provide broadly transferable recommendations for other Low and Middle-Income African Countries. In the following report we present detailed methods, results and discussion from three unique studies we designed and completed between January 2022 and March 2023;

1. **The national adoption and scale up of automated speed enforcement in Rwanda: an approach to guide implementation** | Using structured key informant interviews (7 interviewees), focus group discussions (8 participants) and participatory feedback (several high ranking police) we conducted a qualitative study with stakeholders involved in the ASE program to 1) map and describe the planning and implementation process of ASE; 2) document perceived successes and areas for improvement. We adapted questions from a study conducted by the United States National Highway Traffic Safety Administration (NHTSA) to the Rwandan context and attempted to fill in gaps with the focus group discussion (15). Under optimal conditions our empirical methodology would have captured all data to lower the risk of bias, but these feedback sessions proved invaluable. And verified that most information we collected initially was correct. Implementation guidelines and lessons learned can facilitate future implementations in other countries facing similar issues with excessive speeding and a high burden of road traffic crashes, injuries, and deaths. We believe that our efforts to engage ASE stakeholders in the process of mapping decision points, motivations, and actors relative to design and implementation has the potential to improve both this program and others in the long term, empowering individuals to ask important questions and critically evaluate the planning and implementation decisions.
2. **A Cross-sectional Study with controls of the Impact of Automated Speed Enforcement on Motorist Speeds and Speeding Violations in Rwanda** | We measured the effect of overt speed cameras (exposure sites, called 'case' herein) versus no camera (i.e., only a hidden speed collection device, control) on speeding outcomes including the mean speed, the number of official violations (defined as equal to or above 10% of the set speed limit), and any speed limit violations (defined as going above the designated speed limit) on national roads. There was a significant decrease in mean speeds for all vehicles and each vehicle type in case (overt camera) versus no camera locations, indicating that ASE may be positively affecting road user behaviour and leading to decreased speeds in these localized areas. Despite limitations, our findings are consistent with other literature. Given the limitations of this study, we would recommend that other studies assess the impact of ASE with more rigorous study designs. Specifically, we would recommend studies include an assessment of the effects spatially and temporally. We would highly recommend that speed, crash, and injury data is collected prior to implementation of ASE to establish baseline trends. Relatedly, we would recommend the use of geospatial data on crashes and injuries to understand if mean speeds, number of violations, and number of vehicles exceeding the speed limit affects road safety outcomes in LMICs.

3. **A National Survey to Understand the Public Perception of Automated Speed Enforcement and Road Safety in Rwanda** | Informed by the ASE implementation study findings we designed a cross-sectional study of a nationally representative sample of Rwandans using quantitative surveys with two simple qualitative questions, conducted via in person interviews, to gain insight into the perceptions of people and road users on ASE and road safety. Most road users agree that speed cameras and the delivery of citations are fair, and they confirm the importance of ASE as a tool for improving public safety. We suspect this is a sign of country development, trust of leadership and a government that works for the people. This study provides critical information as it shares the public insights into the first national scale up of ASE in an African, low-income country. Such insights are critical for addressing a research gap in understanding the implementation and the public perceptions of such programs in LMICs and in Africa. Additionally, this study generated a rich data set for local policy makers and the Rwanda National Police to consider in their work and/or to serve as a baseline by which the impact of interventions that may change public knowledge, attitudes and practices can be evaluated.

4. **An Interrupted Time Series Analysis of the Impact of Automated Speed Enforcement on Road Traffic Crashes, Injuries and Deaths in Rwanda from 2010-2022** | We used police reported crash frequencies and outcomes to check if the descriptive trends observed during the period of ASE implementation could be clearly associated with this technology. Unfortunately, the limitations of the data sources make it impossible to draw empiric conclusions about these. We suspect that paper data collection the transfer to a digital database, manually de-aggregating the crash data to the district and monthly level and our lack of a source of true exposure data to understand how many people are using the roads that these crashes occurred on all contributed to our lack of robust findings. We include the full methods and results as **Appendix A** to share the attempted methods and challenges we encountered; however, this exercise had deep value despite its limitations. This was the first opportunity to identify conflict points between the top priorities of researchers (accurate and complete data needed to optimize analyses methods) and the police (the safety and security of the Rwandan people). Recognition is a necessary first step in mitigation and resolution of conflict, and despite differing orders of priorities both the research team and the police share the goal of improving the safety of Rwandan roads to prevent death, disability, and economic losses.

Finally, we present our synthesized and action-oriented recommendations based on the challenges we experienced and endeavoured to overcome as researchers in addition to the findings of our studies in the context of international ASE literature and guidelines. We elaborate the status of Rwanda in relation to the checklist items of the proposed guide for determining readiness for ASE (11). Specifically, we present each consideration recommended in the guide, the minimum requirements associated with each consideration, and corresponding results for each section based on a combination of study participant data and additions from the participatory feedback sessions. Overall, most of the key aspects of readiness were addressed in Rwanda during the implementation processes. Once a country determines its readiness for ASE implementation, we aim for this comprehensive case study to serve as a follow up implementation guide and reference. As a result, a map is provided outlining the steps taken by key stakeholders when it comes to planning, designing, and carrying out automated speed enforcement. Additionally, charts and tables are presented to demonstrate the efficacy of automated speed enforcement and other road safety measures and the public's view of automated speed enforcement. This overall study considers what has been learned from the design, implementation, and evaluation experiences relative to ASE in Rwanda and this study. We provide specific recommendations considering our findings and relevant literature to other African LMICs considering their own ASE programs, imagining these places directly putting the checklist to use as a simple outline to assist them in achieving safer roads and more efficiently enforced speed limits.

This overall study considers what has been learned from the design, implementation, and evaluation experiences relative to ASE in Rwanda and this study. We provide specific recommendations considering our findings and relevant literature to other African LMICs considering their own ASE programs, imagining these places directly putting the checklist to use as a simple outline to assist them in achieving safer roads and more efficiently enforced speed limits.

The national adoption and scale up of automated speed enforcement in Rwanda: an approach to guide implementation

Methods

Objective

To the best of our knowledge, no studies have assessed national ASE implementation in any African nor low-income country. To fill this critical gap, we aimed to describe the implementation of an ASE system in Rwanda and prepare broadly transferable recommendations for LMICs. Specifically, we conducted a qualitative study with stakeholders involved in the ASE program to 1) map and describe the planning and implementation process of ASE; 2) document perceived successes and areas for improvement. Based on the findings, we offer a set of important recommendations for other countries to consider when implementing ASE systems to reduce the burden of crashes, injuries, and deaths.

Study description

We conducted a quantitative and qualitative study to document the design and implementation process of ASE in Rwanda through the perspective of individuals representing agencies that we considered stakeholders in ASE project design, planning, or implementation. We gathered data through key informant interviews and a focus group discussion. This study emerges from an interpretivist perspective, which emphasizes the belief that world is constructed, interpreted, and experienced by people (16); as such, our study aims to capture views by stakeholders in key institutions involved with implementation of a national ASE program in Rwanda, rather than objective truths to be generalized and applied universally.

Selection of study participants

HPR study team members who designed and supervised the data collection methodology included individuals who have been working in transport, academia, medicine, and in road safety research collaborations with the Rwanda National Police for several years. Using our understanding of the road safety landscape in Rwanda, we developed an initial list of potential ASE stakeholders. This list was refined during key informant interviews by asking respondents if there were others we should consider interviewing with knowledge of ASE in Rwanda. Ultimately our invited list included government agencies (Rwanda National Police, Ministry of Infrastructure, Rwanda Transport Development Agency, City of Kigali, Rwanda Information Society Authority, Rwanda Development Board) and Vitronic (the private company involved in implementation).

Invitations to both key informant interview and the focus group discussion were sent by email directly to individuals in institutions or to institutions requesting for them to name a person to participate. After sending an invitation, a follow up call and second follow up was done within a week and 10 business days, respectively. After the second call, if we did not receive a response, we would notify the institution/delegate by email that they would be considered unavailable if they did not provide a response within the next four business days. When requested, we visited the physical offices of the institution and hand-delivered printed letters and had preliminary meetings to explain our intent. Accordingly, a predetermined sample size was not possible, it was instead determined by the willingness of invited people to take part in the process.

Ethical clearance and authorization

The study protocol was approved by the Rwanda National Ethical Committee. Formal, verbal authorization from the Rwanda National Police was obtained through several meetings that aimed to sensitize the institution to our interest and objectives, assuring that our efforts posed no risk of violating contracted agreements related to proprietary knowledge and technology. The support and partnership of the Rwanda National Police also supported respondents from other institutions to be at liberty to share their perspective freely.

Data collection tool development

Key informant interview guide

Key informant interviews were conducted utilizing a semi-structured interview guide (provided in the Supplementary Materials) that aimed to understand the design and implementation processes, successes, and opportunities for improvement of Rwanda's ASE program. The questions were based on a study conducted by the United States National Highway Traffic Safety Administration (NHTSA) and adapted to the Rwandan context (15). In 2008, NHTSA published operational guidelines for ASE camera systems in the US and beyond, which has guided much of this study (10). Although the guidelines are written from a US perspective, they note that lessons are drawn from international experiences as well, indicating they are largely relevant for LMICs (3). The semi-structured key informant interview guide was organized into four key sections, presented in Table 1.

The specific questions adapted to the key informant interview survey tool were collaboratively selected from the NHTSA and expanded on by team members from TIRF and HPR in English language. A bilingual HPR team member then translated the tool to Kinyarwanda and another bilingual HPR team member back translated this to English. An independent reviewer confirmed the validity of the Kinyarwanda translation. Three research team members conducted internal testing of the key informant interview questionnaire. Internal testing resulted in changes in the wording of questions and organization aiming to improve the fidelity of our data collection and reliability of results. After internal testing, a pilot interview was conducted with one participant from the Rwanda National Police, and this was collectively determined by the HPR team to show our key informant interview methods and data collection tools were adequate.

Table 1 | Key informant interview guide key sections

Section	Concepts covered
Design	▪ Design guidelines ▪ Advocacy and legal review ▪ Road crashes reduction strategic plan in relation to the ASE Program ▪ Partnerships ▪ Government authorization
Implementation	▪ Decision-making on locations ▪ Ownership and maintenance ▪ Legal components ▪ Data management
Operations	▪ Operation processes
Violation processing, delivery adjudication	▪ Quality control ▪ Management of revenues

Focus group discussion and facilitation guide

The focus group discussion was conducted to capture additional and/or missing information and understand group views on ASE implementation, successes, and areas for improvement. We developed the focus group discussion guide after partial analysis of the results from key informant interviews using a semi-structured interview guide. We systematically reviewed each question from key informant interviews and related answers to identify missing information. We collaboratively developed questions and prompts to facilitate group discussion focused on six sections (design, implementation, operation, violation processing, delivery/adjudication, and recommendations). The interview guide is provided in the Supplementary Materials.

Data collection processes

Key informant interviews were conducted at locations chosen by participants suited for private communication. The focus group discussion was conducted in a private conference room in Kigali. We described the study to participants and then obtained written informed consent as part of the key informant interviews and focus group discussion. Key informant interviews were conducted in English or Kinyarwanda depending on the preference of the participant. Each interview was conducted by at least two interviewers (one administering the interview, one taking notes if recording was not accepted). The majority (6/7 key informant interviews) were audio recorded. One participant did not consent to recording during a key informant interview. After the key informant interviews, two team members completed an interview evaluation form to rank the clarity, recurrence, and format of questions, as well as the overall verbal communication to assess the quality of the key informant interviews. Each section was scored using a five-point scoring system (1 – very bad; 2 – bad; 3 – average; 4 – good; 5 – very good). Comments were included for each section. The evaluation form and results are included in the Supplementary Materials. The focus group discussion was conducted in both English and Kinyarwanda and all comments were bilaterally translated in real time to facilitate optimal discussion. All recorded interviews were transcribed verbatim by one research team member and when necessary, translated into English from Kinyarwanda verbatim by another bilingual research team member immediately after the data collection.

Data analysis

Data analysis was conducted using a mixed deductive-inductive content-analysis approach. A content analysis approach is commonly used to systematically process text into similar categories/themes (16, 17). Directed content analysis was used, as the initial codes were based on a priori developed themes from the NHTSA's operational guidelines and questionnaire (e.g., general considerations and planning; site selection; enforcement). Also, some of the questions (e.g., "Were you overall satisfied with the design and implementation process of Rwandan ASE?") were particularly well-suited for inductive analysis, hence our mixed deductive-inductive approach.

After key informant interviews and the focus group discussion were conducted, transcribed, and translated, four team members conducted deductive qualitative analysis collaboratively through manual coding of printed transcripts followed by electronic coding in Nvivo (18). Emerging themes were collectively developed and agreed upon. Themes were put into an implementation process map to depict the temporal activities of ASE implementation and identify gaps in our understanding. Process mapping is a broad methodology used to understand a process, which is relevant for studying complex systems and interventions in new contexts (19).

Participatory feedback sessions

In line with our desire to assure this research remains participatory, we shared drafts of this report and presented the most salient findings to some of our respondents, senior officers, and leadership of the Rwanda National Police to verify the accuracy of our findings and fill gaps where possible. This process was not formal, and the structure varied depending on the respondent and the context in which we shared the results. *Within the results the information resultant from these feedback sessions is noted in italicized text.*

Results

Seven institutions (six government agencies; one private company) were invited to take part in this study. In total, seven participants representing four institutions took part in key informant interviews (two from the Rwanda National Police; one from the City of Kigali; two from the Rwanda Transport Development Agency; and two from the Ministry of Infrastructure (the Rwandan Information Security Authority, Rwanda Development Board, and the private company Vitronic did not complete interviews). All key informant interviews took place at the institution's offices, per the participants' request. The interviews lasted between 45-169 minutes (mean: 71 minutes). One focus group discussion with eight participants took place after the key informant interviews and lasted 130 minutes. Participants included individuals from institutions named in Table 2.

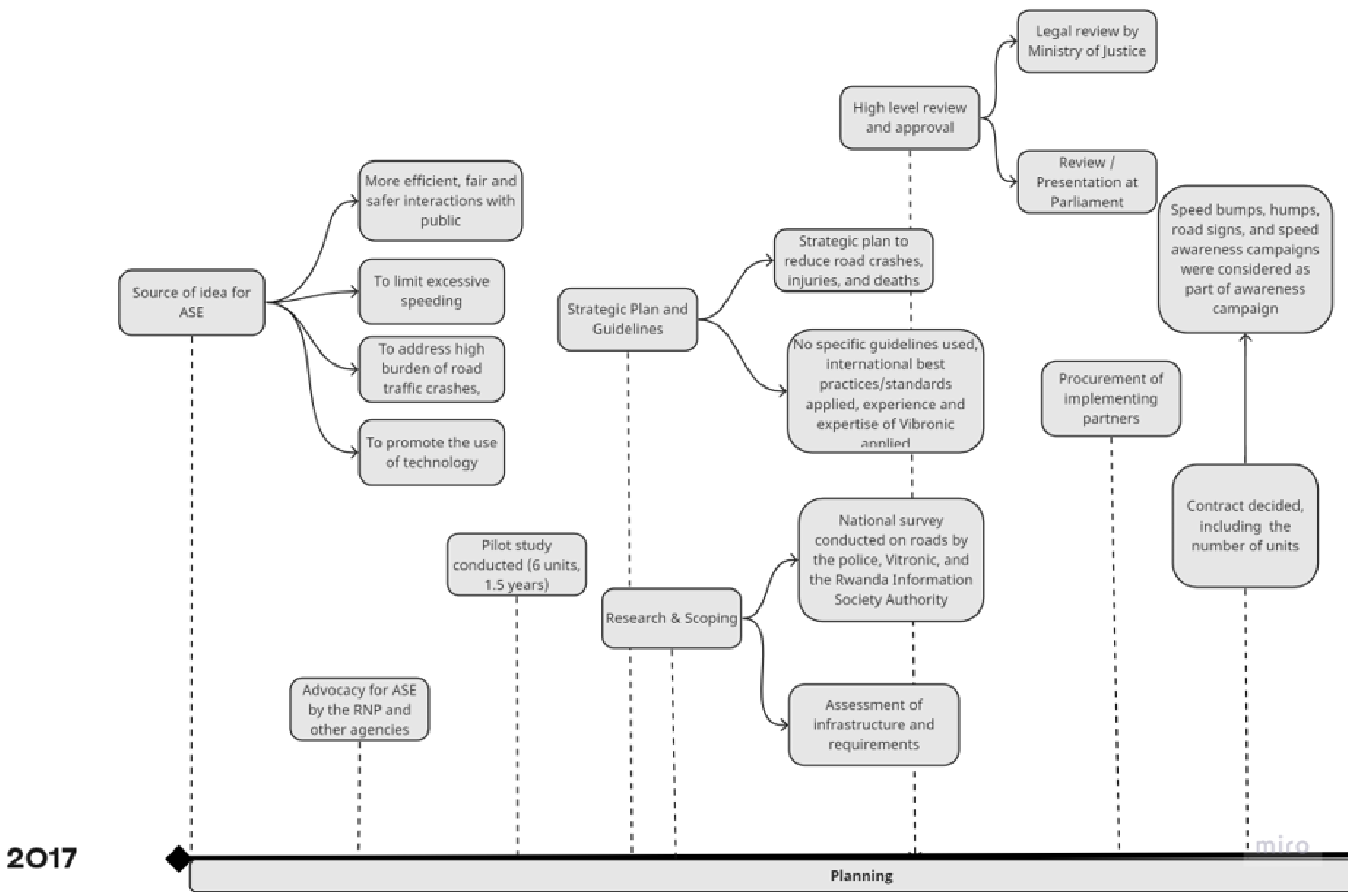
Table 2 | Participant chracteristics (N=15)

Characteristic	Key informant interviews (N=7)	Focus group discussions (N=8)
Sex		
Male	6 (85.7%)	7 (87.5%)
Female	1 (14.2 %)	1 (12.5%)
Institution		
Rwanda National Police	2 (28.5%)	4 (50%)
City of Kigali	1 (14.3%)	1 (12.5%)
Rwanda Transport Development Agency	2 (28.5%)	1 (12.5%)
Ministry of Infrastructure	2 (28.5%)	0 (%)
Rwanda Information Society Authority	0 (0%)	1 (12.5%)
Vitronic	0 (0%)	1 (12.5%)

Design and planning findings

The first steps of the process map include activities related to design and planning, including where the idea for ASE came from, approvals and authorizations, research and scoping, and key decisions (e.g., locations, penalty rules). The following section highlights activities within the planning phase (codes from the qualitative analysis) as subheadings. In addition to the activities (codes), we present illustrative quotes to support the findings. Figures 9 and 10 present a process map for the planning phase.

Figure 9 | Process map for planning and design activities



Source of the Idea of ASE

According to participants, the Rwandan National Police played a key role in advocating for ASE, motivated by several factors including widespread excessive speeding and the high burden of crashes, injuries, and deaths in the country. They noted that ASE cameras could reduce enforcement-related interactions between the police and individuals and that promoting technology aligns well with governmental priorities.

- "The idea was to find a way to reduce the number of accidents caused by over speeding and the authorities came to the conclusion that ASE cameras could be very helpful to tackle this problem and its effects."
- "The idea came from the Police and the Rwandan government's agenda which includes the use of technology."

Feedback sessions verified the police have a significant interest in improving the safety of Rwandan roads. They are the enforcers of traffic laws, and represent the entity most directly impacted by speeding and road traffic crashes. However, it was also noted that Eastern Ventures, the special purpose vehicle representing a consortium of individuals with the shared goal of bringing beneficial interventions and companies to support development of the country, proposed ASE as a tool to achieve this goal. Eastern Ventures knew of the ASE vendors Vitronic and Tatweer from some previous work and helped introduce them to the Rwanda Development Board which facilitated the connections between external investors, the government, and the ASE vendors.

Advocacy efforts by the Rwanda National Police and other agencies

When posed with questions on who advocated for ASE to be implemented, most (71.4%, n=5) key informants stated the Rwanda National Police. However, one participant noted that several institutions collaborated and advocated for the program from the outset, as is demonstrated in the illustrative quote below.

- "I don't think it's a certain department who advocated but institutions that worked together in order to address a problem that needs to be solved. Police are not the only ones involved. Together with various agencies/institutions related to road safety, they sat down and discussed how to deal with the problem."

Both of these findings were verified in our feedback sessions in addition to support from the national road safety committee. Police brought the ASE concept forward and took a leading role in working with Eastern Ventures to advocate for ASE.

Pilot study conducted early on

One of the early stages of planning and design involved the conduct of a pilot study. The Rwanda National Police conducted a small pilot with five fixed and one mobile camera in the country for 12-18 months before advocating for national scale up of the ASE program. The Rwanda National Police worked closely with Vitronic to monitor these units and determine if the solution was a good fit for the country. Of note, feedback sessions added that police think of this pilot period as part of the sensitization campaign.

Engagement with strategic plan and guidelines

Most participants stated that published ASE guidelines like those of NHTSA were not consulted. Instead, they procured companies with experience in implementing ASE, which may indicate that supplier knowledge plays an important role in ASE implementation. The implementing company (Vitronic) adheres to international standards, which was confirmed as part of the focus group discussion.

- "In Rwanda they will follow the European standard in the beginning, but sometimes you have to [consider] [...] the ground [conditions] they are dealing with. Maybe you cannot always follow these standards."

Participants stated that a strategic plan was utilized as part of this process. However, the details of this strategic plan were not reported, even when strategic plan questions were asked as part of the focus group discussion. In key informant interviews, most participants (71.4%, n=5) stated that Rwanda has a strategic plan to reduce speeding violations and crashes. The ASE program is directly aligned with these plans, although participants were not aware of the specifics of the strategic plan (e.g., indicators). On their website the police publish generalized strategic plans covering the periods of 2013-18 and 2018-23 that include road safety, management of speeding and integration with technology that all supports the output of an ASE program (20).

- "Yes, the Rwanda National Police has this [a strategic plan]. They have (...) provided us with some information about the history of accidents and the places. It's an ongoing plan."

Of note, Rwanda, through the National Road Safety Committee, has a road safety strategy and we learned that the committee regularly reviewed the process of design and implementation of the ASE program from feedback sessions. Details of the legislation that directs this committee and is relevant to other road safety and traffic control in Rwanda is available in the Supplementary Materials.

High level processes: legal review, parliamentary approval, and procurement of partners

A notable gap of knowledge among the participants in key informant interviews and the focus group discussion was related to some activities in the early stages of the program, including high level review and approval (e.g., parliamentary/ministry review and approval, legal review) and the procurement process. Participants were either unaware or uncertain of the details involved with each administrative point. When posed with questions on how partners (i.e., private companies) were selected/procured, 6 of 7 participants responded "do not know" in the key informant interviews) whereas one participant stated that the Rwanda National Police relied on existing partners for this work. Feedback sessions informed us that the project contract was negotiated at a high level and was likely too technical to attract the attention of our participants at the conception level of the project. We also learned that a Rwandan team completed due diligence including study visits to countries such as Japan, USA, Singapore, Germany, and UAE where ASE programs have been successfully implemented with the intent of selecting the best system able to meet the expectations of the country. Thereafter, vendors were solicited through standardized, legislated governmental procurement processes as prescribed by the Rwanda Public Procurement Authority (21). The winning bid was offered the contract. Similarly, legal reviews per standard governmental operations were conducted and the findings were presented to policy makers.

Research and scoping

Participants described several research and scoping activities. This included the hiring of a consultant for several months to conduct a scoping study on the feasibility of ASE implementation and locations for cameras and a national road survey focused on selecting camera locations by Vitronic. These simultaneous surveys were compared to understand the highest priority locations for cameras. Feedback sessions corrected this misperception of participants about the consultant reportedly hired to conduct a scoping study. Instead, it was conducted using resources mobilized internally (locally) that assessed the availability of basic digital infrastructure. Additionally, they reviewed police crash report data that identified over 1,000 blackspots with high rates of severe injury and death associated crashes and/or frequent locations of speeding.

Contract signed

After the research, scoping, and piloting, the Rwanda National Police signed a multi-million-dollar contract with Eastern Ventures to import, install and maintain ~500 ASE systems from Germany (14). This is inclusive of the complimentary software package being built by Vitronic and Tatweer. When participants were asked questions about if other measures were considered instead of cameras, all participants stated that other speed reduction measures do exist in Rwanda (e.g., speed humps, handheld speed guns, speed governors), and that these were not implemented instead of speed cameras. The number of speed cameras was determined from the outset and not intended to be reduced or replaced by other measures. However, other speed reduction measures may be utilized in locations where a speed camera may not be appropriate due to traffic patterns or unavailability of required infrastructure.

Engagement and authorization

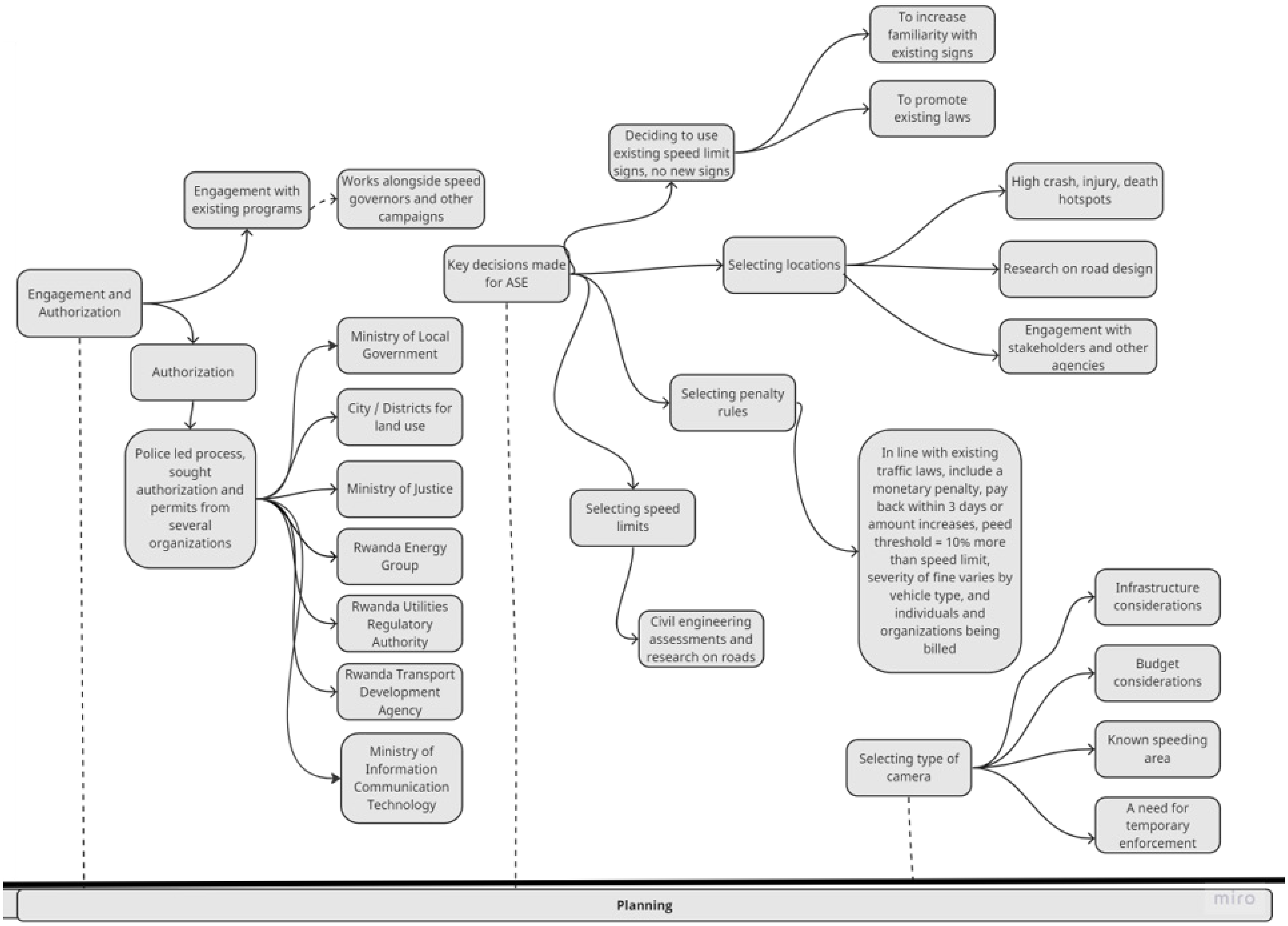
Participants described several components related to engagement with existing programs, and other organizations. Firstly, when posed with questions on how ASE fits into existing road safety strategies in the country, participants stated that all programs work simultaneously and synergistically. For example, Gerayo Amahoro (which translates to "Arrive safely" in English) is an educational campaign aimed at addressing unsafe road user behaviour whereas speed governors are devices installed into commercial vehicles (e.g., buses, trucks) to limit their maximum speed (22). ASE is seen as a continuation of these existing campaigns aimed at making roads safer.

- "Police had various programs and campaigns to sensitize Rwandans about road safety and the ASE cameras have been introduced as well so that people can be aware of them."

In terms of authorization, there was near-universal agreement among participants on which organization provided the overall authorization (the Rwanda National Police) and which organization provided specific authorization to install the cameras. Several agencies were named including the City of Kigali and districts for land use authorization, the Ministry of Justice, the Rwanda Energy Group, Ministry of Ministry of Information Communication Technology (ICT) and Innovation, the Rwanda Utilities Regulatory Authority, and the Rwanda Transport

Development Authority. Eastern Ventures, Vitronic, and Tatweer work closely with these governmental institutions as subcontractors, while they provide the required services and infrastructure for the cameras to operate.

Figure 10 | Process map for planning and design activities (cont'd)



Key decisions made for ASE Implementation

In the next step of planning, several key decisions were made, outlined below. These included the decision to 1) whether to use warning signs for cameras; 2) where to locate the cameras, 3) which rules should apply; 4) what the speed limits should be; 5) what types of cameras should be implemented.

Decision to use existing speed limit signs

One key decision was whether speed cameras would be accompanied by signs warning road users about the speed camera. Participants universally agreed that this was not an approach taken in Rwanda. Rather, the Rwanda National Police opted to utilize existing speed limit signs and to increase the number of signs to correspond to the locations of speed cameras. When asked for the rationale for this decision, participants stated that it would help to promote existing speed laws and encourage drivers/riders to pay attention to existing signs, which is a commonly observed shortcoming among motorists.

Deciding on locations for cameras

On locations, several participants stated that locations were chosen based on known clusters of crashes, injuries, and death hotspots on roads. Other reasons for selecting a location were based on the availability of necessary infrastructure (e.g., internet/data, electricity), prior research on road design, and recommendations by stakeholders and other agencies. This stakeholder committee makeup was not described in detail during the interviews and focus groups but was clarified in feedback sessions by police leadership to include representatives from institutions in charge of roads, utilities regulation, internet and communication technology, urban design, and security. As aforementioned, two large surveys were undertaken to understand suitable locations for cameras prior to signing a contract. As part of this data collection, the team composed of police, Vitronic and the Rwandan Information Security Authority assessed site readiness, including among others access to fibre cable, electricity, visibility, etc.

- "They usually select high risk areas or places where drivers tend to speed up."
- "It [the location decision] comes from inter-agency cooperation. The police work with other involved agencies to decide where these cameras should be installed."

Deciding on penalty rules

Most participants stated that an offense is defined as exceeding the posted speed limit by greater than 10% (e.g., over 88 km/h higher on an 80 km/h road). For the offense, a monetary penalty is imposed. The amount is dependent on the severity of the offense, type of vehicle and the time of repayment per Table 3. No other penalties are applied such as points against suspension of driving licensure or vehicle registration nor higher costs for insurance premiums.

- "On the 60 [km/h] speed limit, if you exceed the speed limit up to 80 [km/h] you will be fined 25,000 Rwandan Francs (RWF) ($25 USD) for Violation of traffic and road post but if you exceed 80 [km/h], you will be fined for over-speeding."

Table 3 | Information on ASE infractions and penalties in Rwanda

<table>
<tr><th>Infraction Type</th><th>Penalty (USD)</th><th>Time to pay</th><th>Late fine</th><th>Context</th></tr>
<tr><td>Vehicle >10% speed limit</td><td>$25</td><td>3 days</td><td>$10</td><td rowspan="4">2021, GDP per capita $2,448 usd
2017, 38% household annually earn <$150</td></tr>
<tr><td>Motorcycle >10% speed limit</td><td>$10</td><td>3 days</td><td>$10</td></tr>
<tr><td>Vehicle >20% speed limit</td><td>$50</td><td>3 days</td><td>$10</td></tr>
<tr><td>Motorcycle >20% speed limit</td><td>$20</td><td>3 days</td><td>$10</td></tr>
</table>

It is not clear precisely why motorcyclists are assigned lower fines that other vehicles, but we suspect it may be related to representation of income brackets of the population. Motorcycle drivers and owners tend to represent lower income Rwandans compare to vehicle drivers and owners. A fine of $25 USD can represent more than 20% of the net monthly income of many Rwandan households, detailed further in the discussion. However, it is difficult to assess the income differences between vehicle owners, drivers, and the rest of the population.

Another key decision was that cars that belong to organizations would be billed to the organization/person that the vehicle is registered to, rather than the driver as the vehicles and associated mobile numbers are linked to the organization.

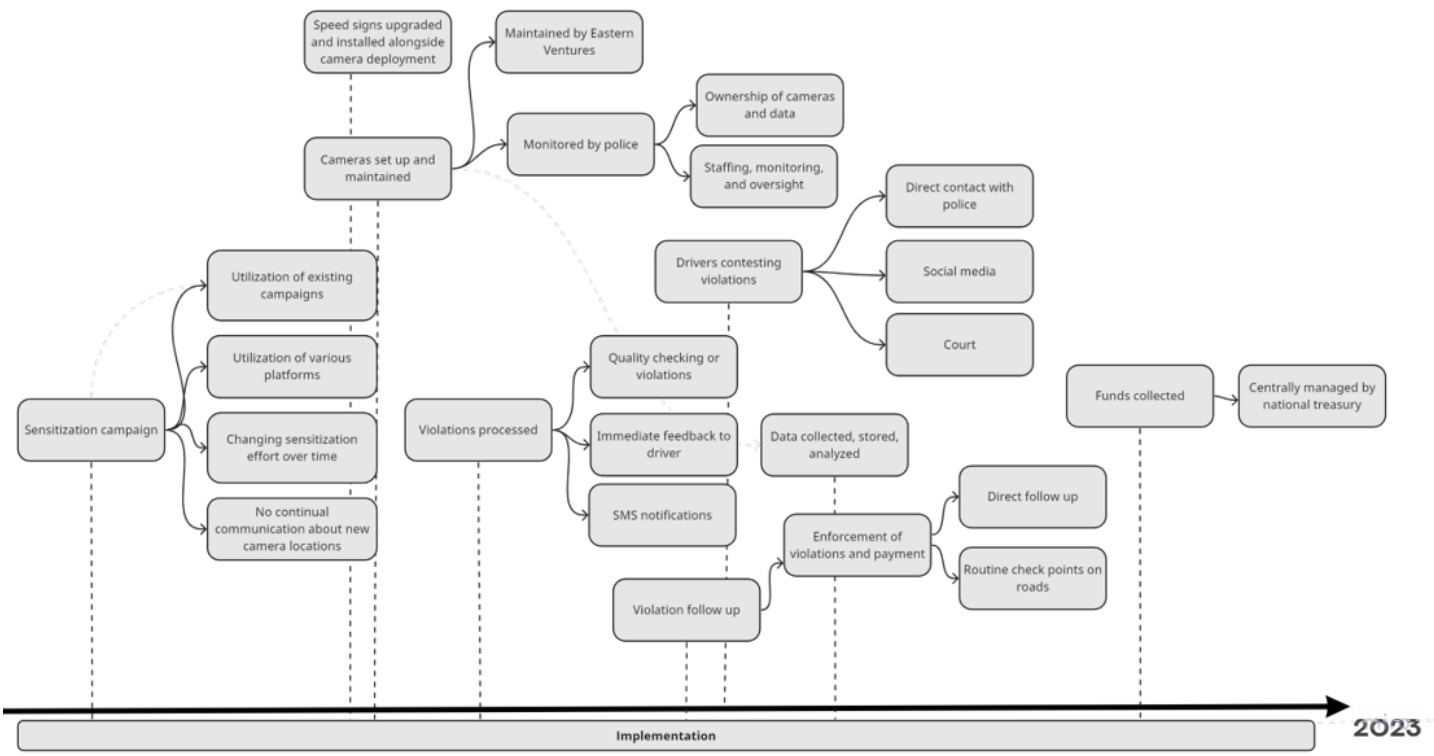
- "We give [a] citation to the vehicle; it is up to the company/organization to determine how they deal with it."

Deciding on types of cameras

Lastly, a key decision was which type of ASE camera to implement. Participants stated that several types of cameras are used including mobile, fixed-location, semi-fixed, and enforcement (e.g., at intersections/red-lights, on certain police vehicles and at enforcement points) cameras. Enforcement cameras can detect unpaid traffic fines, expired or without insurance/motor vehicle inspection, or any wanted vehicle. Decisions were made based on the budget as prices vary between types of cameras, available infrastructure, and what is required in that location. Some locations are known as speeding areas (indicating a fixed camera may be the best option), whereas others may temporarily need enforcement (indicating a mobile camera unit may be the best option). Further, given the requirements for internet and electricity, mobile units may be better suited for areas which lack such infrastructure.

- "The fixed cameras are used in a certain situation because budget wise it's hard to put them everywhere. Where it's not possible, the mobile ones can be used. Also, when all the requirements to install the ASE cameras are not met, the mobiles ones can be used.''
- "They all seem to complete each other because after knowing where the fixed cameras are located, people might overspeed when they are not in that area. The mobile ones can be in every place which is known to cause problems and people won't be able to cheat as they don't know when they will be there. Red light cameras put order on the road, making sure there is no chaos."

Figure 11 | Process Map for Implementation Activities



Implementation findings

Activities during the implementation phase included a sensitization campaign, the set up and maintenance of cameras, designing the violation process (including quality control, contesting violations, follow-up), and the collection of funds from offenses. Each activity (code from the qualitative data analysis) is presented below as a sub-heading along with illustrative quotes. An overview of activities during implementation is presented in the process map in Figure 11.

Sensitization campaign begins

First, a sensitization campaign was conducted as part of the overall road safety campaigns supported by the Gerayo Amahoro approach using various platforms (e.g., news, radio, television) to inform the public about the ASE.

- "Police had various programs and campaigns to sensitize Rwandans about road safety and the ASE cameras have been introduced as well so that people can be aware of them. [...] The police have been explaining and not only in conferences or in public, but also on radio and television."

Participants noted that the campaign is intended to change and has changed over time. One notable change is that there are reduced efforts to sensitize the public about the cameras as they perceive there are high levels of awareness. Police feedback sessions informed us that the public were informed that signs warning road users about upcoming cameras may not be installed. They cited that is it not mandatory to post ASE warning signs and instead encouraged drivers to pay attention and comply with the speed limits, which are all indicated by road signs. Finally, we learned that police may inform the public about the locations of cameras as the campaign matures.

Cameras set up and maintained

The process of camera installation, activation, and maintenance is dynamic and expansive. The maintenance, including annual calibration and upgrading of features, is done by Vitronic. The cameras are owned and monitored by the police. The cameras continuously collect and store data. Participants stated that these data are being routinely analysed but they did not know how the security of these data are maintained.

- "To make sure of quality assurance, cameras are calibrated every year."
- "With the help of artificial intelligence, [the analysis] is done by the system. In cases of complaints, [the] technical team looks at it."

Activated cameras issue violations based on their settings which are then processed by the IT divisions within the traffic police. If a motorist violates a speed limit near a camera, they are provided with immediate feedback (a camera flash). As part of the violation processing procedure, participants noted that there is a quality control process in place. This quality control process involves three staff members at the police reviewing the image, matching it to the license plate, and confirming the offense.

- "It is a team of 3 people. The first one looks at the information provided by the camera and makes sure that it is okay and checks that it is correct. Then, the system links the plate number to the owner's phone. The second one checks it and the third one confirms."

However, police feedback sessions clarified that this human resource intensive process is only utilized when issues arise, they rely on the automated process as much as possible. Soon after, the motorists receive a Short Message Service (SMS) notification informing them about the violation, the amount to pay, the due date and linking them to the digital government payment platform. This digital platform can accept payments in many forms, one of the more common digital payment methods in Rwanda links to one of two telecom services, MTN or Airtel. Because vehicle registrations are linked to mobile numbers, and frequently bank accounts are also linked to the same numbers and given that the system has links with national identification the entire system is designed to function very efficiently.

- "There is an SMS from Irembo [government] website right away. There is a reminder SMS given by the police on the day after and there is a way that the ticket holder can check that he has no citation by going to the police website, they can also use a link shared to the public. The information given are violation type, the place, time, and the penalty."

If a person wants to contest a violation, participants describe several means of doing so. The person can make direct contact with the police by phone or in person. There is also the possibility of using online communications to contest a violation such as social media (Twitter and Facebook) and email. Contested violations are then handled through an internal process that involves checking camera data. There is a team at traffic police in charge of receiving and resolving the filed complaints. Depending on the complexity of the situation an objection can reach different levels within the organization, sometimes up to the commissioner of the traffic police at the top of the division. Lastly, judicial procedures as defined in Law Nº 027/2019 OF 19/09/2019 Relating to the Criminal Procedure are available for contesting violations (23). However, participants noted that this does not seem to be utilized frequently.

- “There is an email we give them to send local complaints, they can write on Twitter and Facebook, they can call us, they can go to the office in person wherever they like. There is an internal structure where, you start at the reception, then they will show him/her to the officer, as the departments are divided, some may reach to the commissioner.”
- “The administrative process that is there ends up satisfying the complaints. So, there is no need to go to court. The way things are organized in Rwanda, we don’t have courts that are specific to road crime.”

Violations that are unpaid are followed by and enforced in two ways; 1) direct correspondence (a direct reminder SMS from the Police is sent one day prior to the deadline); 2) routine check points on roads by Police officers or cameras installed in patrol cars. As part of routine check points, police officers check the registration and determine if, and how many, unpaid violations there are. Consequences were not described in the interviews but were clarified in the feedback sessions to be contingent upon the context such as the magnitude of the unpaid fines and any dispute of the unpaid violation that may be under review currently. Of note, these checkpoints were truly routine at their start, every passing vehicle was stopped and checked for unpaid fines. However, this caused a significant slowing of traffic through busy checkpoints in Kigali and police reported responding to ‘hundreds’ of complaints daily. In response, the police have begun using Enforcement Bar (EB) Vehicles that are strategically positioned a few hundred meters ahead or after a checkpoint. Enforcement Bar Vehicles have automatic number plate recognition cameras which scans and analyses every passing vehicle to check for unpaid traffic violations fines and compliance to other related regulations such as valid insurance, valid motor vehicle inspection certificate, wanted vehicles, etc. They report that it is empirically too soon to tell the impact of this practice given this response has been in action for a short time at the time of our questions but anecdotally the impact has been extremely positive based on the sharp decline in complaints.

When posed with questions on where the penalty funds are collected and managed, most participants were unsure. However, in the focus group discussion, it was noted that the funds are centrally collected and managed by the national treasury but there was no consensus on what these funds will be utilized for within the country.

- “All fines immediately go into the national treasure.”
- “Because all fines are determined by the law, it’s not like the police sit and decide.”

However, police feedback confirmed, the sources of revenue and procedures for allocation within the budget to publicly funded programs of national interest are clearly elaborated in the N° 12/2013/OL of 12/09/2013 Organic Law on State finances and property (24). Examples include public employee compensation costs, payments of goods and services, transfers, and payments relating to servicing of debt and development projects. This law was very recently updated, and approved by the legislative bodies in August 2022 and the official gazette has not yet been published (25).

Design and Implementation Summary

Rwanda’s ASE program began with RNP engagement in foreign study visits to learn about different types of ASE programs in ~2017. Scoping and implementation studies were done in partnership with the selected vendor and used retrospective crash data and police experience to locate >1,000 blackspots associated with over speeding, severe injuries, and deaths. Prospective speed data were assessed at certain blackspots to validate assumptions and the availability of infrastructure needed to operate ASE was determined. Some actions were taken prior to implementation such as assuring that speed limit signs preceded any ASE cameras (considered a surrogate for specific ASE warning signs), setting conditions of penalties for speeding, and some public sensitization efforts.

Figure 12 | SMS text messages

Sunday 10:35PM

Traffic Fine
Fine # | [redacted]
Offense | Non respect of traffic lights
Location | [redacted]
Kinuga
Fees to be paid | 25,000 RWF
Plate No | [redacted]
Issue Date | 07-05-2023
Pay Before | 10-05-2023
Late fees apply after the due date.
Go to https://bit.l/RNPfines or dial
*909# to pay.

Sun, Feb 19 3:06 PM

Traffic Fine
Fine # | [redacted]
Speed | 67 km/h
Location | [redacted]
Rukiril
Fees to be paid | 25,000 RWF
Plate No | [redacted]
Issue Date | 19-02-2023
Pay Before | 22-02-2023
Late fees apply after the due date.
Go to https://bit.l/RNPfines or dial
*909# to pay.

Your application for | TRAFFIC FINES with billing number
[redacted]
was successfully paid. You can track your application with the followiwng details! Application number |
[redacted]
Fees paid | 25,000 RWF

In July 2019 one mobile and five fixed cameras were installed and activated as a pilot and to raise public awareness. Scale up began in January 2021 with four more cameras and continued gradually until September 2021 when 106 ASE cameras were installed with another bolus between January-March 2022 of 98 cameras. As of May 2023, more than 400 cameras are actively in use including unidirectional and bidirectional overt fixed cameras, covert mobile, trailers, intersection/redlight and enforcement patrol vehicle lightbar cameras. Each ASE has ~5 km of paved road before the next camera, though this varies greatly between urban and rural areas given blackspot-targeted locations and varied locations of mobile ASE.

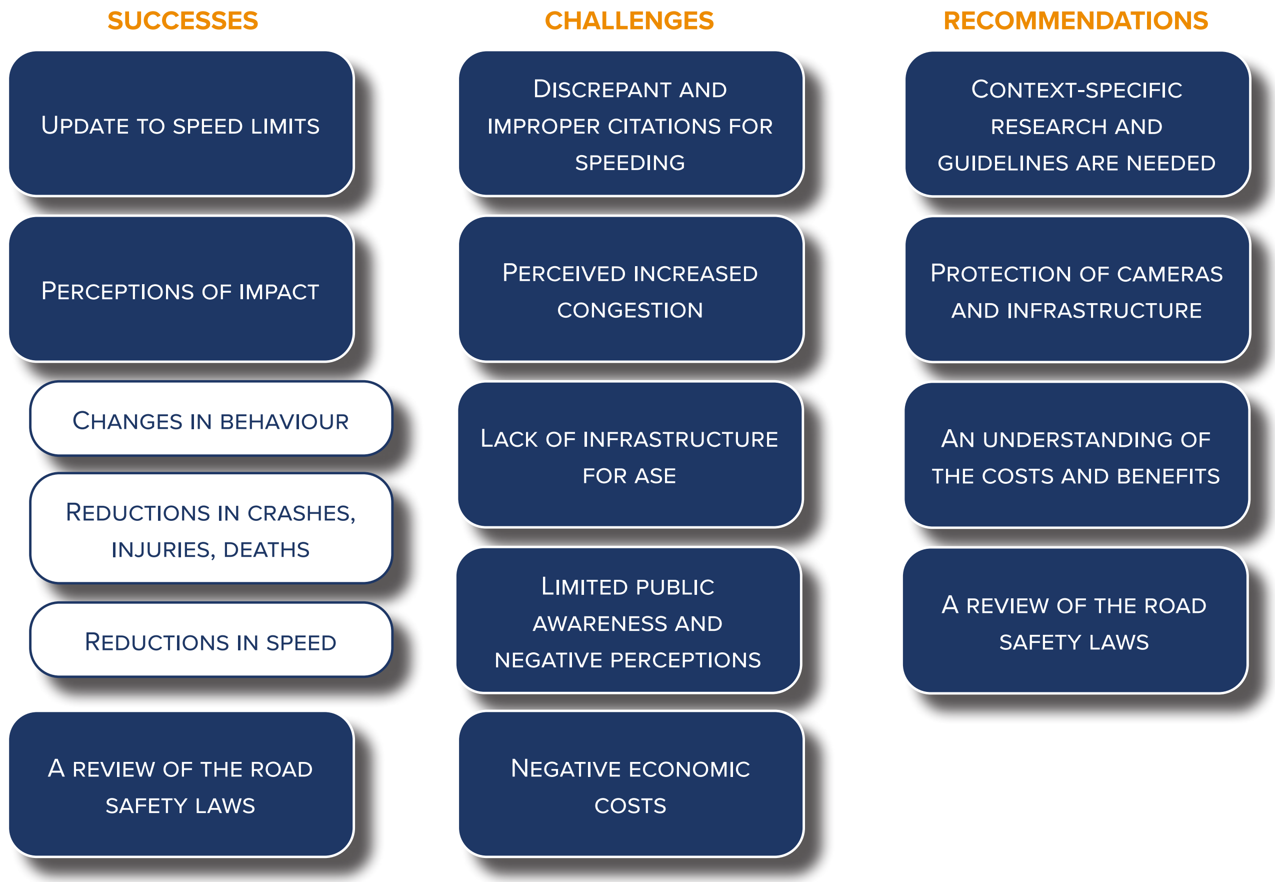
When vehicles are within view and detected to travel >10% over the speed limit approaching or passing the ASE cameras photograph and autodetect the vehicle plate numbers (front or rear) that are crossmatched to the identification database and within minutes to hours an SMS is sent to the registered owner of the vehicle notifying of the penalty, fine and payment terms (detailed later). Rwanda's ASE program leverages existing digital platforms and databases that link vehicle registration with national identification numbers, mobile phone numbers and associated cashless payment systems. These services coalesce in the online government service portal Irembo. On which on can check for and remedy unpaid ASE penalties. A reminder SMS is sent when a penalty is due and when the fines have increased for non-payment. Social media, especially Twitter, is commonly used by the public to raise complaints and contest improper violations they received, and the police will respond as requested. The RNP have also designated phone lines, emails and offices that handle such concerns and can provide doubtful offenders with photographic evidence for verification or re-assignment in the case of errors.

Upon noting a high rate of failure to pay the RNP instituted random checkpoints that caused substantial traffic jams as each vehicle was stopped for a manual check before release, causing many public complaints. Technology provided a solution to this problem through positioning an enforcement lightbar patrol vehicle to survey passing vehicles during peak traffic hours ~500 km prior to police officers who are notified of approaching vehicles with unpaid violations that are targeted for stopping while other traffic continues to flow. Similarly, public complaints have produced changes to speed limit thresholds and additional sensitization campaigns. Collected revenue is distributed to the government treasury for flexible use as needed to fund programming.

Lessons Learned

In the following section, we present participants' reports of their perceived successes, challenges, and recommendations (codes below as sub-headings) in the ASE implementation in Rwanda. An overview is provided in Figure 13 and illustrative quotes are included for each section.

Figure 13 | Lessons learned: successes, challenges, and recommendations



Successes

Successes include perceived impact in the form of reductions in speed, reductions in crashes, positive changes in behaviour, and a review of road safety laws and speed limits.

Perceived impact: reduced road crashes and speed, changes in behaviour

Participants indicated that fatal crashes and crashes involving motorists have reduced. They implied that these views were informed by data. Participants attributed this reduction in crashes to changes in driver behaviour, which was initially triggered by fear of receiving a citation. It was also mentioned that the implementation of ASE has not been able to prevent all road crashes but those related to over speeding have reduced. Participants also express satisfaction regarding the widespread prevalence of speed cameras on almost all roads (apart from those being constructed) and therefore ASE having a far-reaching impact on speed reduction around the country.

- "The drivers' behaviour changed, fatal/serious accidents reduced significantly, Statistics have shown that accidents have reduced, The ASE cameras helped a lot, they reduced accidents and people don't complain a lot anymore."
- "Each road is controlled in terms of speed."

Perceived impact: Reduced conflict

Participants expressed that they experienced a reduction in conflict between drivers and police officers. They perceived that the public is less likely to contest a violation when it is captured by a camera and supported by data/images.

- "Cameras solve conflicts between the police and drivers because you can't argue with the ASE camera, it captures the violation."

Changes and updates in speed limits

The participants believed that the updating and adjustment of speed limits as part of the implementation of ASE was a success. These included both adjustments to decrease and increase speed limits. For speed limits that were increased, participants indicated that such updates were necessary given improvements in roads and infrastructure in the country, which could allow for higher speed limits while maintaining safety. Participants described evaluations that have taken place; these have allowed the Rwanda National Police to make data-informed decisions (i.e., changing the speed limit in some locations based on updated surveys).

- "A lot of places had a speed limit of 60 km/h before and then [it was] changed to 80 km/h to avoid [...] congestion."

Challenges

In the following section, we describe participants reported challenges of the ASE system in Rwanda based on their individual perceptions. They reported experiencing discrepancies between the speed limit and ASE issued citations, improper citations issued, adverse consequences (e.g., increased congestion; economic costs), a lack of infrastructure for ASE, limited sensitization efforts and negative public perceptions. Participatory feedback sessions clarified many instances where participants limited understanding of the implementation processes led to activities being incorrectly described. In the discussion we elaborate on how these lessons can be generalizable to other countries which may consider implementing similar ASE programs.

Discrepant and improper citations for speeding

Participants described some experiences of misaligned ASE citation thresholds with speed limits communicated to road users through posted signs. Consequently, there have been some cases where a violation was charged where people were driving according to the speed limit sign but not according to the speed limit set by the camera.

- "I got a citation for violating speed [...] driving at a speed of 60 km/h in a sign that shows a speed of 80 km/h."

Participants also stated that they have heard public complaints regarding receiving penalties when they were not driving the vehicle. This is believed to be a key issue of a system that relies on vehicle registration, meaning that motorists who rent cars, organizations, and those allowing others to use their vehicles may get incorrectly penalized.

- "We often face 2 problems: the first is people may say [they] received a citation and my car has not left home, the second is that they may say the camera has taken me for exceeding 80 km/h speed limit while I was driving at 60 km/h."
- "[The police] write a violation to the wrong person in case proper vehicle ownership transfer wasn't done."

Police admitted in feedback sessions that faulty citations have happened due to technical problems in the system, and this is why there is a system for issuing complaints and removing improper fines. Additionally, they emphasized the positive benefits of registered license plate number use for citations as an additional layer of accountability and responsibility put on vehicle owners which can address some security issues at that same time. They encouraged vehicle owners to promptly transfer vehicle registrations upon selling a vehicle to prevent many fines from being issued to the wrong drivers.

Perceived increased congestion

Stakeholders also discussed that they perceived that there was increased congestion due to ASE and lower speeds, acknowledging that low speeds make roads safer.

- "In terms of mobility in the city, if you reduce speed a lot, you increase congestion and if you increase speed a lot, you expose people [to risk]."

Participants expressed the need to adjust speed limits as infrastructure changes nationally, as ensuring the speed limit appropriate to the road conditions and road usage can reduce congestion. Curiously, 'changes and updates in speed limits' was also cited as a success of ASE. A related key issue that arose regarding the evaluation and adjustment of speed limits is outdated traffic laws. The infrastructure in the country, and particularly in Kigali, is continuously changing and there is a need to update laws and implement the updates frequently, in the interest of decreasing congestion.

- "Now as we increase infrastructure, there are places where we need to adjust the speed limit."
- "If you look at the traffic law we are using, the traffic law is old."
- "Kigali was not as populated as it is now, we had fewer cars."

Lack of infrastructure for ASE

Required infrastructures for the ASE cameras to work appropriately were mentioned by participants, the lack of which has resulted in adaptations and adjustments, including the use of batteries and alternative locations. Other issues encountered before or during the installation of ASE cameras may include the geographical conditions of a location.

- "It may be found that there is no electricity or optical fiber internet in the zone; there is already another infrastructure; or the nature of that place, such as soft soil."

The feedback sessions led to responses that detailed what a speed camera to be functional; electricity and a stable data network are basic requirements. Optic fiber cable is easily reachable across main roads in the country as well as electricity cables. Where fiber cable was not closer to the road, 4-G network connectivity was used to operationalize the camera. Rwanda never lacked the required infrastructure for the ASE, and they were able to adapt available resources to respond to these challenges.

Limited public awareness and negative perceptions

A few participants felt dissatisfied with the extent to which the public was informed about the implementation of ASE. It was mentioned that not enough effort was made to make the public aware and that this process could have been improved by more campaigning and ensuring speed limit signs are positioned everywhere where there is a speed camera. Of note, participants reported that if cameras are installed in locations without speed limit signs, they are disabled until a sign is installed. These ASE cameras are not actively giving citations.

- "In my opinion, it was not done well as most people were getting ASE violations without knowing it. I think there has not been enough sensitization/awareness. I'm not aware of any campaign that has happened before."
- "[...] some places could have cameras but no speed limit signage"

Stakeholders suggested that it takes time for the public to adjust to changes. The initial reaction to a change, in this case of the implementation of ASE cameras, was commonly negative.

- "Any kind of change often causes problems, especially in the beginning."
- "The main complaint was not that the speed limit is very low, and [that][...] there was a lot of congestion."
- "In the beginning, resistance to change happened."

Understandably, participant dissatisfaction with the sensitization campaign related to ASE was an area that police leadership responsible for public relations was eager to respond to. During our participatory feedback sessions, we became aware that the police were cognizant of the opinion of some members of the public, however, this was deemed unfair, as some drivers deliberately ignored the speed limit. Therefore, the installation of ASE cameras in locations where they were not immediately visible, and without warning signs, was intended to act as a deterrent. This decision not to install signs specifically indicating the camera's location was also made because the cameras were already installed in areas with clear road signs indicating the allowed speed limit.

Police explained that Rwandan road users only need to know what a safe speed limit is for a particular stretch of road, not whether a camera will catch them. One police officer said directly, "If you aren't over speeding you won't have a problem, it's very simple." They also note from experience that public awareness is driven by how profoundly individuals are personally affected. It came as no surprise to the police that with the public now being responsible for paying more fines for speeding violations, some individuals would attempt to shift the blame for their personal decision to exceed the speed limit by claiming that there was no sensitization campaign. The police also provided feedback on the negative perception expressed by the participants, and for the most part, they concurred that it is natural for individuals to resist change and display dissatisfaction when faced with more restrictions on their conduct and behaviour. However, the police believe it is their duty and mandate to ensure road safety, even if that entails strict regulations and enforcement. They highlighted the importance of considering the psychology of some drivers who choose to exceed the speed limit regardless of the overwhelming evidence linking speeding to increased road accidents. As such, the priority is to emphasize the enforcement phase to impress upon the public the importance of complying with traffic rules, with the imposition of fines aimed at motivating behavioural change. An additional benefit of the enforcement phase is the collection and dissemination of local data with details on injuries, and fatalities to raise public awareness about the numerous advantages of fewer road accidents, injuries, and fatalities.

Negative economic cost

A closely related issue is the perceived negative economic cost of implementing speed limits using ASE. Participants believed that travel time increases as operating speeds are reduced which can have negative impacts on the economy (i.e., for tourism and trade). However, in contrast, participants highlighted the substantial economic cost to society to be considered caused by crashes that kill or injure people in the form of direct health system costs and indirect costs (e.g., lost wages).

- "You need to consider many factors, economically what are you paying [for]? If the speed limit is too low and people need to travel long distances to do business, it can damage the economy."

Recommendations

In the following section, we describe participants' recommendations to improve the ASE program in Rwanda and for implementation elsewhere. Recommendations included context-specific research and security infrastructure for cameras. In addition to these recommendations, we [the study team] provide recommendations in the discussion section.

Context specific guidelines and research

One recommendation is a need to assess context-specific factors (e.g., geographical conditions) before implementing ASE. To determine the specific conditions, detailed assessments and surveys must be conducted.

- "There is a need to do assessments and conduct surveys."

Securing cameras and infrastructure

Stakeholders also expressed the importance of having an adequate protection system for the cameras and the infrastructure to prevent theft.

- "It is also appropriate that these cameras have their own protection system because there are thieves who steal the camera cables, and the image of the thief will not be left at least to be searched for."

Cost-benefit analysis and legal review

Participants expressed a need for more research and evaluation. Specifically, participants called for an understanding of the costs and benefits of implementing ASE. Similarly, participants noted a need for a review of the road safety laws (including speed limits) prior to implementation.

- "We should have considered the road safety impact on a country's economy development because ASE reduces development speed."
- "You wouldn't do a project like this without considerations of rules and laws."

Discussion

Our study reports the implementation, successes, areas for improvement, and recommendations from the perspective of stakeholders involved in the ASE national scale-up in Rwanda. In the planning phase, stakeholders reported activities such as ideation, advocacy, and engagement with national strategic plans to reduce crashes, injuries, and deaths. Of note, participants stated Rwanda did not adhere to any international guidelines (such as the NHTSA guidelines) but relied on contracted companies and what they learned on study tours to design the implementation and operations plan. Participants described extensive research and scoping and authorization processes prior to implementation. However, there was limited understanding of the process of procurement of, and engagement with, partners to implement the cameras among stakeholder informants, beyond knowing that it followed standard government procedure. Fortunately, our participatory approach to this study allowed us to clarify some of the gaps in our ability to map the detailed processes that Rwandan institutions engaged in while contracting with a private company for ASE service and reviewing legal aspects. Stakeholders and their respective institutions were tasked with making key decisions about the cameras including where to place them, if they would indicate where speed cameras were located with warning signs, what the speed limit should be, what type of camera to place, and what the penalty should be. Participants stated that Rwanda opted not to publicly communicate about the placement of cameras and to rely on existing speed limit signs. Decisions on which types of cameras to place (fixed, semi-fixed, mobile, redlight) were determined based on location-specific needs, the availability of infrastructure, and budget. During implementation, participants described sensitization campaigns conducted through various platforms (e.g., radio, television) but noted that these efforts could and should have been more extensive given potential negative public perceptions that would come out in the early stages of the program. Participants described implementation procedures, including who owns and monitors the cameras (the police) and who maintains them (a private contracted company, Vitronic). Road users are informed about violations immediately by a camera flash, and when needed violations are quality checked by a team prior to administering a formal notification via SMS message **(shown in Figure 12).** Amounts are determined by the type of vehicle and the severity of the offense. For going 10% or more above the speed limit, the penalty is 10,000 RWF ($10 USD) for motorbikes and

Figure 14 | Tweet describing immediate notification of penalty

ands JEFF
@andsjeff

Rwanda installed cameras that curb traffic offenses

This is their Minister of Justice and Attorney General, his driver was over speeding and they automatically ticketed them, he obliged to pay.

*In Uganda, a Minister would ask the cameras if they went to the bush war in Luweero

Busingye Johnston @BusingyeJohns · Aug 14, 2019
Irembo and Traffic take efficiency 2 the next level! A camera caught us overspeeding a short while ago & now an automated fine bill;

14/08/2019:Over speeding:81 by RAD991V,Ticket#:1014081974741
Location:Gihuta, Bill ID:190814403265, Frw:50,000, Pay by:18-08-2019...
Show more

1:19 AM · Aug 15, 2019

Source | Twitter

25,000 RWF ($25 USD) for vehicles). If it is not paid within three days, the fine increases by 10,000 RWF [$10 USD). Enforcement was originally conducted through stopping all vehicles at routine check points but amended to target offenders automatically through enforcement cameras recently deployed ahead of these check points. Individuals may contest violations in a variety of ways (e.g., direct contact with the police; social media). Funds from offenses are managed centrally by the national treasury, not directed to support specific initiatives like road safety or police operations. These efforts to elucidate and document the history of the landmark, national ASE campaign in Rwanda highlighted several considerations worthy of further exploration.

Economic costs and benefits of reduced vehicle speeds

Many of our respondents reported that ASE would have adverse economic consequences as slower transport speeds slow development. There is the obvious extension of the direct economic costs associated with payment of a penalty fine for speeding, compounded by the high probability that ASE will lead to an increased number of penalties issued to offenders compared to traditional police enforcement of speed limits. Lastly, this technology in Rwanda includes enforcement potentiators through the devices which scan all passing vehicles and alert a police officer 500 m ahead to stop a particular offender with unpaid penalty fines. All vehicle speed laws in Rwanda, including the penalty magnitude, timeframe of payment, and additional penalties for late payment when given a citation for driving over the speed limit are established by members of the legislative branch of the government. These aspects were in place prior to ASE and the automation of citations for speeding. As a point of reference, 2021 World Bank data report GDP per capita of $2,440 USD (12). Assuming 30% flat income taxes are assessed against incomes of this magnitude, so one can extrapolate a net take home monthly of $142. However, of note, nationally in 2017, about 38.2% and 16.0% of people live below the national poverty line (RWF 159,375 [$149.57 USD] per year) and the national extreme poverty line, (RWF 105,064 [$98.60 USD] annually) respectively (26). Relatedly, as of 2021 only 244,112 vehicles were registered in the country, indicating that most individuals do not own a vehicle (24). One can assume that those with access to a vehicle may be substantially wealthier than the average Rwanda citizen. However, the magnitude of the penalties assessed for over-speeding is substantial in the context of low incomes, but these penalties have been static since at least 2018, despite significant inflation and de-valuation of the Rwandan franc against the US dollar.

Given these facts, the penalty for over speeding in Rwanda is unlikely to be commonly ignored, which would facilitate lower vehicle speeds, fewer crashes resulting in serious injury or death and in turn lower costs to the public health system and cut loss of economic activity of individuals. Additionally, slower speeds consume less fuel therefore decreasing the costs of vehicle operations and they also decrease harmful emissions of greenhouse gases that contribute to poor air quality. Finally, uniform speeds are associated with less congestion, which could compensate for overall reduced speeds by reducing episodes of complete stoppage of vehicle flow. Nevertheless, when the speed you can travel is reduced by 20% (in a simple model) your transportation time increases by 20%, which reduces time that could be spent in other forms of economic productivity. Illustrated well by Spanish investigators who sought to evaluate whether policymakers were making good decisions about speed limits, there may be an optimal speed limit that maximizes the benefits and limits the costs (27). More uniform urban speeds allow other measures that can reduce transport time such as traffic light timing to prevent intersection congestion. These considerations will be especially challenging to navigate given other structural contexts more common to LMICs (under resourced health systems, fewer services for people living with disabilities from road traffic injuries, older vehicle fleets with high carbon emissions, etc) than more developed countries where most cost-benefit analysis data originates.

Alignment with ASE Guidelines including the Proposed Guide for Determining ASE Readiness

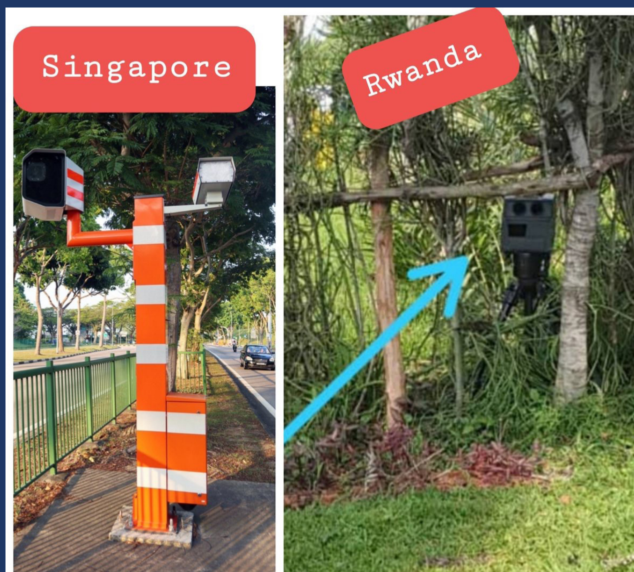
Rwanda's ASE implementation is well-aligned with the international operational guidelines set out by the NHTSA and prior literature in several ways. Throughout the planning phase, crash data were analysed to determine hot spots and if speed contributed to crash frequency, as recommended (10). Relatedly, the National Road Safety Committee has a strategy for reducing crashes, injuries, and deaths; such a strategic plan with documented objectives is recommended by the NHTSA. Another well-aligned aspect of the program was the creation of a committee (10). In Rwanda, stakeholders including the police, traffic engineers, infrastructure specialists, and others all came together and provided input on ASE implementation. The program also has a quality check process in place, reducing the risk of unfair or incorrect penalties.

Traffic calming elements in the built environment such as speed bumps have been widely implemented for many years prior to ASE implementation and were not abandoned in favor of ASE, but they were felt not to be sufficient and so ASE was added to the measures. The number of cameras to be installed was determined at the outset of the program before the contract was signed, informed by two national surveys. We believe the simultaneous data collection for comparison and triangulation of results is a strength of the program. However, consequently, speed control measures such as speed bumps were not necessarily installed instead of cameras. Additional road safety initiatives including an educational campaign (Gerayo Amahoro) and speed control devices (speed governors in commercial vehicles) work alongside ASE.

Rwanda elected not to provide a warning period prior to introducing ASE, considered a crucial component of implementation by NHTSA (10). This finding is closely related to the Rwanda program's decision to not display camera signs **(Figure 15)** justified by participants to increase awareness of existing speed limit signs and educate road users. The police responded to this finding in feedback sessions by illustrating the root objective of the entire Rwandan ASE campaign; to globally decrease speeds on high-risk roadways such that all roads become safer and fewer economic and human losses are experienced across the country. In addition, the police consider the 18 month-long pilot of very few fixed ASE cameras was equivalent to a warning period. They acknowledge that covert ASE may contribute to negative public perception in Rwanda and are comfortable accepting that consequence in light of the urgency of the problem they are addressing. Indeed, the inclusion of some mystery, through covert cameras and related techniques, is supported by literature as an effective means of decreasing overall speeds on the road and preventing spill over impacts that could increase crashes in areas where previous crashes were few (28) (29).

Figure 15 | Facebook post comparing overt and covert cameras with Rwanda as an example

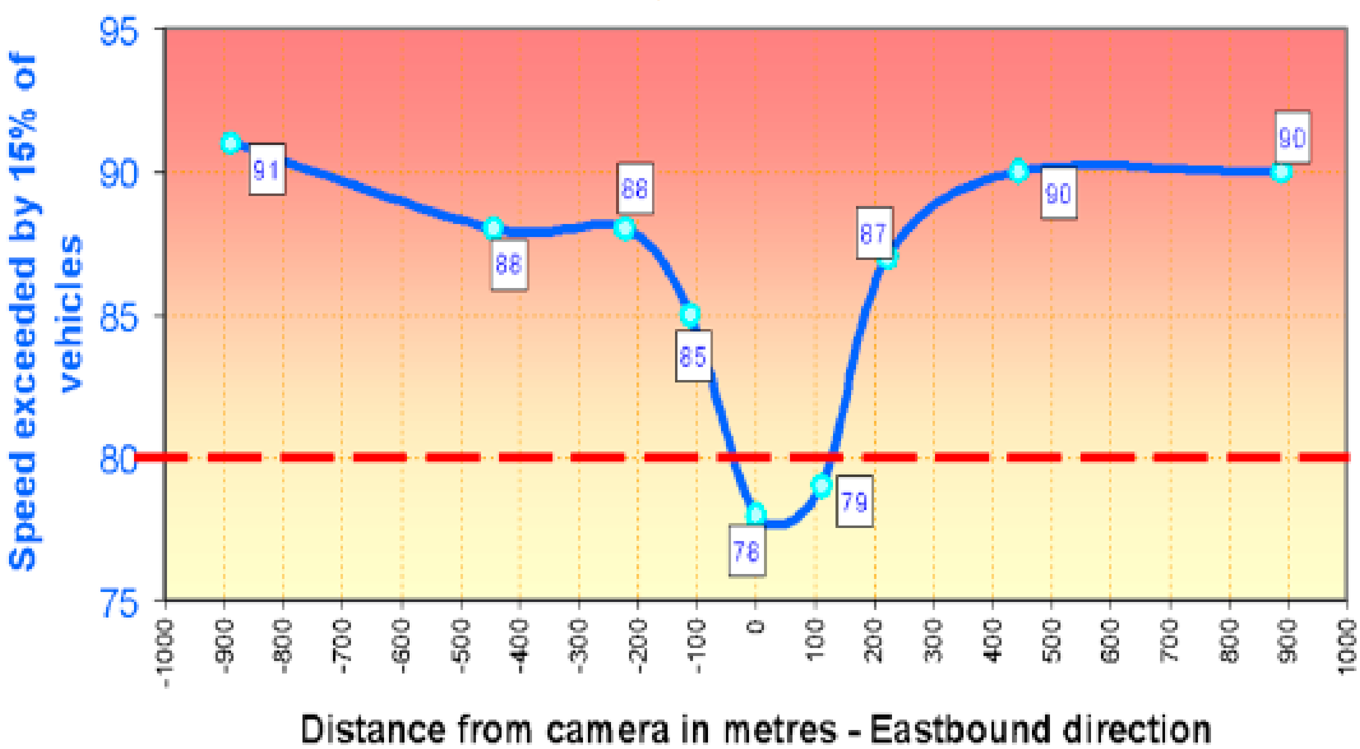
Source | Facebook



In his recent review of ASE outcomes and policy implications, Soames Job shares a figure from a 2013 presentation where he describes the observed vehicle speeds in reference to a visible, signposted fixed camera in New South Wales Australia (Figure 16). He further notes, “For fixed cameras, the risk of detection and punishment approaches 100% at camera locations, and thus suppression of speeding is substantial but quite location-specific, especially if camera locations are signposted. On the other hand, a (hypothetical) program of 50 mobile cameras operating across a state with 300,000 km of road means that even if the cameras are operating 100% of the time, only 1 in every 6000 km of road contains a mobile camera, and thus the percentage reduction in speed and in deaths and injuries might reasonably be smaller. However, such programs remain vital because the effect is spread over a much larger area, capturing benefits of smaller percentage reductions of much larger baseline numbers of deaths and injuries. (30)”

Figure 16 | Review of speed camera intervention outcomes

A typical result for speeds around visibly signposted fixed camera, showing common speeding on approach and departure from the camera with drivers reducing speeds around the camera.



Source | Job RS. Evaluations of speed camera interventions can deliver a wide range of outcomes: Causes and policy implications. Sustainability. 2022 Feb 3;14(3):1765.

Other studies have demonstrated different effects with covert and visible cameras, potentially explained by the geographic area. One study found that visible cameras were effective in reducing fatal crashes in areas limited to within a few hundred meters which were signposted as 'speed camera areas (31). Covert cameras may be more effective globally (i.e., for a whole area) rather than a specific localized area (32) and that these positive impacts are sustained over time (28). Other studies have documented the positive impacts of dynamic speed displays suggesting that "covert speed cameras combined with immediate feedback" may be an optimal approach to reduce speeds across an entire road network (15). Evidence for best practices in ASE camera visibility, signage, and dynamic feedback in LMICs is limited and thus further knowledge generation from this potentially unique context is one of our recommendations for future studies.

Other administrative differences include that NHTSA recommends an extensive legal review. Relatedly, the NHTSA and US law set out how proceeds from penalties are allocated. Penalties are collected and utilized at smaller administrative levels, rather than centrally. In comparing Rwanda to larger countries like the US, it is important to consider the difference in context not limited to sources of revenue with which to fund the national budget, culture, and different styles of government. Geographically and based on population, Rwanda is smaller than many states within the US, and relies on centralized leadership and management of many policies and programs, indicating that decentralized allocation of ASE generated revenue may not be feasible nor desirable.

Sensitization and public perception considerations

Rwanda's implementation approach was less focused on obtaining community support and buy-in prior to launching their ASE program than many transport professionals recommend. Public complaints were noted among all participants and could have been potentially avoided with a participatory approach to ASE decision-making and scale-up. This is a particularly important finding as prior studies have indicated limited benefits of ASE without public campaigns aimed at promoting speed deterrence (33, 34). These findings are well-aligned with widely documented limited success of fear-based health promotion programs (35). However, the police shared in feedback sessions that they are not ignorant to complaints about ASE. Rather, they see the task of quickly improving the safety of Rwandan roads to be so mission critical that they have intentionally chosen to do what they believe will be most effective, while generating data that can be used to gain public support later. Additionally, one could argue that Rwandan public servants are highly accessible to the population as evidenced by how many ministers, members of parliament and senators make public their personal mobile phone numbers and the extensive use of social media to provide feedback to the government.

This report describes several decisions related to ASE that generated significant feedback from the public and how these policies were amended in response, one is shown in Figure 17. Additionally, there are many examples of Rwandan public campaigns aimed at promoting over speeding deterrence of many different forms such as infrastructure alteration through speedhumps, traffic calming road designs like roundabouts, speed governors installed on high-risk vehicles some shown in Figure 18.

The national road safety campaign of Gerayo Amahoro that frequently implored Rwandan road users to reduce their speeds and even to hold each other accountable for dangerous driving (taxi customer to the driver, children to their parents, etc). Nearly all prior studies have noted that ASE systems are often associated with recurring controversies related to fine revenue (i.e., a perception that they are used to generate revenue, not for safety), fairness (i.e., a perception that the system is not set up fairly), privacy (i.e., a perception that these systems are used for surveillance), and others. Despite these controversies, speed cameras are especially supported in specific contexts involving vulnerable road users (i.e., children who must navigate the roads as pedestrians to get to school).

Examples of participatory research methods have built empirical evidence for the value of directly engaging oppositionist road users. Researchers in the state of Minnesota hypothesized that if they could understand the nuanced perceptions of ASE opponents, they could improve their ability to effectively communicate the benefits

Figure 17 | Tweets by the President of Rwanda, Paul Kagame, regarding the ASE system and associated speed limits

Presidency | Rwanda
@UrugwiroVillage

President Kagame on road safety: People have been complaining about excessive traffic penalties for speed limits and paying fines for going beyond 40km/h. That is the same speed as those of us who are used to walking.

8:30 AM · Nov 19, 2021

Presidency | Rwanda @UrugwiroVillage · Nov 19, 2021

President Kagame on road safety: I have spoken to National Police, the speed should not be so high that it leads to accidents, nor should it be so low that people never get where they are going.

20 101 276

Source | Twitter

Figure 18 | Speed control strategies in Rwanda in addition to ASE

Source | https://ruminationsfromrwanda.blog/2019/08/20/bicycling-in-rwanda/ & https://www.visitrwanda24.com/news/kigali-city/

of ASE (36). Opponents of ASE identified through an online survey were queried for the specific reasons for their criticism that centered generally around invasion of privacy, revenue generation, ineffectiveness, and unfairness (36). Based on this, a new series of questions were designed that asked respondents to consider-the-opposite. For example, when ASE revenue generation was criticized the opposite question would engage respondents by asking “what positive benefits could be achieved by increased government revenue?”. Almost half (47%) of the ASE opponents who completed the customized follow up survey reported at the end that their opinion of ASE had improved with many describing it favourably now. This research lacked a control arm, so it is not possible to know if this intensive methodology is more effective than presenting generalized, positive ASE benefits. We similarly believe that our efforts to engage ASE stakeholders in the process of mapping decision points, motivations, and actors relative to design and implementation has the potential to improve both this program and others in the long term, empowering individuals to ask important questions and critically evaluate the planning and implementation decisions.

Recommendations

Guided by these qualitative data, we share recommendations for Rwanda and other LMICs hoping to implement similar programs to control speed. For Rwanda, we recommend greater transparency about the program, including for key decisions such as locations of speed cameras and choosing covert versus overt cameras. Other research has indicated that along with these factors, an evaluation and results demonstrating the impact may help with the level of public acceptance and success of the ASE program (36). A consortium of concerned agencies is currently engaging in this exercise of documenting the details above, which will be an excellent follow up to our efforts in this report. Secondly, we recommend additional, context-specific research on camera placement, signage, and penalty payment strategies in Rwanda. Conclusions in the literature on the benefits and drawbacks of covert versus overt cameras are non-existent for LMICs. Similarly, to the best of our knowledge, there are no studies that aim to identify optimal penalty magnitudes and required payment timelines, even though these factors likely represent significant sources of ASE opposition. In a future public perception survey, we will assess these domains which will be especially interesting in that the penalty payment strategies were thoughtfully considered to align with other government issues fees.

For other countries, broadly, we would recommend focusing efforts on deterring drivers from exceeding speed limits, rather than finding ways to apprehend or punish drivers (37). ASE is a critical piece of speed management but would be most effective if working alongside other initiatives and campaigns (e.g., Gerayo Amahoro in

Rwanda) and road safety policies. Prior to implementing ASE, firstly, we would recommend ensuring readiness for ASE implementation. Next, we would recommend substantial resources on public sensitization prior to ASE system roll out, including a warning period of reasonable length, as is recommended by the NHTSA (10). This may reduce negative public perceptions that have been described in Rwanda and internationally. Beyond sensitization, there is a need for extensive research and a national road safety law review. Several participants noted that the ASE program prompted Rwanda to update speed limits and safety laws, and other countries can similarly benefit through alignment with evidence-based road safety policies. Closely related is the need for an understanding of the costs and benefits of introducing ASE systems. As noted by participants, ASE led to perceptions about adverse economic consequences (i.e., slower speeds and longer travel times). However, views of positive economic benefits included reduced crashes, injuries, and deaths. A detailed cost-benefit analysis prior to introduction may provide useful information on the trade-offs. Lastly, infrastructure, including high-quality access to certain utilities (e.g., internet, electricity), and measures to physically protect the cameras arose with this project and will be key considerations for the success of ASE programs everywhere but especially in resource constrained settings.

Finally, a valuable aspect of this overall ASE research project in Rwanda is to inform a follow up publication to the "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement," aimed specifically at African LMIC's where the highest burden of road traffic crashes, injuries, and deaths are experienced (11). The activities outlined in this report document stakeholder impressions of the design and implementation processes required to build the current ASE program in Rwanda. Once a country has determined they are ready to pursue their own ASE program using the aforenoted guide, they can examine the case study from Rwanda to support their own design and implementation strategies. We have adapted the checklist with our assessments of Rwanda's specific readiness as reported by our respondents. Notable achievements include substantial political support for ASE, strong regulatory and enforcement frameworks that promote vehicular registration, and linking national identification to a unique mobile phone number that facilitates real-time, digital feedback to vehicle owners of an over-speeding infraction. Although Rwanda was already undertaking tasks related to ASE design and implementation when this readiness guide was published in 2020, review and concordance with GRSF recommendations can help guide improvements to implementation strategies.

Limitations

Our study is subject to some limitations. Firstly, we applied US-based operational guidelines as a comparison for this program and based our questionnaire on a study conducted by the NHTSA. We refined the questions to better suit the context but may have unknowingly introduced bias. However, in the document, the NHTSA states, "the guidelines are written from a US perspective and emphasize US contexts and best practices. However, they are also drawn from the experiences of exemplary programs internationally. Though international differences in law, history, and culture might influence best practices for ASE, most of these guidelines are relevant to ASE programs worldwide" (10).

Another challenge of this study was the difficulty in reaching and interviewing stakeholders. We had initially sought to speak to stakeholders from seven agencies (Rwanda National Police, Ministry of Infrastructure, Rwanda Transport Development Agency, City of Kigali, Rwanda Information Society Authority, Rwanda Development Board) and a private company involved with implementation (Vitronic). All but one (Rwanda Development Board) agreed to participate, though Vitronic and the Rwanda Information Security Authority are represented exclusively through their focus group participation. Gaps in our understanding of the implementation, and particularly the high-level administrative approvals and reviews, may be a result of this limitation; however, we followed a standardized process in approaching and following up with agencies and potential participants, providing numerous opportunities for them to take part.

While our respondents represented relevant agencies, they may have been too new to the agency to know or feel free to answer some questions, which could affect our results in ways that are quite difficult to measure reliably. One needs only to briefly attempt to read the text of the sometimes >500-page gazette documents that describe legislation in which government procedures are prescribed to understand why all public servants may not recall specific information on the spot. It is also understandable that within a large, complex organization like a national government the different ministries and authorities that play some role in programs like ASE and road safety could limit their deep knowledge to their specific domains, such as road design in the Ministry of Infrastructure and enforcement within the police. During data analysis we recognized the discrepancies in our results and what members of our research team in Rwanda had personally experienced and/or learned from interactions with police leadership through shared efforts to promote road safety. Therefore, we developed an additional method to improve the accuracy of our mapping of the design and implementation of ASE in Rwanda through participatory feedback sessions. Drafts of this report were iteratively shared across interview and focus group discussion respondents and a purposefully selected group of high-level leaders from the Rwandan National Police. Different police commissioners take responsibility for different aspects of policing such as public relations, finance, and ICT so we targeted each with the gaps we identified in this report that their division would be the lead on. We also had some group sessions between police and Rwandan leadership of Vitronic to discuss details of our results and assure that the presentation of this report accurately reflects the processes and motivations of institutions that contributed to ASE design and implementation. Not only was this process effective at closing gaps and improving the accuracy of our report, but it was an opportunity for our team to describe the potential benefits associated with sharing the knowledge and experience developed by Rwandan institutions responsible for the ASE program. Under optimal conditions our empirical methodology would have captured the information we gained from the feedback sessions by participation of these informants in leadership roles, but rapid development of a low-income country requires these leaders to remain focused and devoting their full attention to complete interviews and engage in focus groups on a short timeline is understandably challenging. Fortunately, these feedback sessions allowed us to verify that the ~90% of the information we collected initially was correct and we were able to be very efficient in discussion of the remaining 10% of which our understanding was limited. We clarified the roles of the different partners, the procurement process utilized, administrative decisions, ASE location study methodology details, content of the sensitization campaign, penalty rules, identification, and mitigation of problematic penalty enforcement strategies. Finally, this process generally improved the quality of this report and assured that our reporting would not compromise ASE industry commercial sensitivity, Rwandan security nor future efforts to collaborate with Governmental institutions that share our teams strong desire to improve the safety of Rwandan roads.

Conclusion

We have documented the first implementation of a comprehensive national ASE system in a low-income country in Africa. Implementation guidelines and lessons learned can facilitate future implementations in other countries facing similar issues with excessive speeding and a high burden of road traffic crashes, injuries, and deaths. This report is the first in a series of several that will quantitatively describe the impacts of ASE in Rwanda in terms of road traffic crashes, injuries, and deaths and to explore the reported public perception of ASE from a nationally represented sample of the population.

A Cross-sectional Study with controls of the Impact of Automated Speed Enforcement on Motorist Speeds and Speeding Violations in Rwanda

Methods

Objective

Given the high burden, the ongoing implementation of ASE, and the commitment of the government to reduce crashes, injuries, and deaths, Rwanda is well positioned to study the impact of ASE. In this study, our objective was to measure the effect of overt speed cameras versus no camera (i.e., only a hidden speed collection device) on speeding outcomes including the mean speed, the number of official violations (defined as equal to or above 10% of the set speed limit), and any speed limit violations (defined as going above the designated speed limit) on national roads. Beyond this, this study aimed to generate data on speed distribution in LMICs, another notable gap in the literature. We collaborated with the RNP to select exposure and control locations that were matched on enforcement measures, road quality, vehicle volumes, and land use patterns. We hypothesized that there would be statistically significant differences in speed outcomes when comparing exposure sites (overt camera) locations to those without a camera, and that this difference would be most pronounced among passenger vehicles and motorcycles as Rwandan commercial vehicle speeds are restricted by speed governors. Through this study, we believe that Rwanda can serve as an exemplar for other LMICs seeking to understand if and how ASE may affect driver behaviour, speed outcomes, and subsequently, road safety outcomes.

Study design

The current study took place in January and February 2023 in partnership with the RNP. We selected a cross-sectional with controls design as ASE cameras had already been installed at the time of the study, prohibiting us from conducting a matched pre-post study which would have been more rigorous. Trained study staff worked closely with the RNP to develop a detailed data collection protocol.

Ethical clearance and authorization

The overall study was approved by the Rwanda National Ethics Committee and the RNP.

Study Site Selection

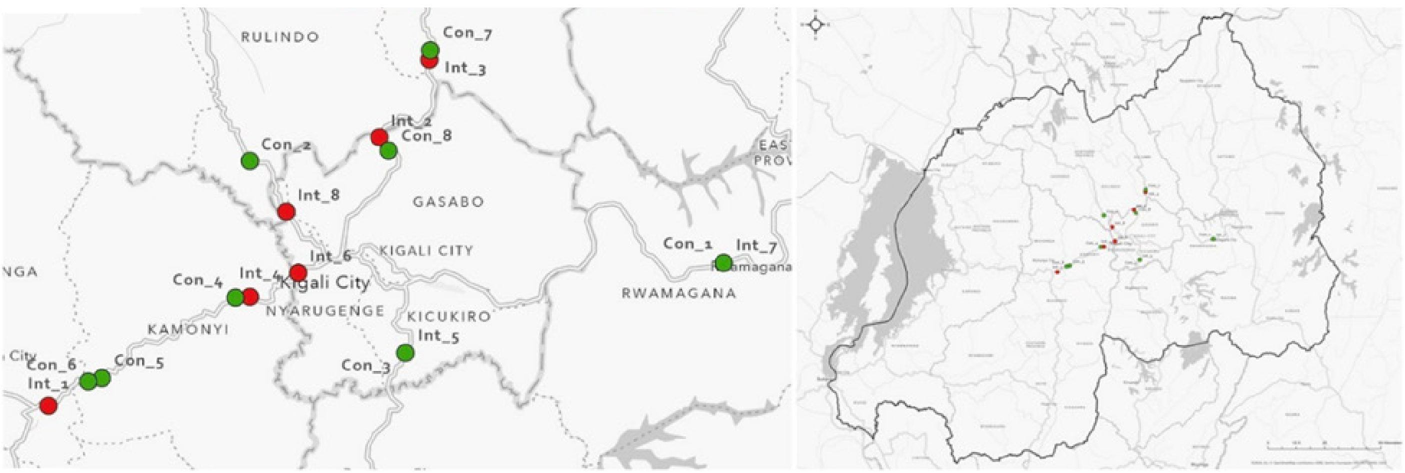
We collaborated with the RNP to select study site locations with the aim of having at least four control sites and four exposure sites. We use the term case and exposure site interchangeably. We utilized the RNP's database and knowledge of locations of overt cameras (termed 'fixed ASE units') for the study. The terms 'fixed camera' and 'overt camera' are interchangeably in this report. Next, we worked collaboratively with the police to select matched locations for control sites. We aimed to match locations on the criteria described in Table 4 including enforcement, land use, and traffic patterns. The study site selection was facilitated by the expertise and experience of the RNP. Prior to ASE implementation, they conducted a national survey of sites suitable for ASE units. Findings on suitable locations were leveraged for this study. In total, we initially identified a higher number of case and control locations (24), but ultimately only were able to collect and receive data for 16 locations (8 cases, 8 controls) which were similar on matching criteria.

Table 4 | Matching criteria for site selection

Criteria for site selection
Similar frequency and type of enforcement (i.e., number of RNP officers, signs)
Similar quality of roads
Similar speed limits and trends
Similar road design (e.g., width, shoulders, divided, shoulders)
Similar road use in terms of vehicle volumes and types
Similar road conditions (i.e., slopes, intersections, curves)
Similar land use patterns (i.e., residential, commercial

In Figure 19 we present a map of all the study sites, and in Table 5, we present descriptions of each site. Most sites were on national roads to and from the capital of Kigali, 65% (n=11) of sites were on 60 km/hr road. Most sites were on two-lane roads except for case and control six, which took place on a six-lane road. Most of sites were on a flat stretch of road, followed by a sloped stretch of road.

Figure 19 | Mapped Case (Int_X) & Control (Con_X Sites of Data Collection



At Con_1 & Int_7 as well as Int_5 & Con_3 you see only the green marker obscuring the red marker of the case site underneath it. Scan the QR Code or visit https://bit.ly/hpr-experiment-sites to download the KLM file or view site data embedded in Google Maps.

Table 5 | Data collection site information

Mapped Site	Road name	Camera ID	Natl. Road #	Speed limit (km/hr)	Road type	# of Lanes	Long A	Lat A	Date & Time
Case Sites – overt ASE camera and speed data collection device									
Int_1	Muhanga – Ruhango	MUHA26	1	60	Flat	2	-2.07802	29.77432	10 Feb 14:00-14:56
Int_2	Marembe - Nyacyonga	GASA05	3	60	Flat	2	-1.83037	30.07893	14 Feb 10:42-12:17
Int_3	Rwafandi – Gaseke	GICU15	3	60	Curve	2	-1.75891	30.12492	14 Feb 13:13 -14:18
Int_4	Kamonyi-Kigali	KAMO11	1	60	Slope	2	-1.9775	29.95985	14 Feb 16:05 -17:17
Int_5	Gahanga - Nyanza	KICU05	5	60	Flat	6	-2.02918	30.10296	15 Feb 15:42-16:44
Int_6	Kigali-Kamonyi	NYAR04	1	80	Flat	2	-1.95524	30.00446	10 Feb 17:25-17:48
Int_7	Mwurire-Gishali	RWAM08	3	80	Flat	2	-1.94606	30.39566	15 Feb 11:37-12:36
Int_8	Nyarugenge-Rulindo	NYARA03	4	80	Slope	2	-1.8989	29.99325	8 Feb 17:42-18:24
Control Sites – covert speed data collection device									
Con_1	Mwurire-Gishali	RWAM07	3	80	Flat	2	-1.94606	30.39562	8 Feb 12:10-12:59
Con_2	Rulindo-Gakenke	RULI17	4	80	Flat	2	-1.85205	29.95966	8 Feb 15:55-16:57
Con_3	Gahanga - Nyanza	KICU05	5	60	Flat	6	-2.02902	30.10296	9 Feb 16:32-17:11
Con_4	Kamonyi-Kigali	KAMO11	1	60	Slope	2	-1.97804	29.94624	9 Feb 14:12-15:35
Con_5	Kamonyi -Muhanga	KAMO01	1	80	Curve	2	-2.05224	29.82326	10 Feb 12:53-13:32
Con_6	Kamonyi -Muhanga	KAMO01	1	60	Flat	2	-2.05539	29.81077	10 Feb 11:03-12:54
Con_7	Rwafandi – Gaseke	GICU15	3	60	Curve	2	-1.74992	30.12588	7 Feb 12:04 -13:09
Con_8	Marembe - Nyacyonga	GASA05	3	60	Flat	2	-1.84265	30.08743	7 Feb 15:53-17:09
A - Geocoordinates are for World Geodetic System 1983.									

Data collection

The fixed ASE units were installed prior to the study. To prevent disruption of routine enforcement, we set up speed data collection devices to collect speed data (termed ‘speed data collection devices’ herein) either near the existing fixed speed camera for the case locations or hidden discretely for the control locations. For the case locations, we ensured that speed data collection devices were placed with the camera facing in the same direction as existing units and less than 35 meters away from it. This distance was recommended by the police who were concerned about having the data collection device directly adjacent to the fixed ASE would give people the impression that perhaps that camera was broken and that could change driver behavior. Police have estimated that within 50 m the ASE devices can accurately detect speeds and capture a photo for citation issuance to both oncoming and driving away vehicle.

Figure 20 | Data collection site examples

Each speed data collection device data collection device in case and control locations were set up no more than six meters lateral to the nearby lane to meet the equipment’s requirements to accurately collect data. Two RNP personnel, including a camera operator and a high-ranking officer, and one HPR research staff member, were present for installation and data collection. Figure 20 demonstrates some methods of placing speed data collection devices at case and control sites. At times it was difficult to meet all the requirements of case and control site data collection due to lack of foliage or other structures that could conceal the device but also allow a clear view of the road to capture data, we will explore this challenge and the implications more in the discussion.

To collect data on each vehicle that drove past the camera, rather than only those which violated the speed limit, the cameras were calibrated to collect data on any vehicle traveling 22 kilometres (km) per hour (hr) or above. During data collection, the camera operator and RNP officer hid to not introduce bias to the study given drivers may behave differently in the presence of RNP officials. Data was collected for approximately an hour, the time required for an estimated 200 vehicles to pass the data collection device. The intention of collecting 200 or more vehicle data points was that it would ensure we met recommended sample size requirements to detect a significant difference in speed data (e.g. 2,000 or more vehicles in total, 500 or more in each strata) (38). To minimize the impact of traffic congestion on drivers' behaviour, we tried to avoid collecting data during the busiest times of the day (e.g., mornings and evenings when people are driving to or from work or school). We collected several variables on the location, vehicle, and speed from each device, which is listed in Table 6. In addition to the data collected by the cameras, the research staff collected detailed notes on each location.

Table 6 | Variables collected by ASE cameras in case and control locations

Vehicle-level data	Location-level data
Unique case ID	Speed camera device ID
Plate registration number	Address
Country of registration	Geocoordinates
Day/time	Speed limit
Type of vehicle	
Measured speed	

Outcomes

The primary study outcome was the mean speed of vehicles traveling past speed data collection sites compared to overt cameras. Secondary outcomes included ASE violations, which are defined as going equal to or above 10% of the speed limit (e.g., 66 km/hr in a 60 km speed limit zone), and any exceeding of the speed limit (e.g., equal to or over 61 km/hr in a 60 km speed limit zone).

Data processing and statistical analysis

Once data were collected it was cleaned and processed to meet the analysis requirements. First, we developed variables for the secondary outcomes (violations, exceeding the speed limit). In 60 km/hr zones, violations were any vehicles traveling >=66 km/hour and exceeding the speed limit was any vehicle traveling >60 km/hour. In 80 km/hr zones, violations were defined as any vehicles driving >=88 km/hour whereas exceeding the speed limit was defined as any vehicle traveling >80 km/hour.

We organized vehicle types into four categories: 1) cars, jeeps, and trucks; 2) motorcycles; 3) commercial trucks and heavy goods vehicles; 4) commercial transport vehicles (buses, minibuses). The ASE system currently categorizes the captured vehicles into three categories namely: Motorcycles, Car and lorry. The Car category includes small vans, SUVs, jeeps and minibuses while buses and trucks are in the lorry category. For this study, the RNP provided more detailed categories to determine which vehicles may have a speed governor. Types of cars were manually recorded as follows: Car (Sedan cars), Jeep, Pick-up, Minibus, Coaster, Bus, Medium tuck, Semi-trailer, Dyna, Daihatsu, truck trailer, and truck. For analysis, we organized vehicle types into four categories: 1) cars, jeeps, and trucks; 2) motorcycles; 3) commercial trucks and heavy goods vehicles; 4) commercial transport vehicles (buses, minibuses). We added an additional variable to determine if vehicles are speed governed. This is relevant in Rwanda which has a national speed governor policy. In 2016, all commercial vehicles, including those used for transporting goods and people, have devices that limit their speed to 60 km/hour (22). Although we did not intend to collect data while the roads were busy, some data collection took longer than an hour in the afternoon, extending into rush hour. We developed a category 'afternoon rush hour', defined as between 17:00-19:00 hours for the analysis.

We report descriptive statistics for all vehicles, passenger vehicles, motorcycles, commercial or heavy-duty goods vehicles, and commercial public transport vehicles. We present the mean speed, the 85th percentile of speed (intended to measure how vehicles behave when free flowing, unrestricted by a vehicle in front of them), the number of violations, and the number of vehicles exceeding the limit in each category. We conducted an analysis of variance (ANOVA) test to assess significant differences in mean speed between groups, and chi-squared tests to assess group differences in the number of vehicles violating the speed limit and exceeding the speed limit. Lastly, we conduct multivariate analyses to assess variables associated with the outcomes. We fit a linear regression to assess mean speed, and logistic regressions for the violation and exceeding speed outcomes. To understand the impact on each vehicle type (i.e., motorcycle, commercial goods, commercial public transport), we conducted separate regressions for each group if counts were sufficient. All analyses were conducted in R 4.1.3.

Results

In the following section, we present descriptive statistics by vehicle type and inferential statistics to assess the difference in speed outcomes between case and control sites. We conduct this analysis for all vehicles, cars, motorcycles, commercial truck or heavy goods vehicles, and commercial public transport vehicles.

Table 7 | Descriptive statistics for vehicles in the study

Variable	All vehicles (n=3,590)	Cars (n=1,564)	Motorcycle (n=1,136)	Commercial heavy goods vehicle (n=356)	Commercial public transport vehicle (n=534)
	N (%)	N (%)	N (%)	N (%)	N (%)
Site type					
Cases	1,901 (53)	743 (48)	758 (67)	173 (49)	227 (43)
Controls	1,689 (47)	821 (53)	378 (33)	183 (51)	307 (57)
Day of data collection					
Tuesday	1,068 (30)	580 (37)	262 (23)	141 (40)	152 (28)
Wednesday	888 (25)	333 (31)	197 (17)	129 (36)	162 (36)
Thursday	441 (12)	190 (12)	182 (16)	17 (5)	52 (10)
Friday	1,193 (33)	461 (29)	495 (44)	69 (19)	168 (32)
Speed limit at site					
60 km/hr	2,366 (66)	1,031 (66)	784 (69)	208 (58)	343 (64)
80 km/hr	1,224 (34)	533 (34)	352 (31)	148 (42)	191 (36)
Afternoon rush hour					
1700-1900	676 (19)	256 (16)	277 (24)	53 (15)	90 (17)
Time of day					
Morning	366 (10)	177 (11)	66 (6)	47 (13)	76 (14)
Afternoon	3,224 (90)	1,387 (89)	1,070 (94)	309 (87)	458 (86)

Descriptive results by vehicle type

We present descriptive results A total of 3,590 vehicles were included in this study. Of these, 1,564 were cars, 1,136 were motorcycles, 356 were commercial trucks, and 534 were commercial public transport vehicles. Most data were collected in 60 km/hr speed limit zones. About 25% or less of the total data was collected during afternoon rush hour for total and each individual vehicle type. Most data were collected on Tuesdays, Wednesdays, and Fridays, with a small amount collected on Thursdays, and no data collection taking place on Mondays or the weekend. Most data (62-84% depending on vehicle type) was collected in the afternoon.

When assessing speed outcomes (presented in Table 16), we found that the highest mean speed was among cars (50.7 km/hr), followed by commercial public transport vehicles (49.1 km/hr). The 85th percentile of speed was also highest among cars (61 km/hr) compared to a low of 53 km/hr for motorcycles. Nearly all violations (103 of 130) were committed by cars. About 7% (n=51) of total cars got violations, compared to 1% or lower of all other vehicle types. When looking at the number of vehicles exceeding the speed limit by any amount, we found similar trends; an estimated 163 cars exceeded the speed limit (11% of total cars), compared to 35 motorcycles (3%), 5 commercial trucks (1%), and 6 commercial public transport vehicles (1%). We found statistically significant differences in mean speed, the number of vehicles violating the speed limit, and the number of vehicles exceeding the speed limit between vehicle groups.

Table 8 | Speed outcomes by vehicle types

Speed outcome	All vehicles (n=3,590)	Cars (n=1,564)	Motorcycle (n=1,136)	Commercial truck or heavy goods vehicle (n=356)	Commercial public transport vehicle (n=534)	Difference between groups
Mean speed (km/hr)	47.8 km/hr	50.7 km/hr	44.4 km/hr	45.6 km/hr	49.1 km/hr	F statistic: 38.22 p-value = 7.04e-10
85th % of speed	56 km/hr	61 km/hr	53 km/hr	53 km/hr	55 km/hr	-
Violations (>10% limit)	N=120 (3%)	N=103 (7%)	N=13 (1%)	N=2 (0%)	N=2 (0%)	X2 =90.984 p-value = 2.2 e-16
Any excess of speed limit	N=214 (6%)	N=168 (11%)	N=35 (3%)	N=5 (1%)	N=6 (1%)	X2=116.05 p-value = 2.2 e-16
For mean speed, we conducted an ANOVA. For the number of vehicles violating and exceeding the speed limit, we conducted a Pearson chi-squared test. Neither of these tests are recommended to assess statistically significant differences in percentiles (e.g., the 85th percentile).						

Inferential results by exposure status

In the next section, we present results for our primary research question on the effect of ASE fixed cameras versus control (no camera). We present detailed findings for mean speed, 85th percentile speed, violations, and exceeding the speed limit for cases and controls for all vehicle types in Table 17. Overall, the mean speed of cases was 45.7 km/hr compared to 51.0 for control sites. The 85th speed percentile was lower (56 km/hr) in cases compared to controls (60 km/hr). This is particularly striking for cars (case 85th percentile: 55, compared to control: 66, a 17% decrease). This indicates that the ASE cameras may bring the speeds down to below the posted limit. Similarly, there were substantially fewer violations (27 in cases versus 93 in controls), and fewer vehicles exceeding the speed limit by any amount (54 in cases versus 160 in controls). These differences were statistically significant.

When assessing these trends within each vehicle type, we found significant differences in the mean speed between cases and controls of cars, motorcycles, between cases and controls of commercial truck or heavy goods vehicles, and between cases and controls of commercial public transport vehicles. We also found significant differences with case and controls between the number of violations and number of vehicles exceeding the speed limit by any amount for cars and motorcycles. However, these trends did not hold for any type of commercial vehicle.

In the next section, we present multivariate linear regression results for mean speed among all vehicles, and each vehicle type (cars, motorcycles, commercial heavy goods, and commercial public transport) in Table 17.

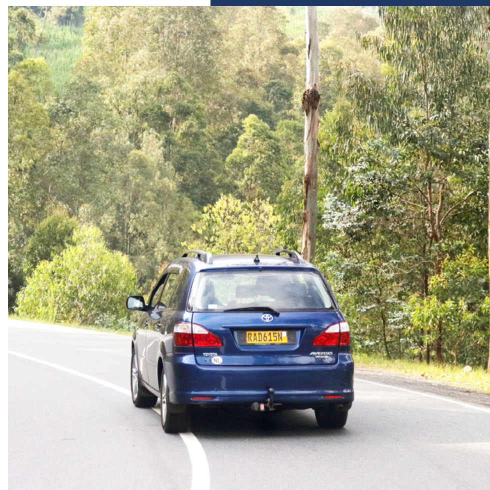
Table 9 | Mean speeds, 85th percentile speeds, number of vehicles violating the speed limit, and number of vehicles exceeding speed limit – group comparisons

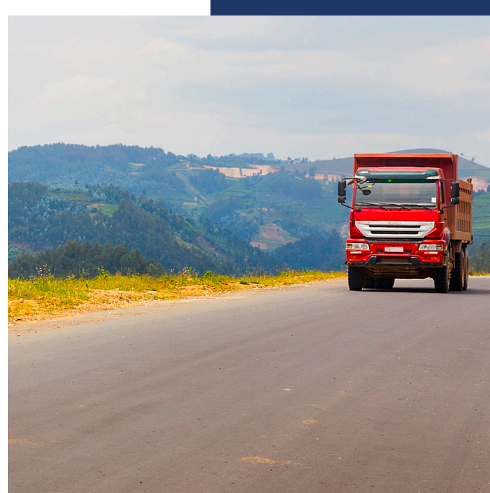
Vehicle type (n)	Site type (n)	Mean speed (km/hr)	85th % speed (km/hr)	>10% speed limit violations, n (%)	any excess of speed limit, n (%)
All vehicles (3,590)	Case (1,901)	45.7	56	27 (1)	54 (3)
	Control (1,689)	51.0	60	93 (6)	160 (10)
Difference between groups [A]		T=17.6, p=2.2e-16*, 95% CI=5.1-6.4	9.3% decrease	X^2=45.0, p=2.013e-11*	X^2=69.0, p=2.2e-16*
Cars (1,564)	Case (743)	47.4	55	23 (3)	41 (6)
	Control (821)	53.7	66	80 (10)	127 (15)
Difference between groups		T=11.9, p=2.2e-16*, 95% CI=5.2-7.3	17% decrease	X^2=27.0, p=2.0831e-07*	X^2=39.2, p=3.7e-10*
Motorcycle (1,136)	Case (758)	43.0	51	3 (0)	9 (1)
	Control (378)	47.1	57	10 (3)	26 (7)
Difference between groups		T=6.27, p=6.8e-10*, 95% CI=2.9-5.3	11% decrease	X^2=9.3, p=0.002*	X^2=25.5, p=4.5e-07*
Commercial heavy goods vehicle (356)	Case (173)	43.5	49	0 (0)	1 (0)
	Control (183)	47.9	55	2 (1)	4 (2)
Difference between groups		T=6.3, p=6.8e-10*, 95% CI=3.8-5.8	11%	X^2=1.5, p=1	X^2=0.7, p=0.4
Commercial public transport vehicle (534)	Case (227)	47.0	53	1 (0)	3 (1)
	Control (307)	50.6	56	1 (0)	3 (1)
Difference between groups		T=6.3, p=5.6e-10*, 95% CI=2.3-4.6	5%	X^2=0.5, p=0.51	X^2=4.6e28, p=1
A - For mean speed, we conducted a Welch Two Sample t-test. For the number of vehicles violating the speed limit and the number of vehicles exceeding the speed limit, we conducted Pearson's Chi-squared tests.					

Case sites were associated with a 5.64 km/hr reduction in mean speed (p<2e16) for all vehicles. Two other variables, afternoon hours (compared to morning hours) and a speed limit of 80 km/hr (compared to 60 km/hr), were significantly associated with a decrease in mean speed (-1.91 and -1.59 km/hr, respectively). Case locations, compared to control locations were associated with a significant decrease in speed for all vehicle types. This as most pronounced among cars (a decrease of 6.06 km/hr), followed by motorcycles (a decrease of 3.62 km per hour). Among motorcycles, two other variables (afternoon compared to morning, and afternoon rush hour compared to all other times) were significantly associated with mean speed. Holding all other variables constant, afternoon hours were associated with a decrease of 3.02 km/hr. Afternoon rush hour was associated with an increase of 2.27 km/hr of mean speed.

Table 10 | Linear regression results – mean speed

Variable	Estimate	p-value
All vehicles, N = 3,590		
Cases	1,901 (53)	743 (48)
Controls	1,689 (47)	821 (53)
Intercept	51.2 km/hr	
Case - Overt ASE Present	-5.64	2e-16*
Rush hour (1700-1900)	-0.03	0.94
Afternoon	-1.91	0.00*
Slope	-0.00	0.99
Curve	-0.40	0.55
Speed limit 80 km/hr	-1.59	3.4e-05*
Cars, N = 1,564		
Intercept	53.7 km/hr	
Case - Overt ASE Present	-6.06	2e-16*
Rush hour (1700-1900)	-1.50	0.07
Afternoon	-0.58	0.51
Slope	1.40	0.04
Curve	-1.63	0.12
Speed limit 80 km/hr	1.51	0.02
Motorcycles, N = 1,136		
Intercept	49.2 km/hr	
Case - Overt ASE Present	-4.72	2.1e-13*
Rush hour (1700-1900)	2.27	0.01*
Afternoon	-3.02	0.01*
Slope	-0.21	0.75
Curve	-0.04	0.98
Speed limit 80 km/hr	1.82	0.02*
Commercial heavy goods vehicles, N = 356		
Intercept	49.94 km/hr	
Case - Overt ASE Present	-3.62	1.5e-05*
Rush hour (1700-1900)	-1.22	0.31
Afternoon	-2.1	0.07
Slope	-1.79	0.06
Curve	-2.14	0.14
Speed limit 80 km/hr	0.40	0.62
Commercial public transport vehicles, N = 534		
Intercept	51.37 km/hr	
Case - Overt ASE Present	-2.94	3.2e-06*
Rush hour (1700-1900)	-1.19	0.17
Afternoon	-1.11	0.19
Slope	-0.32	0.63
Curve	0.76	0.44
Speed limit 80 km/hr	0.31	0.63





Next, we present multivariate logistic regression on predictors of violation status (defined as equal to or above 10% of the speed limit) among all vehicles and each vehicle type. We present detailed results in Table 11. Among all vehicles, the model suggests that case and speed limit are significantly associated with decreased log odds of violations. The odds of violation are 74% lower in cases compared to controls (Odds Ratio [OR]:0.26, p-value=3.9e-09). holding all other variables constant. The odds of a violation are 87% lower in an 80 km/hr zone compared to a 60 km/hr zone. We did not find any predictors which increased the odds of a violation among all vehicles.

When assessing the association between predictors and the odds of a violation for each vehicle type (Table 19), we find that case sites compared to control are associated with a 69% decrease in odds of a violation (OR: 0.31, p-value=2.0e-06) among cars, and 88% decreased odds among motorcycles (p-value=0.002). There were so few commercial heavy goods vehicles (2) or public transport vehicles (2) that exceeded the speed limits by >10% at case and control sites combined that we did not feel a regression analysis was appropriate for each group.

Lastly, we conducted a multivariate logistic regression to assess predictors of exceeding the speed limit, defined as a vehicle driving above the speed limit (e.g., >60 km/hr or >80 km/hr depending on the sites) among all vehicles and each individual vehicle type. We present detailed results in Table 12. There were so few commercial heavy goods vehicles (5) or public transport vehicles (6) that exceeded the speed limits at case and control sites combined that we did not feel a regression analysis was appropriate for that group. Among all vehicles, the model suggests that case sites were associated with 71% decreased odds of exceeding the speed limit, when compared to control sites, holding all other variables constant (OR: 0.29, p=1.5e-13). A road with a slope compared to a flat road with no slope decreased the odds of exceeding the speed limit by 73% (OR: 0.27, p-value=5.06e-07). A speed limit increase to 80 km/hr compared to 60 km/hr, holding all other variables constant, was associated with 87% decreased odds of exceeding the speed limit by any amount. For individual vehicle types, we found significant associations between case, slope, and speed-limit for cars, and between case and slope for motorcycles.

Table 11 | Logistic regression – equal to or above 10% speed limit violations

Variable	Estimate	p-value	Odds ratio
All vehicles, N = 3,590			
Intercept	-2.04	-	-
Case - Overt ASE	-1.33	3.9e-09*	0.26
Rush hour (1700-1900)	-1.11	0.06	0.32
Afternoon	-0.23	0.32	0.79
Slope	-1.03	0.0	0.36
Curve	-0.77	0.14	0.46
Speed limit 80 km/hr	-2.10	9.3e-07*	0.13
Cars, N = 1,564			
Intercept	53.7 km/hr		
Case - Overt ASE Present	-6.06	2e-16*	0.31
Rush hour (1700-1900)	-1.50	0.07	0.22
Afternoon	-0.58	0.51	0.77
Slope	1.40	0.04	0.74
Curve	-1.63	0.12	0.52
Speed limit 80 km/hr	1.51	0.02	0.14
Motorcycles, N = 1,136			
Intercept	-2.26	-	-
Case - Overt ASE Present	-2.14	0.002*	0.12
Rush hour (1700-1900)	-0.14	0.89	0.86
Afternoon	-0.37	0.61	0.69
Slope	-19.07	0.99	<0.00
Curve	-16.87	0.99	<0.00
Speed limit 80 km/hr	-18.38	0.99	<0.00
Too few commercial heavy goods vehicles (2) & public transport vehicles (2) exceeded the speed limits by >10% at case and control sites combined for a regression analysis			

Table 12 | Logistic regression – any excess of speed limit

Variable	Estimate	p-value	Odds ratio
All vehicles, N = 3,590			
Intercept	-1.43	-	-
Case - Overt ASE	-1.23	1.5e-13*	0.29
Rush hour (1700-1900)	-1.49	0.004*	0.22
Afternoon	-0.19	0.28	0.81
Slope	-1.29	5.06e-07*	0.27
Curve	-0.88	0.03*	0.41
Speed limit 80 km/hr	-2.00	6.46e-11*	0.13
Cars, N = 1,564			
Intercept	-0.97	-	-
Case - Overt ASE Present	-1.12	7.75e09*	0.32
Rush hour (1700-1900)	-1.67	0.005*	0.19
Afternoon	-0.19	0.37	0.82
Slope	-0.55	0.047*	0.57
Curve	-0.68	0.098	0.50
Speed limit 80 km/hr	-1.87	1.03e-08*	0.15
Motorcycles, N = 1,136			
Intercept	-0.83	-	-
Case - Overt ASE Present	-2.06	5.61e-07*	0.13
Rush hour (1700-1900)	-1.22	0.24	0.29
Afternoon	-0.84	0.06	0.42
Slope	-3.34	0.001*	0.03
Curve	-14.75	0.99	<0.00
Speed limit 80 km/hr	-2.63	0.011	0.07
Too few commercial heavy goods vehicles (5) & public transport vehicles (6) exceeded the speed limits at case and control sites combined for a regression analysis			

Discussion

This study aimed to assess the impact of ASE through overt speed cameras versus no camera (i.e., only a hidden speed collection device) on speeding outcomes including the mean speed, the number of official violations over the 10% threshold, and any exceeding of the speed limit on national roads in Rwanda. We also aimed to describe speed distribution of vehicles in a low-income country. In doing so, our most important finding was that there was a significant decrease in mean speeds for all vehicles and each vehicle type in case (overt camera) versus no camera locations, indicating that ASE may be positively affecting road user behaviour and leading to decreased speeds in these localized areas. We found similar significant differences between case and control sites for all vehicles, all cars, and all motorcycles for two additional speed outcomes: violating the speed limit and exceeding the speed limit. Second, we were able to understand and compare mean speeds and 85th percentile speeds between vehicle types, and between cases and controls overall and within each vehicle. We found the highest mean speed was among cars, followed by commercial public transport vehicles. The 85th percentile of speeds followed similar trends. Cars were responsible for most ASE violations, although the vast majority were in control sites where overt ASE was not present. It is interesting that the mean speeds travelled by most vehicles even at control sites are >10% lower than the speed limit of 60 km/hr and in the areas where the limit was increased to 80 km/hr among all vehicles they drove even slower on average but even those who drove faster as one might expect only increased by a few km/hr.

When placing these findings in the context of existing literature, we find similarities despite nearly all studies taking place in high resource settings. In a recent systematic review (37) of ASE, 23 included studies assessed the impact of ASE on average vehicle speeds. Most studies found that ASE reduced mean and 85th percentile speed and mean speeds by up to a third (37). Among cars, our study found that ASE may have led to a 17% decrease in mean speeds, when compared to sites without an ASE camera. Other studies also found that ASE lead to reductions in vehicles violating or exceeding the posted speed limits (39, 40). Our finding on the local effect of overt cameras is similar to another study in New Zealand, which found that visible cameras led to reductions in speeds and crashes in the immediate speed camera areas (which included signs), but may not have larger effects on the road network (32).

This raises a complexity associated with our finding. Although it may be expected that drivers would behave differently (i.e., drive slower) in areas with a visible ASE system, an alternative hypothesis may have been that speeds are similar across all settings in Rwanda. This alternative hypothesis acknowledges features of the context, including the ubiquity of ASE systems (i.e., over 400 nationally), high public awareness, the substantial violation fine amount (i.e., $25 USD), and that warning signs are not posted before cameras. Such features may indicate that drivers would behave and drive similarly in the absence or presence of overt cameras for fear of the penalties. However, our findings did not show this. Rather, the findings demonstrated significant localized effects of fixed overt ASE units on speed. This raises the question of how to reach broader compliance with speed measures to extend the benefits beyond localized settings. Rwanda elected not to post signage specifically warning of ASE ahead, considering signs to mark the speed limit at that site within one km of the camera to be a surrogate for ASE signage. Additionally, police relayed their perception that avoiding signage and clearly documentation of ASE locations would make the devices more effective at reducing speeds diffusely across the road network of the country and making a greater impact on reduction of road traffic crashes and injuries. In Rwanda mapping services like Waze will commonly indicate a speed camera up ahead. An additional confounder may be that a convenience sample of Rwandans who drive frequently reported that a system of hand signals, flashing of headlights and turn signals are widely recognized and utilized while driving to warn other drivers of hazards such as ASE. A keyword search for the independent terms 'drivers signal each other warning' in Google scholar on May 9, 2023 produced 310,000 and review of the titles and abstracts returned in the first 100 results did not describe anything similar to the hand and light signals drivers make to each other in Rwanda. The impacts of ASE signage is inconsistently reported in the literature from other contexts and Rwanda's decision to forgo signs make this contribution to the literature especially interesting.

Limitations

There are a few notable limitations of this work. First, there were some data collection challenges including questionable accuracy of obtained geocoordinates and limited documentation of the data collection process. On the first, while cleaning and processing data, we found some inconsistencies between the stated methods for site selection and set up and documentation of the sites. For example, we noticed the first problem in visualization of the mapped geo locations of two different controls and cases were located within less than a few meters of each other as pictured in Figure 21. If these coordinates were accurate, we would have induced observation bias in the control data from these two sites being adjacent to the overt (e.g., fixed gray and black ASE cameras in the image) that would be present at the case sites. The data collectors disputed the finding and reported that they distinctly recall the characteristics of the control sites being far removed from the case site. However, we did not obtain any photos to verify this. We discussed the method of obtaining the geocoordinates for each control site and found that the data collectors had opened a mapping program and dropped a location pin at the location using a mobile phone. The data collectors do not recall any measure of the accuracy of the location estimation, so we suspect that this is the cause of the nearly identical coordinates between cases and controls. However, it is not impossible to be certain given a lack of photos of the covert data collection device for this site.

Figure 21 | Adjacent case (Int_X) and control (Con_X) sites of data collection

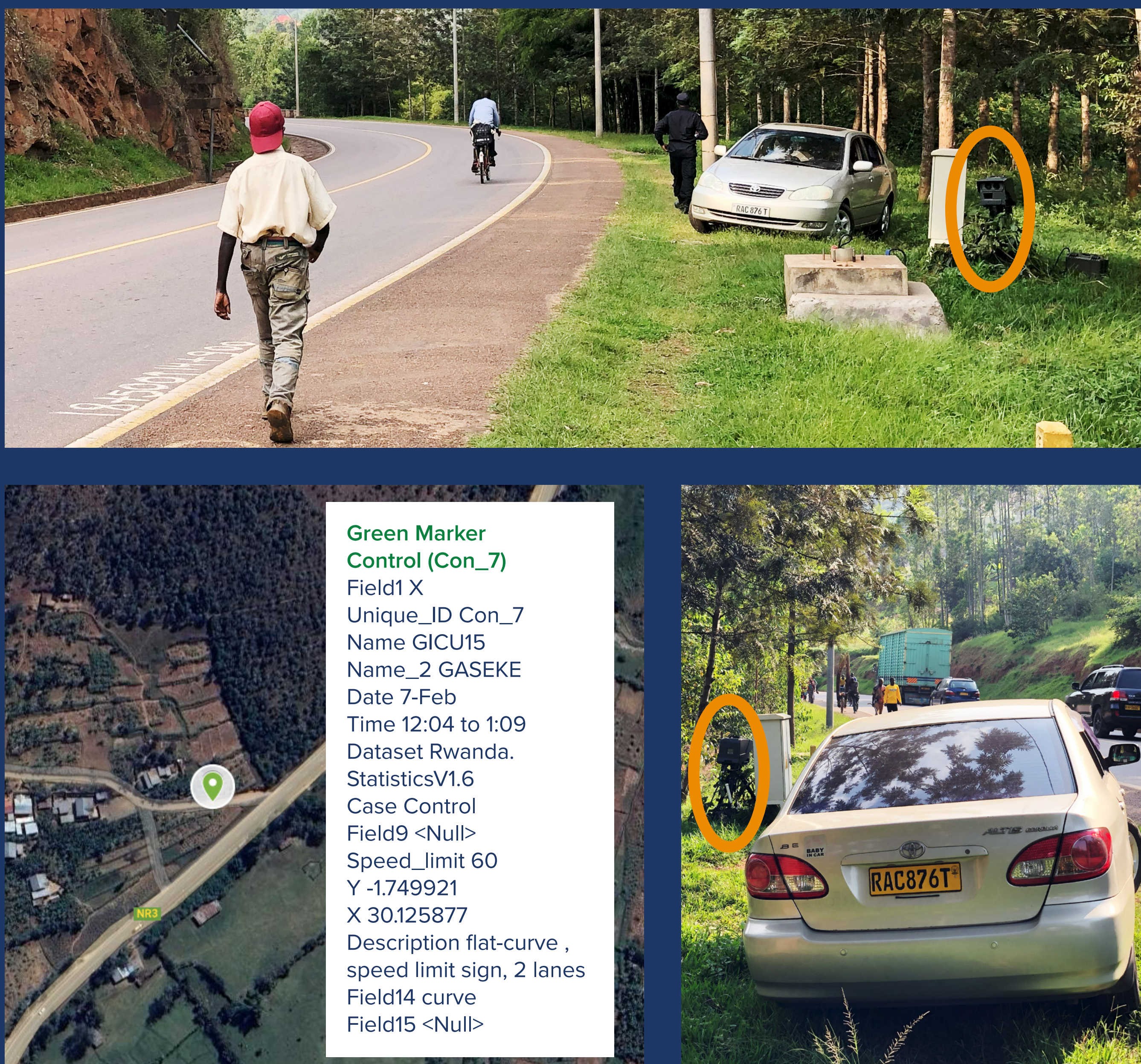
Orange Marker | Case (Int_X)   Blue Marker | Control (Con_X)

In terms of the limited data collection documentation, we identified another cause for some uncertainty in our dataset, as one of the data collection photos indicates that at a control site there was no way to conceal the speed detection device from motorists in one direction on the road as pictured in Figure 21. The data collector explained that the curve of the road made them believe that even though the device could not be fully concealed the vehicles who saw it would not be able to slow down in response. Upon checking the map, we found the geocoordinates associated with the assigned coordinates to be in a clearly different place with minimal curves and off the main road entirely as shown. It seems more possible that we could have induced observation bias in at least one direction of motorists that were captured at this site. Unfortunately, not all sites were photographed during data collection, and it appears more likely from these photos that the dropped pin technique for determining the geocoordinates had limitations. We would recommend greater documentation (including images), and more reliable devices for obtaining coordinates in future work. We do not suspect that either of these limitations substantially affected the results or interpretation of the findings.

Secondly, we were not able to conduct a pre-post study before the ASE camera units were installed. Without data on the baseline speed outcomes, it is impossible to comment on casualty in this study or confidently state that the cameras affect speed. However, we work closely with the RNP, the implementers of ASE, to select locations which were matched on road types, speed limits, and enforcement to be able to compare vehicle speeds across case and control sites. Additionally, we conducted multivariable regression analyses to account for any potential differences in the outcomes due to other factors (e.g., a sloped road, speed limit).

Thirdly, our analysis was limited geographically to national roads within and near Kigali city (within approximately 50 kilometres), limiting our ability to generalize these findings beyond those areas. Lastly, we had sought to match the locations and the data collection procedures (e.g., the time and day of week) as part of this study. However, due to limitations of RNP staff time and equipment, we were not able to do so. Instead, we have chosen to be transparent about how and when data was collected and where these results are derived from.

Figure 22 | Images of data collection device placement control (Con_7) site of data collection



Recommendations

To conclude, we end with a couple of recommendations for researchers and implementers in Rwanda and beyond. Overall, this study expands the literature on the impacts of ASE on speeding outcomes and demonstrates the utility of ASE as a tool for speed management in LMICs. However, given the limitations of this study, we would recommend that other studies assess the impact of ASE with more rigorous study designs. Specifically, we would recommend studies include an assessment of the effects spatially and temporally. We would highly recommend that speed, crash, and injury data is collected prior to implementation of ASE to establish baseline trends. Relatedly, we would recommend the use of geospatial data on crashes and injuries to understand if mean speeds, number of violations, and number of vehicles exceeding the speed limit affects road safety outcomes in LMICs.

Secondly, for implementers, as is demonstrated in this study, ASE shows potential in reducing excessive speeding. However, our study cannot definitively state if ASE has reduced adverse outcomes of speeding or associated crashes or injuries, either locally or to larger geographies. There may be potential ways in which to improve compliance with speed limits or reduce speed-related crashes, injuries, and deaths in the country. This could include updates to the existing program (e.g., making cameras hidden and putting warning signs about these, as has been done in New Zealand) (28). It could also include improving existing speed management tools and implementing new ones. Examples could include engineering treatments to slow down motor vehicles and separate road users, change behaviour through campaigns, and implement speed zones/limits by functions (41).

Conclusion

Overall, we would conclude that ASE is an important and potentially effective tool but is not a single solution to the problem. Rather, there is a need for a comprehensive set of speed management activities to be implemented and evaluated to generate evidence for Rwanda and other LMICs.

A National Survey to Understand the Public Perception of Automated Speed Enforcement and Road Safety in Rwanda

Methods

Objective

To the best of our knowledge, there have been no public perception studies on ASE in Africa and research on ASE more broadly is limited in Africa and other LMICs. As Rwanda is the first low-income country in Africa to implement ASE on a national scale, there is an opportunity to address this research gap. Our overall objective is to measure the public's experience, views, and perceptions on ASE and road safety in Rwanda. Such data are critical for informing and improving the initiative in Rwanda and in other countries interested in pursuing ASE.

Overall study description

This study included a representative survey to understand the public's perception of ASE and road safety in Rwanda. Data was collected in December of 2022 and analyzed in early 2023.

Survey tool development

Quantitative surveys with two simple qualitative questions were conducted via in person interviews to gain insight into the perceptions of people and road users on the implementation of ASE, the complete tool is available upon request. The questionnaire was designed by HPR staff, based on the results of our evaluation of the design and implementation processes used to create the Rwandan ASE program as detailed in the complimentary first report written by our team; "Design and Implementation of Automated Speed Enforcement in Rwanda". We added some other questions adapted from comparable studies of public perceptions of road safety and ASE in other contexts and adapted to the Rwandan context. A bilingual HPR team member translated the tool into Kinyarwanda, and then a separate HPR team member back-translated to English and this was reviewed against the original English by a native speaker and the process was repeated until consensus of satisfactory translation was achieved. Both English and Kinyarwanda versions were available for use by the data collection and analysis teams. The questionnaire was finalised in October 2022 apart from slight additional refinement after piloting in December 2022.

Setting, sampling frame, randomization, and recruitment processes

Rwanda is a low-income country in East Africa with a population of 13.2 million. The country is organised into four provinces (Northern, Western, Southern, Eastern) and the City of Kigali, 30 districts, 416 sectors, 2,148 cells, and 14,837 villages. Data collection proceeded from December 6-22, 2022.

For the general population, the sampling frame was the 2012 Population and Housing Census, conducted by the National Institute of Statistics of Rwanda in 2012 (PHC2012) (42). This frame was used to sample 1,200 representative respondents in terms of age and sex. The formulas used to determine the required sample sizes for the general population and complete details of the sampling frame recruitment are available in the Supplementary Materials.

This evaluation was conducted in 13 districts in the four provinces and the City of Kigali. Ten districts from the four provinces were selected using a simple random sampling technique where each had an equal probability of selection. All districts in the City of Kigali were included in the sample because Kigali practically represents a unique road user experience in Rwanda based on the consensus of our research team. Within each district, villages were randomly selected and based on the populations of those villages the number of households we needed to collect data from was determined in order for our study cohort to be representative of the entire Rwandan population. The complete list of randomly selected villages is included in the Supplementary Materials.

The survey was designed for road users from the general population and drivers aged >17 years living in randomly selected villages. Throughout this report we refer to different strata of this population based on their recruitment as members of randomly selected households that approximates a nationally representative sample based on the 2012 National Census sampling frame, drivers of any vehicle besides exclusively motorcycles, and drivers that primarily drove only as motorcyclists. A convenience sample of drivers and motorcyclists were purposively selected by the enumerators who did so by convening at the village centre (the same randomly selected village where households were recruited) and approaching the first drivers and motorcyclists they encountered and inviting them to respond to the survey.

However, some household respondents were also drivers and motorcyclists per their reported history of driving. Therefore, we categorised respondents into three groups 1) household non-drivers, 2) vehicle drivers, and 3) motorcyclists. Which stratification composition used in different analyses is indicated in our results.

Ethical clearance and authorizations

The study was approved and facilitated by the Rwanda National Ethics Committee, the Rwanda National Police, the Ministry of Infrastructure, the National Institute of Statistics Rwanda, and the Ministry of Local Government.

Data collection

Enumerators were trained in the use of CSpro and tablet devices, the sampling processes and survey techniques. The results of piloting and further review by enumerators who would collect data with the tool led to some changes incorporated into the final version of the questionnaire. From December 6-22, 2022 data collection was performed by enumerators and their team leaders among the randomly selected villages. Before accessing households' data collection teams visited the local government offices and were personally introduced by a village leader once authorization was obtained. The survey was conducted in Kinyarwanda after obtaining consent from the respondent. Respondents under the age of 18 years and those refusing consent were excluded. Screening questions were used to classify respondents based on their knowledge of ASE in Rwanda, and those specific questions were deferred though demographic and road safety perceptions were asked about. Enumerators reported back to the team leads who checked the data quality daily. In the **Supplementary Materials**, we share excerpts from a report written by an HPR staff member who played an instrumental role in the data collection process that summarises feedback from enumerators and the rest of the data collection team members.

Figure 23 | Age / sex distribution in Rwanda (2022)

Specific age group	Population			Percentage		
	Both sexes	Male	Female	Both sexes	Male	Female
Total Resident Population	**13,246,394**	**6,429,326**	**6,817,068**	**100**	**48.5**	**51.5**
<1	339,900	170,246	169,654	2.6	1.3	1.3
<5	1,708,460	856,228	852,232	12.9	6.5	6.4
1-4	1,368,560	685,982	682,578	10.3	5.2	5.2
3-5	1,071,139	536,957	534,182	8.1	4.1	4.0
3-6	1,425,212	713,927	711,285	10.8	5.4	5.4
0-15	5,270,262	2,637,972	2,632,290	39.8	19.9	19.9
0-17	5,896,601	2,949,970	2,946,631	44.5	22.3	22.2
6-11	1,937,762	970,363	967,399	14.6	7.3	7.3
7-12	1,894,300	948,050	946,250	14.3	7.2	7.1
12-17	1,886,896	940,635	946,261	14.2	7.1	7.1
13-18	1,868,015	931,523	936,492	14.1	7.0	7.1
14+	8,619,109	4,111,820	4,507,289	65.1	31.0	34.0
14-35	5,153,898	2,536,585	2,617,313	38.9	19.1	19.8
16-30	3,595,670	1,767,063	1,828,607	27.1	13.3	13.8
15-24	2,683,890	1,322,706	1,361,184	20.3	10.0	10.3
16-24	2,370,440	1,166,123	1,204,317	17.9	8.8	9.1
15-49	6,716,136	3,270,471	3,445,665	50.7	24.7	26.0
16-64	7,424,204	3,571,680	3,852,524	56.0	27.0	29.1
16+	7,976,132	3,791,354	4,184,778	60.2	28.6	31.6
18+	7,349,793	3,479,356	3,870,437	55.5	26.3	29.2
21+	6,492,924	3,056,093	3,436,831	49.0	23.1	25.9
60+	862,929	356,467	506,462	6.5	2.7	3.8
65+	551,928	219,674	332,254	4.2	1.7	2.5

Source: Fifth Rwanda Population and Housing Census, 2022 (NISR)

Variable categorization and statistical analysis

At the time of this research design the 2012 census results were the most recent available from which to weight our sample and derive a nationally representative sampled population. To assure we had sufficient numbers, we aimed to recruit equal numbers of men and women; 42% aged 18-34, 42% aged 35-64 and 16% >65 years old. Very recently the 2022 census results were released with a slight predominance of females and new categorization of ages such as youth being designated as <30 years old compared to <35 years previously. Therefore, we shifted our age categories to reflect these changes made in light of greater life expectancy of the Rwandan population. We elected not to apply weights to the results within this report as originally planned given that the particular questions analysed here reflect the singular respondent and not the household.

Another independent variable we transformed included the categorization of urban and rural populations. In the 2012 census the following definition of an urban area was applied "The 2012 General Population and Housing Census defined an urban area based on the smallest administrative entity, the village (Umudugudu). To qualify as urban, a village must fulfil two main criteria of possessing: (1) an important built-up area and (2) important infrastructures (education facilities, electricity and water, markets, banks and other financial institutions)." We decided to apply this to our total population to create three strata that practically represented most accurately different road user experiences (and therefore potentially interesting contrasts between the responses of different types of road users) including urban Kigali, everywhere else in the country that met that definition of urban and rural populations in any of the provinces.

Other variables were periodically collapsed into categories based on the distribution of responses and/or the significance of categories, such as monthly income categories based upon Rwanda Revenue classifications. We presented two questions on the perception of the safety of Rwandan roads in general and requested respondents in each stratum to indicate which types of factors are most likely to increase your risk of being injured or killed in a crash. While the incidence of road traffic crashes and the final outcomes are reported based on the strata of household non-drivers, drivers, and motorcyclists. Finally, we asked a total of 18 questions to understand the perceptions of the respondents from our three strata regarding ASE in Rwanda. All questions required a response ranging from ‘Strongly Agree’ to ‘Strongly Disagree’ or they could choose ‘I don’t know.’ Any respondent who reported not knowing about ASE was excluded from these questions.

Data were output from CSpro and Microsoft Excel and IBM SPSS were used for analysis. The data were cleaned and the total population was divided into the three strata of households, drivers and motorcyclists as described previously. Descriptive statistics were calculated for the totals and each of the strata. When sample sizes were sufficiently large we assessed if responses were significantly different between groups by conducting three types of tests: 1) the Levene test which assesses the equality of variances (in our case, for mean, median, and truncated mean); 2) Analysis of Variance (ANOVA) to check if means differ significantly across groups; 3) post-hoc tests, which are conducted as a follow up to an ANOVA to determine which pairwise comparisons contribute to the significant differences observed. Thematic analysis was done for two qualitative variables and frequencies were presented.

Results

We present our results in four sections: 1) Overview of respondents; 2) Demographics and driving experience; 3) Road traffic crash risk perception, experiences, and injuries; and 4) Perceptions of ASE purpose, function, and impacts.

Section 1 - Overview of respondents

A total of 1,509 (of 1510, one refused consent) randomly (household) and purposively (drivers, motorcyclists) selected respondents consented to participate in this study; of these, 1,280 respondents (84.82%) were aware of ASE. Those who were enrolled but not aware of ASE were not asked the ASE oriented questions but are included in other questions. The average interview time was 43 minutes.

We categorised respondents into three groups (non-drivers, vehicle drivers, and motorcycle drivers) shown in Table 13. Of household respondents (1,210), most were not drivers (1,072). A total of 92 drivers and 46 motorcyclists were included in this sample. From the purposively selected sample we recruited 193 drivers and 106 motorcyclists. Categorised by driving history our sample consists of 1,072 non-drivers from households, 285 drivers, and 152 motorcyclists (combined randomly and purposively selected).

We report the geographical and sex distribution in Table 21 and the age and sex in Table 22. Across all provinces and both sexes, most respondents were not drivers. Very few women were drivers (2.1% of households and 0 drivers or motorcyclists). Trends were consistent across regions.

Table 13 | Categories of respondents

		Households				Drivers and Motorcyclists		Combined Totals		
Sex	**Province**	**All Household N(%)**	**Non-drivers N(%)**	**Drivers N(%)**	**Motorcyclists N(%)**	**Drivers N(%)**	**Motorcyclists N(%)**	**Drivers N(%)**	**Motorcyclists N(%)**	**Total N(%)**
Male	City of Kigali	178(28.2)	125(24.7)	45(56.3)	8(17.4)	47(26.0)	18(17.0)	92(35.2)	26(17.1)	243(26.4)
	South	68(10.8)	57(11.3)	5(6.3)	6(13.0)	30(16.6)	18(17.0)	35(13.4)	24(15.8)	116(12.6)
	West	141(22.3)	122(24.1)	12(15.0)	7(15.2)	25(13.8)	30(28.3)	37(24.3)	37(23.3)	196(21.3)
	North	95(15.0)	82(16.2)	7(8.8)	6(13.0)	25(13.8)	21(19.8)	32(12.3)	27(17.8)	141(15.3)
	East	150(23.7)	120(23.7)	11(13.8)	19(41.3)	54(29.8)	19(17.9)	65(24.9)	38(25.0)	223(24.3)
	Total	632	506	80	46	181	106	261	152	919
Female	City of Kigali	227(39.3)	220(38.9)	7(58.3)	0(0.0)	7(58.3)	0(0.0)	14(58.3)	0(0.0)	234(39.7)
	South	87(15.1)	86(15.2)	1(8.3)	0(0.0)	0(0.0)	0(0.0)	1(4.2)	0(0.0)	87(14.7)
	West	123(21.3)	123(21.7)	0(0.0)	0(0.0)	3(25.0)	0(0.0)	3(12.5)	0(0.0)	126(21.4)
	North	46(8.0)	44(7.8)	2(16.7)	0(0.0)	2(16.7)	0(0.0)	4(16.7)	0(0.0)	48(8.1)
	East	95(16.4)	93(16.4)	2(16.7)	0(0.0)	0(0.0)	0(0.0)	2(8.3)	0(0.0)	95(16.1)
	Total	578	566	12	0	12	0	24	0	590
Total	City of Kigali	405(33.5)	345(32.2)	52(56.5)	8(17.4)	54(28)	18(17.0)	106(37.2)	26(17.1)	477(31.6)
	South	155(12.8)	143(13.3)	6(6.5)	6(13.0)	30(15.5)	18(17.0)	36(12.6)	24(15.8)	203(13.5)
	West	264(21.8)	245(22.9)	12(13.0)	7(15.2)	28(14.5)	30(28.3)	40(14.0)	37(23.3)	322(21.3)
	North	141(11.7)	126(11.8)	9(9.8)	6(13.0)	27(14.0)	21(19.8)	36(12.6)	27(17.8)	189(12.5)
	East	245(20.2)	213(19.9)	13(14.1)	19(41.3)	54(28.0)	19(17.9)	67(23.5)	38(25.0)	318(21.1)
	Total	1210	1072	92	46	193	106	285	152	1509

In this study, we aimed to be nationally representative in terms of age and sex for the household survey. In the household survey, we had 52.2% men (n=632) and 47.8% women (n=578). In the household survey, most respondents (53.5%, n=573) were 31 to 50 years of age, followed by 18–30-year-olds (27.3%, n=293). Most drivers and motorcyclists were between the ages of 31-50.

Table 14 | Age and sex distribution of each participant type

Groups surveyed	Age group	Sex		Total
		Male	Female	
		N(%)	N(%)	N(%)
Households	18 - 30	127(25.1)	166(29.3)	293(27.3)
	31 - 50	290(57.3)	283(50.0)	573(53.5)
	>50	89(17.6)	117(20.7)	206(19.2)
	Total	506	566	1210
Drivers	18 - 30	53(20.3)	5(20.8)	58(20.4)
	31 - 50	188(72.0)	18(75.0)	206(72.3)
	>50	20(7.7)	1(4.2)	21(7.4)
	Total	261	24	285
Motorcyclists	18 - 30	54(35.5)	0(0.0)	54(35.5)
	31 - 50	88(57.9)	0(0.0)	88(57.9)
	>50	10(6.6)	0(0.0)	10(6.6)
	Total	152	0	152
Total	18 - 30	234(25.5)	171(29.0)	405(26.8)
	31 - 50	566(61.6)	301(51.0)	867(57.5)
	>50	119(12.9)	118(20.0)	237(15.7)
		919	590	1509

Section 2 - Demographics and driving experience

In the following section, we present an overview of sociodemographic characteristics of respondents for the total group, all non-drivers in households, and all drivers including those who drive vehicles and those who drive motorcycles. We present detailed findings for each variable in Table 15. Overall, 31.6% (n=477) of respondents were from the City of Kigali, 13.5% (n=203) were from the Southern Province, 21.3% (n=322) were from the Western Province, 12.6% (n=189) were from the Northern Province and 21.1% (n=318) were from the Eastern Province. The geographic distribution of road user types (e.g., non-drivers versus vehicle drivers versus motorcycle drivers) varied by province. For example, in Kigali, the numbers of non-drivers (32.2%, n=345) and vehicle drivers (37.2% n=105), were much higher than other provinces. Non-drivers ranged from 11.8-22.9% of the total sample (n=126-245) and vehicle drivers ranged from 12.6-23.5% (n=36-67). When assessing type of geography (rural versus urban, most respondents are located in rural areas (47.2%, n=713), followed by respondents from Kigali urban areas (25.6%, n=386) and other urban areas (27.2%, n=410). The proportions of three different types of road users in both urban and rural areas differ; non-drivers households and motorcyclists have a higher representation in rural areas, 48.5% (n= 108) and 55.9% (n= 85) respectively.

We present age as a category (18–30, 31–50, and 51 years and older) and as a median value. for each group. The median age among road users reveals that motor drivers are younger (34 years old) and drivers are older (38 years old). Furthermore, the 31-50 age range was the most prominently represented, accounting for 57.4% (n=867). The 31-50 age range also has higher representation than the other age ranges where 53.8% (n=573) for non-drivers, 72% (n=206) for drivers and 57.9% (n=88) for motorcyclists. Overall, we had more men in the study

(60.9%, n=919) than women (n=590, 39.1%). Sex distribution is equal in the non-driver category (men account for 47.2% [n=506] and women account for 52.8% [n=566]. Males make up the majority of drivers, at 91.6% (n=261), and are the only ones represented in the moto driver group, with 100% (n=152).

When respondents were asked about three types of work (n=1,316), the majority were in agriculture, forestry, and fishing 41.3% (n=563), followed by transport 17.4% (n = 229), business 15.7% (n=207), and services 12.9% (n= 170). Work sector distribution differed by road user group; Most non-drivers (60.3%, n=536) work in agriculture, forestry and fishing, whereas 49.8% (n=137) of vehicle drivers and 56.6% (n=86) of motorcyclists reported transport as their occupation.

In terms of education, of the 1,509 respondents surveyed, 37.5% (n=567) of respondents studied at most primary, 18.9% (n=286) have secondary ordinary education level and 15.3% (n=231) have secondary advanced level education. Education levels differed between groups. Most non-drivers and motorcyclists had completed primary education (43.7% for non-drivers; 38.2% for motorcyclists). vehicle drivers had higher levels of education, with 22.8% (n=65) having completed university education, 7.4 (n=21) completing vocational education, and 26.7% (n=76) having completed secondary advanced education.

Respondents were asked to report their net monthly household income and expenditures. The mean income for all the respondents is 117,774.2(107,683.2-127,865.2) Rwf while the mean expenditure was 101,062.8(93,649.1-108,476.4) Rwf. Of the 1,418 respondents, the majority 55.4% (n=786) earned less than 60,000 RWF (an estimated 55 United States Dollars [USD]), 15.8% (n=224) earned between 60,001 to 100,000 RWF (55 to 91 USD) and 28.8% (n=408) earned above 100,001 RWF (over 91 USD). Non-drivers and motorcyclists had lower monthly income (71% [n=712] of non-drivers and 41% [n=59] of motorcyclists reported earning less than 60,000 RWF monthly. Most drivers (79%, n=216) earned above 100,000 RWF. Of the 1,420 respondents who reported monthly expenditure, the majority spent below or equal to 60,000 RWF (54.2%, n=797), while 17.3% (n= 254) spent between 60,001–100,000 RWF and 25.1% (n=369) spent above 100,000 RWF. Those who spend 60,000 RWF or less represented the majority of both non-drivers 69.4% (n = 697) and motorcyclists 50.7% (n = 73), while those spending more than 100,000 RWF comprised 72.8% (n= 198) of drivers.

Table 15 | Characteristics of respondents by category

Characteristics	**Category of Respondents**			
	Household Non-Drivers	**Drivers**		**Total**
		Vehicle Drivers	**Motorcyclists**	
	N (%)	N(%)	N(%)	N (%)
Province of residence				
City of Kigali	345(32.2)	106(37.2)	26(17.1)	477(31.6)
South	143(13.3)	3(12.6)	24(15.8)	203(13.4)
West	245(22.9)	40(14.0)	37(24.3)	322(21.3)
North	126(11.8)	36(12.6)	27(17.8)	189(12.5)
East	213(19.9)	67(23.5)	38(25.0)	318(21.1)
Total	**1072**	**285**	**152**	**1,509**
Location category				
Kigali urban	276(25.7)	88(30.9)	22(14.5)	386(25.6)
Other urban	276(25.7)	89(31.2)	45(29.6)	410(27.2)

Characteristics	Category of Respondents			
	Household Non-Drivers	Drivers		Total
		Vehicle Drivers	Motorcyclists	
Rural	520(48.5)	108(37.9)	85(55.9)	713(47.2)
Total	**1072**	**285**	**152**	**1509**
Age				
Median (CI 95%)	37 (36-38)	38(37-39)	34 (32-36)	
18-30	293(27.3)	58(20.4)	54(35.5)	405(26.8)
31-50	573(53.5)	206(72.3)	88(57.9)	867(57.5)
51 and above	206(19.2)	21(7.4)	10(6.6)	237(15.7)
Total	**1072**	**285**	**152**	**1509**
Sex				
Male	506(47.2)	261(91.6)	152(100)	919(60.9)
Female	566(52.8)	24(8.4)	0(0.0)	590(39.1)
Total	**1072**	**285**	**152**	**1509**
Work sector of occupation				
Agriculture, Forestry, and Fishing	536(60.3)	9(3.3)	18(11.8)	563(42.8)
Industry	8(0.9)	4(1.5)	1(0.7)	13(1.0)
Services	94(10.6)	47(17.1)	29(19.1)	170(12.9)
Engineering	53(4.9)	10(3.6)	4(2.6)	67(5.1)
Transport	6(0.7)	137(49.8)	86(56.6)	229(17.4)
Health sector	11(1.2)	11(3.9)	3(1.9)	25(1.9)
Business	146(16.4)	52(18.9)	9(5.9)	207(15.7)
Others	35(3.9)	5(1.8)	2(1.3)	42(3.2)
Total	**1072**	**285**	**152**	**1316**
Level of education				
None	178(16.6)	1(0.4)	6(3.9)	185(12.3)
Primary	468(43.7)	41(14.4)	58(38.2)	567(37.6)
Secondary - Ordinary Level	168(15.7)	71(24.9)	47(30.9)	286(19.0)
Secondary - Advanced	134(12.5)	76(26.7)	21(13.8)	231(15.3)
Vocational	46(4.3)	21(7.4)	7(4.6)	74(4.9)
University	76(7.1)	65(22.8)	12(7.9)	153(10.1)
Masters or higher	2(0.2)	10(3.5)	1(0.7)	13(0.9)
Total	**1072**	**285**	**152**	**1509**

Table 16 shows how the mean incomes were nearly five times higher in drivers compared to households, and their household mean expenditures consumed virtually all that income while drivers had a mean of ~60,000 RWF left after expenditures (enough to pay two ASE speeding violations and a late charge).

Table 16 | Mean reported monthly household income and expenditures in Rwandan Francs (RWF)

Characteristics	Category of Respondents			
	Household Non-Drivers	Drivers		Total
		Vehicle Drivers	Motorcyclists	
Mean monthly household net income in RWF (95% CI)	68,711 (62,540-75,309)	305,343 (270,614.-345,232)	106,521 (92,150-122,596)	117,774 (107,683-127,865)
Less than 60,000	712(66.4%)	15(5.5%)	59(38.8%)	786(55.4%)
60,001-100,000	143(14.3%)	40(14.8%)	41(28.5%)	224(15.8%)
100,001 and above	148(14.8%)	216(79.7%)	44(30.6%)	408(28.8%)
Total	**1003(71.%)**	**271(19%)**	**144(10%)**	**1418(100%)**
Mean monthly household expenditures in RWF (95% CI)	66,550 (60,292-72,807)	237,757 (213,210-262,304)	101,063 (71,493-95,493)	101,063.8 (93,649-108,476)
Less than 60,000	697(69.4%)	27(9.9%)	73(50.7%)	797(56.1%)
60,001-100,000	167(16.6%)	47(17.3%)	40(27.8%)	254(18.9%)
100,001 and above	140(13.9%)	198(72.8%)	31(21.5%)	369(26.0%)
Total	**1004(71%)**	**272(19%)**	**144(10%)**	**1420(100%)**

In the next set of questions, we asked vehicle and motorcycle drivers to report their years of driving experience, how often they have driven in the past 30 days, the frequency of driving in the past 30 days, and the primary reason for driving in the past 30 days. We present detailed results in Table 25. Overall, most drivers had 2-10 years of driving experience (n=256). Driving experience differed by type of vehicle; vehicle drivers had a mean of 8.66 years of driving experience, whereas motorcyclists had a mean of 5.63 years. Most respondents (92.6%, n=373) have driven in the past 30 days. The frequency of driving was high with the majority of drivers reporting driving 5-7 days a week (78.5%, n=293). This was consistently high among vehicle drivers and motorcyclists. The primary reasons for driving differed between the driver groups. About 66.4% (n=216) of motorcyclists drove for professional reasons, compared to 54.1% (n=139) of drivers. An estimated 30.4% (n=78) of vehicle drivers drove primarily for personal reasons, compared to 19% (n=22) of motorcycle drivers.

Most of drivers (64.8%) whether driving for professional, personal reasons or both report feeling that Rwanda road are safe (<3 out of 10). 21.3% (n=51) of professional drivers have given the rate 3, 18.3%(n=44) rate 1, 17.9%(n=43) rate 2 compared to 33.1%(n=44) rate 1, 21.1%(n=28) rate 2 and 21.1%(n=25) rate 3 for those driving for personal reasons, meaning that most personal drivers feel roads are safer than professional drivers. Only 2.9%(n=7) of professional drivers have given rate 10 (very dangerous) compared to 0.8%(n=1) of those driving for personal reasons.

It was also found that most of drivers think in a similar pattern about the primary reason Rwanda decided to implement ASE. 82.1%(n=193) of professional drivers and 85%(n=113) think the primary reason was to improve road safety and reduce driving speed while 5.1% vs 4.5% think it was to make money through citations. More professional drivers think ASE was implemented to make the jobs of police safer and easier (2.1%) and to improve security with added surveillance (3.8%) compared to 0.8% and 1.5% of personal drivers respectively.

Table 17 | Driving experience by categories of drivers

Years of driving experience	Vehicle Drivers	Motorcyclists	Total
	Mean: 8.66	**Mean: 5.63**	
	N(%)	N(%)	N(%)
0 to 2	24(8.7)	28(22.2)	52(12.9)
2 to 10	177(63.9)	79(62.7)	256(63.5)
above 10 years	76(27.4)	19(15.1)	95(23.6)
Total	**277**	**126**	**403**
Have you driven in the last 30 days?			
Yes	257(92.8)	116(92.1)	373(92.6)
No	20(7.2)	10(7.9)	30(7.4)
Total	**277**	**126**	**403**
Frequency of driving in last 30 days			
Very often (5-7 days a week)	195(75.9)	98(84.5)	293(78.6)
often (2-4 days a week)	48(18.7)	14(12.1)	62(16.6)
sometimes (1 day per week)	9(3.5)	3(2.6)	12(3.2)
Rarely (once a month)	5(1.9)	1(0.9)	6(1.6)
Total	**257**	**116**	**373**
Primary reason for driving in last 30 days			
Professional reasons	139(54.1)	77(66.4)	216(57.9)
Personal reasons	78(30.4)	22(18.9)	100(26.8)
Both professional and personal	40(15.6)	17(14.7)	57(15.3)
Total	**257**	**116**	**373**

Section 3 - Road traffic crash risk perception, experiences, and injuries

In the following section, respondents report their perceptions of road safety and experiences with crashes, injuries, and deaths in Rwanda. We present detailed findings for the question, 'how safe or dangerous do you believe that Rwandan roads are (1=very safe, 10=very unsafe)' in Table 18. The mean score for safety or danger perception for the overall sample is 3.13 (SD 2.15). The mean score for the three categories is 2.98 for non-drivers in households, 3.51 for drivers, and 3.43 for motorcyclists.

Results of the test of homogeneity of variances, which assesses whether the variance of safety or danger perception scores is similar across the three categories are also shown in the table below. The table presents the Levene statistic and associated p-values for tests based on mean, median, and trimmed mean. All tests indicate that the variances are not equal across the three categories, with p-values less than 0.05. Relatedly, the ANOVA table presents the results of the analysis of variance for safety or danger perception scores, with the categories of respondents as the independent variable. The table shows that there is a significant difference in the mean scores of safety or danger perception among the three groups, with a p-value of 0.000.

The post hoc tests table provides additional information on the pairwise comparison of the three groups using the Scheffe method to understand which groups differ. The table shows the mean difference, standard error, significance level, and 95% confidence interval for each comparison. The results indicate that the mean difference between households and drivers is significant with a p-value of 0.001, and the mean difference between households and motorcyclists is marginally significant with a p-value of 0.054. This indicates that drivers perceive roads to be significantly more dangerous than non-drivers do. Motorcyclists perceive Rwandan roads to be significantly more dangerous than non-drivers do.

However, the mean difference between drivers and motorcyclists is not significant, indicating they have similar perceptions of safety and danger on the roads. Overall, the results suggest that there are significant differences in safety or danger perception scores across groups, with household respondents perceiving the environment to be more safe or less dangerous compared to drivers and motorcyclist respondents.

Table 18 | Results for 'How safe or dangerous do you believe that Rwandan roads are (1= very safe, 10 = very unsafe as the scale)?' including Descriptives, Comparisons (Post Hoc tests) and ANOVA from top to bottom

Descriptives								
	N	Mean	Std. Dev	Std. Error	95% Confidence Interval		Min	Max
					Lower Bound	Upper Bound		
Household (non-drivers)	1040	2.98	2.043	0.063	2.86	3.11	1	10
Driver	285	3.51	2.363	0.140	3.23	3.78	1	10
Motorcyclist	152	3.43	2.377	0.193	3.05	3.82	1	10
Total	**1477**	**3.13**	**2.155**	**0.056**	**3.02**	**3.24**	**1**	**10**

Comparisons (Post Hoc tests)						
(I) Category of respondents		Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
Household (non-drivers)	Driver	-.524*	0.143	0.001*	-0.88	-0.17
	Motorcyclist	-0.450	0.186	0.054	-0.91	0.01
Driver	Household	.524*	0.143	0.001*	0.17	0.88
	Motorcyclist	0.075	0.215	0.942	-0.45	0.60
Motorcyclist	Household	0.450	0.186	0.054	-0.01	0.91
	Driver	-0.075	0.215	0.942	-0.60	0.45

ANOVA					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	76.931	2	38.466	8.367	0.000*
Within Groups	6776.324	1474	4.597	-	-
Total	**6853.255**	**1476**	-	-	-

In Table 19, we present results related to which set of factors (road user, road, vehicle, or limited post-crash vehicle risk factors) is perceived to increase the risk of injury/death, the prevalence of crash involvement, and the outcome of the crash (not injured, minor injury, severe injury, fatal, do not know). All results are presented in the three study strata (non-drivers, vehicle drivers, motorcycle drivers). Overall, most respondents, believe that road user risk factors, such as excessive speeding, drink-driving, not wearing helmets or seatbelts, and attitudes, increase the risk of injury or death in Rwanda. Speed was ranked top (91.8%) followed by drink-driving (87.1%) (Figure 24). Most respondents felt these factors contributed most to injury or risk (97.9% of non-drivers; 97.2% of vehicle drivers; and 98% of motorcyclists selecting this response). Consistent views were shown about the importance of road risk factors (e.g., limited infrastructure) and vehicles (e.g., limited impact protection). One notable difference was that more drivers (40.4%) believed that 'limited post-crash care capacity played a key role in increasing the risk of injury or death, compared to non-drivers (28.9%) and motorcyclists (24.3%).

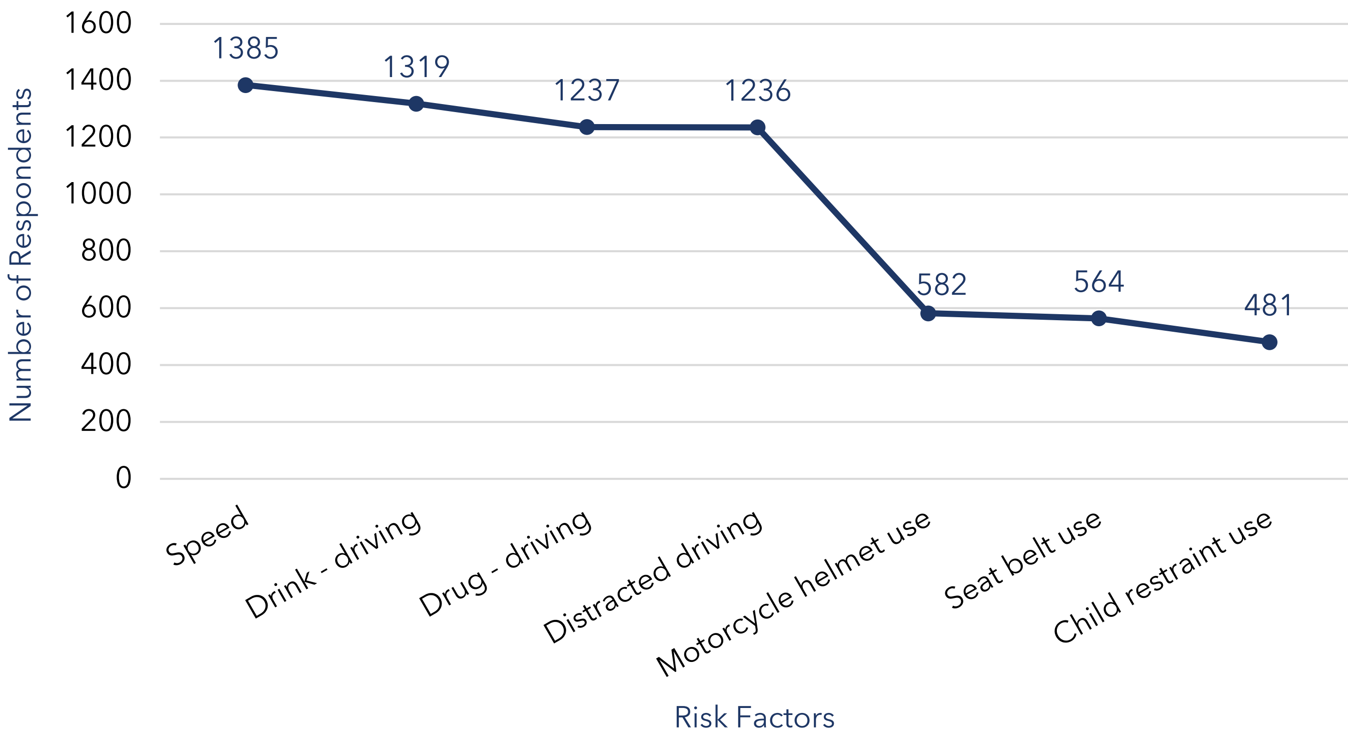


Figure 24 | Ranking of road user factors that increase the risk of being injured or killed in a crash

We asked questions about the prevalence of crash involvement and found that 29.1%(n=83) of vehicle drivers, 24.3% (n=37) of motorcyclists, and 13.3% (n=143) of non-drivers have been involved in a crash. These results are expected given higher risk exposure and higher crash involvement of drivers compared to non-drivers. Among those who were involved with the crash or had someone in their household involved in a crash, the majority sustained minor injuries (88.1% of drivers [n=89], 89.4% of motorcyclists [n=42]). Most of those who reported to be involved in a crash were passengers on a moto (26%, n=115) followed by pedestrians (17.2%, n=76), driving a car/truck/bus (14.9%, n=66), driving a moto (14%, n=62).

Among those who reported being involved in a crash themselves, 25% (n=73) were passengers on a moto, 18.8%(n=55) were driving a car/truck/bus, 16.8%(n=49) driving a moto, 13%(n=38) pedestrians, 12.3(n=36) passengers in a car/truck/bus, 8.6(n=25) riding a bicycle and 5.5%(n=16) passengers on a bicycle. On the other hand, those who reported someone else was involved in a crash, 29.1%(n=37) were pedestrians, 27.6(n=35) passengers on a moto, 11%(n=14) passengers on a bicycle, 10.2%(n=13) passengers in a car/truck/bus, 8.7%(n=11) moto drivers, 7.1%(n=9) driving a car/truck/bus and 6.3%(n=8) driving a bicycle. 23 respondents reported that both them and someone in their household were involved in a crash.

Table 19 | Road traffic crash experiences and injuries

Question	Category of respondents			
	Non-Drivers Households	Drivers		Total
		vehicle drivers	Motorcyclists	
	N (%)	N(%)	N (%)	N (%)
Which factors do you believe increase the risk of being injured or killed the most?				
Road user risk factors	1018(97.9)	277(97.2)	149(98.0)	-
Road risk factors	620(59.6)	186(65.3)	92(60.5)	-
Vehicle factors	435(41.8)	144(50.5)	62(40.8)	-
Limited post-crash care capacity	301(28.9)	115(40.4)	37(24.3)	-
Involvement in a crash				
Yes, I have	143(13.3)	83(29.2)	37(24.3)	263(17.4)
Yes, someone in my house	90(8.4)	16(5.6)	9(5.9)	115(7.6)
Yes, both I and someone in my house	9(0.8)	2(0.7)	1(0.7)	12(0.8)
No, we have not to my knowledge	830(77.4)	184(64.6)	105(69.1)	1119(74.2)
Total	**1072**	**285**	**152**	**1509**
Type of road user in the crash				
I was driving a car/truck/bus	20 (6.1)	46(59)	0(0.0)	66(14.9)
I was driving a moto	28(8.5)	5(6.4)	29(85.3)	62(14.0)
I was riding a bicycle	37 (11.2)	1(1.3)	0(0.0)	38(8.6)
I was a passenger in a car/truck/bus	42 (12.7)	11(9.5)	0(0.0)	51(11.5)
I was a passenger on a moto	102 (30.9)	12(15.4)	1(2.9)	115(26.0)
I was on a bicycle as a passenger	32 (9.7)	1(1.3)	1(2.9)	34(7.7)
I was a pedestrian	69 (20.9)	4(5.1)	3(8.8)	76(17.2)
Total	**330**	**78**	**34**	**442**
Results of the crash				
Not injured	0(0.0)	1(1.0)	0(0.0)	1(0.3)
Minor Injury	200(83.1)	88(88.1)	42(89.4)	332(85.6)
Severe Injury	33(13.6)	10(9.9)	5(10.6)	48(12.4)
Fatal injury	6(2.5)	1(1.0)	0(0.0)	5(1.3)
Don't know	2(0.8)	0(0.0)	0(0.0)	2(0.5)
Total	**241**	**100**	**47**	**388**

Section 4 - Perceptions of ASE purpose, function, and impacts

In the following section, respondents report their views related to ASE awareness and knowledge, and their perceptions on why Rwanda implemented ASE. We present detailed results in Table 20. respondents reported different sources of information about ASE (n=832 of non-drivers, n=285 of vehicle drivers, n=151 of motorcyclists). Of these, most respondents reported hearing about ASE on the road (75.2% of non-drivers, 87.0% of vehicle drivers, and 87.4% of motorcyclists). Many respondents reported hearing about ASE by word of mouth (ranging from 10.6-16.7% depending on the group) and television (13.6% among non-drivers, 40.4% of drivers, and 17.9% of motorcyclists). Nearly all of the sources of information significantly differed between groups, with the exception of school, word of mouth, and none of the above. High percentages of households (96%, n=799), drivers (99.3%, n=281) and motorcyclists (100%, n=151) correctly knew that ASE cameras are monitoring drivers driving over the speed limit and the differences between groups, while not large, are statistically significant (p=0.001). Less than half of respondents of all groups stated that cameras are able to check ‘running red lights’, ‘driving with unpaid violations’, ‘driving while not wearing a seatbelt’, ‘speaking on the phone while driving’, ‘driving without a licence’, and ‘driving with no insurance’.

Interestingly, drivers and motorcyclists reported in larger numbers that ASE were also monitoring other events. Drivers (38.5%) and motorcyclists (24.5%) were much more likely to report ASE was monitoring for running red lights than were households (13.7%) and these differences were significant (p<0.001). Additionally, drivers (23.0%) and motorcyclists (17.9%) were more likely to report ASE was monitoring driving with unpaid violations than were households (11.2%) with these differences also being statistically significant (p<0.001). For other types of enforcement activities asked the differences were not statistically significant and/or the magnitude of the differences were small. When asked about the primary reason that Rwanda decided to implement ASE, 80% (n=1,025) of total respondents selected ‘to improve road safety and reduce driving speed,’ The next most common response was that 7.2% of total respondents (n=92) reported ‘to reduce corruption and conflict between police and road users’ followed by 5.2 (n=66) reporting ‘to improve security with added surveillance.’

Table 20 | Purposes of using ASE and Source of information

Variable	Category of respondents				
	Non-Drivers Households	Drivers			Total
		vehicle drivers	Motorcyclists		
	N (%)	N(%)	N (%)	P-value	N (%)
Source of information about ASE in Rwanda	832	285	151		1268
Radio	359(43.1)	131(46.0)	82(54.3)	0.038*	572(45.1)
TV	113(13.6)	115(40.4)	27(17.9)	0.0001*	255(20.1)
Online/website	18(1.8)	24(8.4)	3(2.0)	0.018*	45(3.5)
Printed publication or billboard	19(2.3)	23(8.1)	7(4.6)	0.003*	49(3.9)
Social media	49(5.9)	70(24.6)	9(6.0)	0.0001*	128(10.1)
On the road	626(75.2)	248(87.0)	132(87.4)	0.0001*	006(79.3)
School	10(1.2)	2(0.7)	1(0.7)	0.689	13 (1)
Police	6(0.7)	31(10.9)	13(8.6)	0.0001*	50 (3.9)
Training	9(1.1)	19(6.7)	14(9.3)	0.0001*	42 (3.3)
Word of mouth	139(16.7)	42(14.7)	16(10.6)	0.148	197 (15.5)

Variable	Category of respondents				
	Non-Drivers Households	Drivers			Total
		vehicle drivers	Motorcyclists		
	N (%)	N(%)	N (%)	P-value	N (%)
None of the above	1(0.1)	1(0.4)	0(0.0)	0.61	2 (0.1)
What do you think ASE cameras are monitoring or checking?	832	283	151		1266
Driving over the speed limit	799(96.0)	281(99.3)	151(100%)	0.001*	1266
Running red lights	114(13.7)	109(38.5)	37(24.5)	0.0001*	
Driving with unpaid violations	93(11.2)	65(23.0)	27(17.9)	0.0001*	
Driving while not wearing a seatbelt	59(7.1)	19(6.7)	12(7.9)	0.892	
Speaking on the phone while driving	102(12.3)	39(13.8)	22(14.6)	0.646	
Driving without a license	42(5.0)	5(1.8)	2(1.3)	0.011	
Driving with no insurance	**20(2.4)**	**6(2.1)**	**4(2.6)**	**0.936**	
Other (specify...)	**41(4.9)**	**10(3.5)**	**1(0.7)**	**0.045***	
I don't know	**27(3.2)**	**1(0.4)**	**1(0.7)**	**0.007***	
What do you think is the primary reason that Rwanda decided to implement ASE?	832	283	151	0.0001	1268
To improve road safety and reduce driving speed	668(79.1)	242(84.9)	115(76.2)		1025 (80)
To make money through citations	11(1.3)	16(5.6)	15(9.9)		42(3.3)
To reduce corruption and conflict between police and road users	67(7.9)	15(5.3)	10(6.6)		92(7.2)
To make the jobs of police safer and easier	16(1.9)	0(0.0)	3(2.0)		19(1.5)
To improve security with added surveillance;	49(5.8)	12(4.2)	5(3.3)		66(5.2)
I don't know	33(3.9)	0(0.0)	3(2.0)		36(2.8)

Table 21 shows the frequencies and proportions of different opinions in response to questions about the intent and functions of ASE in Rwanda stratified by respondent type as shown. Respondents were asked a series of questions relating to the intent and functions of ASE with a Likert-scale response (i.e., 'strongly agree', 'agree', 'neutral', 'disagree', 'strongly disagree'). Respondents were also able to select 'I do not know.'

When asked questions on the road safety intent of speed cameras ('Rwanda uses speed cameras because they make the roads safer by reducing the speeds of drivers'), most respondents strongly agreed (47.3-50.5% depending on road user type), or agreed (46-50%). Similar responses were shown for 'Rwanda uses speed cameras to reduce crashes, injuries, and deaths on the roads.

When asked for questions related to enforcement and surveillance, the vast majority of respondents either strongly agreed or agreed with the following statements: "Rwanda uses speed cameras because they reduce confrontation between traffic police and drivers and prevent corruption," "Rwanda uses speed cameras because it makes the job of the police safer and easier" and "Rwanda uses speed cameras because they provide security with more surveillance of the roads."

One question asked respondents about their perception of the fairness of speed cameras ("speed cameras in Rwanda are fair to drivers"). Most respondents strongly agreed (29.4% of non-drivers, 33.3% of vehicle drivers, 32.5% of motorcycle drivers), or agreed (52.3% of non-drivers, 55.8% of drivers, and 51.7% of motorcyclists). Similar results are shown for two questions relating to the accuracy and violation processing ("when a violation is sent to a driver, it is accurate and matches the actual speed the driver was travelling"; "when a violation is sent to a driver, it is only issued when they exceed the posted speed limit in that area"), indicating most respondents find the speed cameras fair, accurate, and trustworthy.

Some questions addressed knowledge of the ASE implementation including about sensitization ("the police had a campaign to sensitize road users about these speed cameras), and selected locations ("the locations where these cameras are installed make sense to me", "different features of the road were considered when ASE were installed", "all districts were equally targeted for speed cameras"). There were mixed views on the sensitization campaign, with 10.9-12.2% of respondents strongly agreeing, 26.3-29.3% of respondents agreeing, 7.6% of non-drivers disagreeing, 38.6% of drivers disagreeing, and 29.1% of motorcyclists disagreeing. An estimated 7.6% (n=64) of non-drivers, 38.6% (n=110) of drivers, and 29.1% (n=44) of motorcyclists strongly disagreed with this statement. This may indicate that the sensitization campaign may not have reached the public as intended.

Most respondents strongly agreed or agreed with the statements regarding the locations of cameras making sense and different features of the road being considered. Views were more mixed when asked if districts were targeted equally. Only 6.2-10.2% of respondents strongly agreed with this statement, 20.1-30.5% strongly agreed, and 24.5-30.2% disagreed, indicating a lack of knowledge about the distribution of cameras among the study population.

Relatedly, views were mixed on the statement that cameras are hidden and drivers are not specifically warned about cameras operating ahead so that drivers respect speed limits everywhere not just at the camera sites. Some respondents strongly agreed (8.2-21.9%) or agreed (20.1-37.9%), whereas a high proportion disagreed (34.1% of non-drivers; 30.2% of vehicle drivers, and 24.5% of motorcyclists).

One question posed aimed to understand a potential unintended consequence of speed cameras, which was raised as a potential issue in our qualitative study of stakeholders. We asked 'these speed cameras have caused problems with the flow of traffic because vehicles are going too slow now and its causing congestion.' Responses were mixed for this question, with most respondents disagreeing (53.8% of non-drivers; 53.7% of vehicle drivers; 47.7% of motorcycle drivers), and others agreeing (17.7% of non-drivers; 28.1% of vehicle drivers, and 27.2% of motorcycle drivers).

There were several questions about the financial aspects of speed cameras. One question posed ('Speed cameras are costing drivers too much money because of so many violations') aimed to understand the financial impact of ASE. Some respondents strongly agreed (7.9% of non-drivers, 17.9% of vehicle drivers, and 15.2% of motorcycle drivers) or agreed (21.3% of non-drivers, 36.5% of vehicle drivers, and 35.1% of motorcycle drivers). However, a substantial portion disagreed (31.8-44.5%). There was very high agreement among respondents for two questions, 'the money raised for speed cameras is used to improve road quality and public safety' and 'if the money that is raised from all the speed violations was used only for improving road quality and safety, the public would really support the campaign.'

When posed with a question about the substantial cost of cameras ('Rwanda spent too much money on these speed cameras that should have been used for other things'), most respondents (60.2% of non-drivers, 56.5% of vehicle drivers, and 50.3% of motorcycle drivers) disagreed, indicating high support for spending resources on ASE. Of note, between 11.1-18.5% of respondents did agree with this statement, with slight variations by group.

Table 21 | Perception about the intent and functions of ASE[A]

Question	Strongly Agree			Agree			Disagree			Strongly Disagree		
	N (%)			N (%)			N (%)			N (%)		
	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Moto (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)
Rwanda uses speed cameras because they make the roads safer by reducing the speeds of drivers	399 (47.3)	144 (50.5)	74 (49)	422 (50.0)	131 (46.0)	72 (47.7)	8 (0.9)	7 (2.5)	3 (2.0)	1 (0.1)	1 (0.4)	1 (0.7)
Rwanda uses speed cameras to reduce crashes, injuries, and deaths on the road	409 (48.5)	144 (50.5)	72 (47.7)	416 (49.3)	134 (47.0)	67 (44.4)	7 (0.8)	7 (2.5)	7 (4.6)	2 (0.2)	0	1 (0.7)
Rwanda uses speed cameras because they make a lot of money for the country	71 (8.4)	31 (10.9)	21 (13.9)	175 (20.7)	94 (33.0)	53 (35.1)	414 (49.1)	128 (44.9)	56 (37.1)	67 (7.9)	11 (3.9)	10 (6.6)
Rwanda uses speed cameras because they reduce confrontation between traffic police and drivers, and prevent corruption	320 (37.9)	111 (38.9)	59 (39.1)	416 (49.3)	138 (48.4)	69 (45.7)	55 (6.5)	25 (8.8)	14 (9.3)	6 (0.7)	6 (2.1)	3 (2.0)
Rwanda uses speed cameras because they make the jobs of police safer and easier	249 (29.5)	79 (27.7)	39 (25.8)	463 (54.9)	157 (55.1)	93 (61.6)	65 (7.7)	27 (9.5)	10 (6.6)	3 (0.4)	1 (0.4)	1 (0.7)
Rwanda uses speed cameras because they provide security with more surveillance of the roads	265 (31.4)	84 (29.5)	47 (31.1)	508 (60.2)	160 (56.1)	85 (56.3)	34 (4.0)	24 (8.4)	5 (3.3)	5 (0.6)	5 (1.8)	3 (2.0)
Speed cameras in Rwanda are fair to drivers	248 (29.4)	95 (33.3)	49 (32.5)	441 (52.3)	159 (55.8)	78 (51.7)	40 (4.7)	14 (4.9)	13 (8.6)	10 (1.2)	7 (2.5)	2 (1.3)
When a violation is sent to a driver it is accurate and matches the actual speed the driver was traveling	221 (26.2)	110 (38.6)	43 (28.5)	313 (37.1)	135 (47.4)	69 (45.7)	22 (2.6)	22 (7.7)	15 (9.9)	2 (0.2)	2 (0.7)	2 (1.3)

Question	Strongly Agree			Agree			Disagree			Strongly Disagree		
	N (%)			N (%)			N (%)			N (%)		
	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Moto (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)
When a violation is sent to a driver it is only issued when they exceed the posted speed limit in that area	210 (24.9)	98 (34.4)	46 (30.5)	338 (40.0)	134 (47.0)	63 (41.7)	41 (4.9)	41 (14.4)	27 (17.9)	4 (0.5)	5 (1.8)	1 (0.7)
The police had a campaign to sensitize road users about these speed cameras	103 (12.2)	31 (10.9)	17 (11.3)	247 (29.3)	75 (26.3)	40 (26.5)	64 (7.6)	110 (38.6)	44 (29.1)	64 (7.6)	110 (38.6)	44 (29.1)
The locations where these cameras are installed makes sense to me	189 (22.4)	57 (20.0)	39 (25.8)	464 (55.0)	165 (57.9)	68 (45)	21 (2.5)	26 (9.1)	18 (11.9)	7 (0.8)	6 (2.1)	2 (1.3)
Different features of the road were considered when ASE locations were installed	151 (17.9)	46 (16.1)	25 (16.6)	368 (43.6)	113 (39.6)	56 (37.1)	12 (1.4)	26 (9.1)	11 (7.3)	4 (0.5)	3 (1.1)	1 (0.7)
Cameras are hidden and drivers are not specifically warned about cameras operating ahead so that drivers respect speed limits everywhere not just at the camera sites	69 (8.2)	48 (16.8)	33 (21.9)	170 (20.1)	108 (37.9)	53 (35.1)	288 (34.1)	86 (30.2)	37 (24.5)	49 (5.8)	12 (4.2)	8 (5.3)
All districts were equally targeted for speed cameras	52 (6.2)	29 (10.2)	13 (8.6)	189 (22.4)	87 (30.5)	40 (26.5)	137 (16.2)	51 (17.9)	22 (14.6)	45 (5.3)	7 (2.5)	5 (3.3)
These speed cameras have caused problems with the flow of traffic because vehicles are going too slow now and it's causing congestion	39 (4.6)	26 (9.1)	12 (7.9)	149 (17.7)	80 (28.1)	41 (27.2)	454 (53.8)	153 (53.7)	72 (47.7)	86 (10.2)	15 (5.3)	14 (9.3)
Speed cameras are costing drivers too much money because of so many violations	67 (7.9)	51 (17.9)	23 (15.2)	180 (21.3)	104 (36.5)	53 (35.1)	376 (44.5)	102 (35.8)	48 (31.8)	55 (6.5)	10 (3.5)	11 (7.3)

Question	Strongly Agree			Agree			Disagree			Strongly Disagree		
	N (%)			N (%)			N (%)			N (%)		
	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)	House (N=844)	Driver (N=285)	Moto (N=151)	House (N=844)	Driver (N=285)	Motor (N=151)
The money raised for speed cameras is used to improve road quality and public safety	102 (12.1)	19 (6.7)	21 (13.9)	276 (32.7)	83 (29.1)	37 (24.5)	18 (2.1)	13 (4.6)	9 (6.0)	5 (0.6)	3 (1.1)	1 (0.7)
If the money that is raised from all the speed cameras violations was used only for improving road quality and safety, the public would really support the campaign	458 (54.3)	109 (38.2)	65 (43.0)	292 (34.6)	115 (40.4)	57 (37.7)	26 (3.1)	18 (6.3)	4 (2.6)	2 (0.2)	3 (1.1)	0 (0.0)
Rwanda spent too much money on these speed cameras that should have been used for other things	45 (5.3)	13 (4.6)	7 (4.6)	94 (11.1)	38 (13.3)	28 (18.5)	508 (60.2)	161 (56.5)	76 (50.3)	101 (12.0)	31 (10.9)	15 (9.9)
We do not present 'I do not know' nor 'neutral' for this set of questions												

To understand if responses significantly differed by group (non-drivers, vehicle drivers, and motorcycle drivers, multiple comparisons were conducted. We present only the statistically significant findings in Table 30 while the complete table of all results is included in the Supplementary Materials. Several questions had significant differences between groups. Some questions only had pairwise differences between households versus drivers and households versus motorcyclists, including 'Rwanda uses speed cameras because they make a lot of money', 'speed cameras in Rwanda are fair to drivers', 'these speed cameras have caused problems with the flow of traffic because vehicles are going too slow', and 'speed cameras are costing drivers too much money because of so many violations'. These results indicate that vehicle and motorcycle drivers tend to be well-aligned with their perceptions of ASE. Three questions 'the police had a campaign to sensitize road users about these speed cameras' and 'all districts were equally targeted for speed cameras', and 'the money raised for speed cameras is used to improve road quality and public safety' significantly differed for the pairwise combination of household and vehicle drivers. One question, 'When a violation is sent to a driver it is accurate and matches the actual speed the driver was travelling', significantly differed between motorcyclists and vehicle drivers, albeit just (p=0.045).

Table 22 | Multiple comparisons about the perception of ASE[A]

Dependent Variable			Mean Difference (I-J)	Std. Error	P-value*	95% Confidence Interval	
						Lower Bound	Upper Bound
Rwanda uses speed cameras because they make a lot of money for the country	Household	Driver	.527*	0.093	0.000	0.30	0.75
		Motorcyclist	.665*	0.119	0.000	0.37	0.96
Speed cameras in Rwanda are fair to drivers	Household	Driver	.386*	0.092	0.000	0.16	0.61
		Motorcyclist	.294*	0.118	0.046	0.00	0.58
When a violation is sent to a driver it is accurate and matches the actual speed the driver was traveling	Household	Driver	1.156*	0.127	0.000	0.84	1.47
		Motorcyclist	.689*	0.164	0.000	0.29	1.09
When a violation is sent to a driver it is only issued when they exceed the posted speed limit in that area	Household	Driver	.897*	0.122	0.000	0.60	1.20
		Motorcyclist	.557*	0.158	0.002	0.17	0.94
The police had a campaign to sensitize road users about these speed cameras	Household	Driver	.492*	0.131	0.001	0.17	0.81
Cameras are hidden and drivers are not specifically warned about cameras operating ahead so that drivers respect speed limits everywhere not just at the camera sites	Household	Driver	1.124*	0.108	0.000	0.86	1.39
		Motorcyclist	1.209*	0.139	0.000	0.87	1.55
All districts were equally targeted for speed cameras	Household	Driver	.516*	0.127	0.000	0.20	0.83
These speed cameras have caused problems with the flow of traffic because vehicles are going too slow now and it's causing congestion	Household	Driver	.610*	0.087	0.000	0.40	0.82
		Motorcyclist	.519*	0.112	0.000	0.25	0.79
Speed cameras are costing drivers too much money because of so many violations	Household	Driver	.908*	0.099	0.000	0.67	1.15
		Motorcyclist	.771*	0.128	0.000	0.46	1.08
The money raised for speed cameras is used to improve road quality and public safety	Household	Driver	-.358*	0.142	0.043	-0.71	-0.01

The survey participants were also asked two open questions. Figure 25 demonstrates the responses on a question asking what comes in mind first when you think of ASE. 1,268 respondents gave various answers which were grouped in different themes. 21.7%(n=275) reported thinking about slowing down, 13.9%(n=176) think about fines, 11.9%(n=151) think about safety or security while a good number (n=139) reported nothing. Few participants reported negative thoughts such as Poverty or loss, unfair and hidden, arriving late and fear.

Figure 25 | First thoughts of participants about ASE

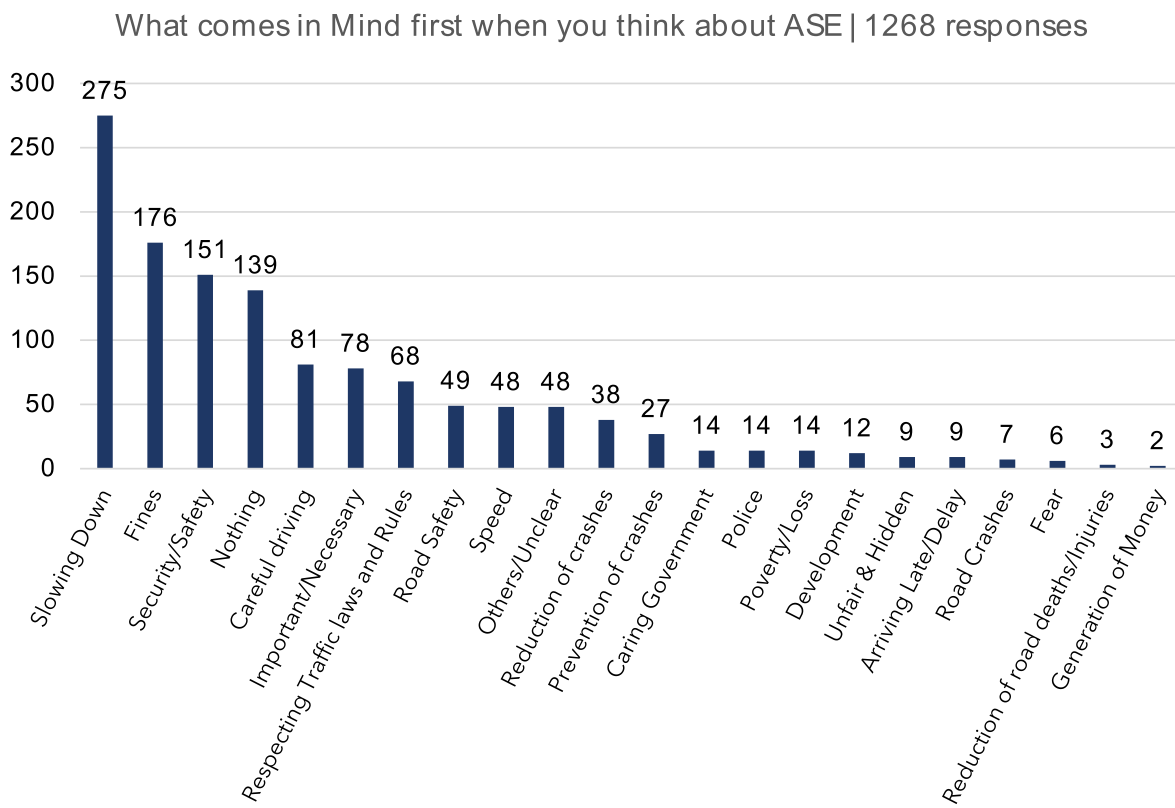


Figure 26 | Public perception of the benefits of ASE

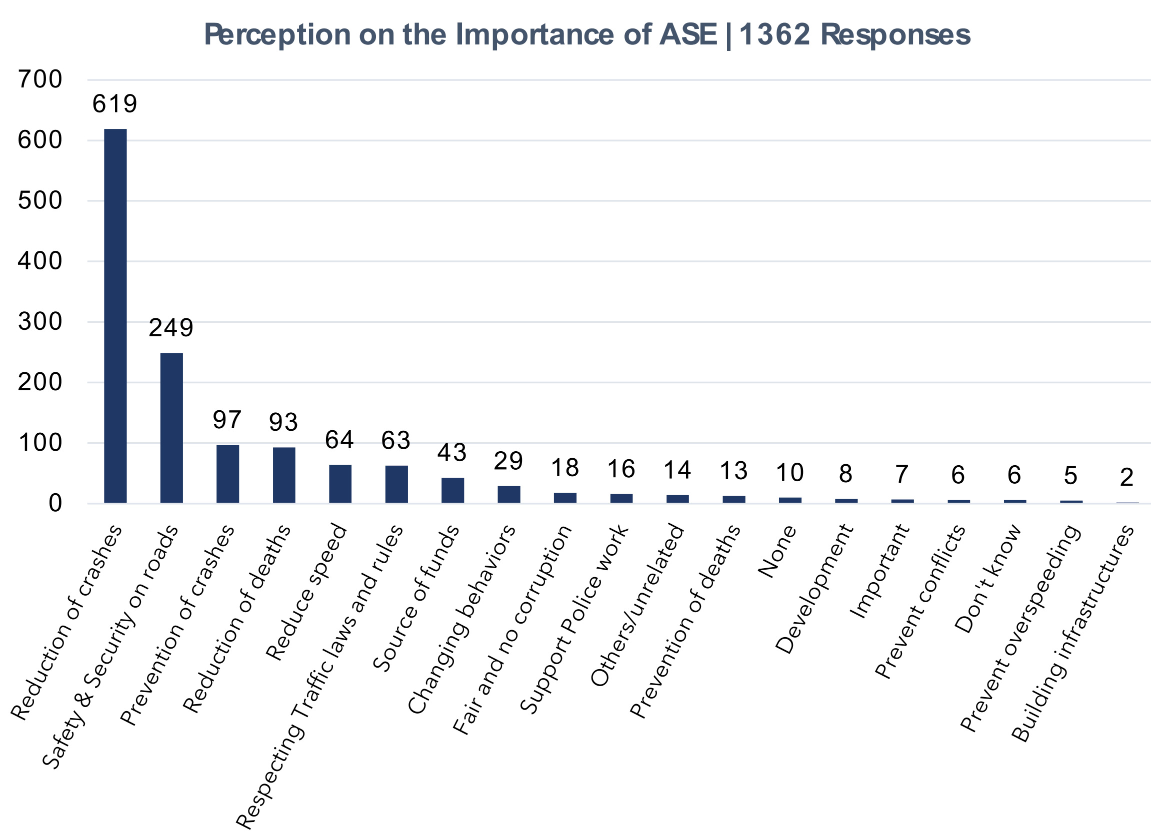


Figure 26 demonstrates what participants thought of in considering the positive benefits of ASE. The majority reported reduction of crashes (45.4%, n=619) and safety on roads (18.3%, n=249). Other reported benefits include prevention of crashes (7.1%), reduction of deaths (6.8%), respecting traffic laws and rules (4.6%), source of funds (3.2%)

Discussion

We aimed to measure the public's experience, views, and perceptions on ASE and road safety in Rwanda, and to assess if perceptions differed by driving status (non-drivers versus vehicle drivers, versus motorcycle drivers). This study provides critical information as it shares the public insights into the first national scale up of ASE in an African, low-income country. Such insights are critical for addressing a research gap in understanding the implementation and the public perceptions of such programs in LMICs and in Africa. Additionally, this study generated a rich data set for local policy makers and the Rwanda National Police to consider in their work and/or to serve as a baseline by which the impact of interventions that may change public knowledge, attitudes and practices can be evaluated.

Key findings related to ASE included those respondents reported hearing about ASE through a variety of sources, but namely "on the roads" and through "word of mouth". Few respondents reported hearing about ASE from the police. Nearly all respondents understood that cameras are used to monitor speed, with a smaller proportion reporting that cameras can enforce when vehicles do not adhere to a red-light signal, drivers drive with unpaid violations, or speak on the phone while driving. To the best of our knowledge, cameras in Rwanda can assess speed violations, signal violations, unpaid violations, driving without active insurance, and driving without active vehicle inspection, indicating some gaps in knowledge among respondents.

When posed with questions on the primary reason that Rwanda implemented ASE, most respondents reported good intentions including 'to improve road safety and reduce driving speeds' and 'to reduce corruption and conflict between police and road users. Similar trends were shown when respondents were asked to select if they agree with numerous statements about ASE. A majority of respondents agreed with positive statements about ASE including that the system makes roads safer, reduces injuries and deaths, reduces corruption, and increases security. Most respondents felt that speed cameras are fair, accurate, and trustworthy. When comparing these results between groups, most of the significant differences were shown between households and drivers/motorcyclists.

Two specific items which had some disagreement included 'the police had a sensitization campaign to sensitise road users about speed cameras.' Given the lack of agreement on this statement, it may indicate that the sensitization campaign was not as extensive or as far reaching as it could have been. A related item which had mixed views was "cameras are hidden and drivers are not specifically warned about cameras operating ahead so that drivers respect speed limits everywhere, not just at the camera sites." respondents did not widely agree on the utility or purpose of covert speed cameras, which may be related to the finding on sensitization above, in which this could have been communicated more clearly as part of campaigns. However, most ASE implementation guidelines recommend an intensive public sensitization campaign to decrease the risks of negative public perception that could instigate removal or disabling of ASE by the judiciary or other sectors of governments. It is interesting to note that several reports indicate that ASE programs are generally controversial anywhere they are deployed, but this was not the case in Rwanda despite the potential of limited reach of public sensitization campaigns (43).

One notable finding from the survey which may explain some results was that respondents nearly universally stated that road user risk factors such as excessive/inappropriate speeding, drink-driving, and not wearing a seatbelt contributed to injuries and deaths in the country. Drivers reported that limited post-crash care capacity played a key role in increasing the risk of injury or death than other categories. Such strong buy-in was not demonstrated for any other category of risk factor (e.g., road, vehicle). This finding may explain why the public feel strong support for ASE given it targets a key road user risk factor. However, it's especially interesting that there was so much awareness of the association between speeding and the risk of road traffic crashes and injuries in Rwanda, as other studies have found less awareness in their respondents. Study participants from rural England who had been charged with speeding offences frequently expressed anger and injustice, claiming that because they personally were highly skilled drivers and the evidence that speeding was dangerous did not apply to them (44). We can only speculate on the reasons for these differences, but they are interesting, validate the need for research to understand what systematic cultural differences between people may be that demand different types of road safety initiatives and motivate future studies.

Unsurprisingly, 43.2% of participants who reported being involved in a crash were passengers on a moto or pedestrians, followed by car and moto drivers. This finding is consistent with what were found in different studies where the two categories were found to be the most vulnerable road users (3). Driving a bicycle or being a passenger on a bicycle were the least to contributory factors to the involvement in a crash and that can be explained by small numbers, underreporting, or using roads that are not clouded by vehicles mostly in rural areas.

Another interesting finding from the survey was the contrast between how people feel about the safety of the roads, in which respondents indicated that Rwanda roads are safe. On a scale of 1 to 10, with 1 indicating very safe and 10 indicating very unsafe, the overall mean was 3.13. There were some differences between groups indicating that vehicle and motorcycle drivers think roads are significantly less safe than household non-drivers do. The finding is similar to what was found in the ESRA2 study in 12 African countries where a general trend towards feeling safe on roads was found and pedestrians felt safer than those using other transport modes among which powered two wheelers felt less safe (45). This finding is also striking in light of the high incidence of road traffic crash involvement (29.1% of vehicle drivers, 24.3% of motorcycle drivers, and 13.3% of non-drivers) in the survey, and the high reported injuries associated with these crashes.

Limitations

Our results are subject to some limitations especially in that we cannot verify that respondents understood the questions being posed to them but dutifully responded as if they had an informed opinion. Quantitative surveys to assess perceptions will always be subject to this risk and we attempted to mitigate it through training of enumerators in the subject matter the questions addressed and delivery of the survey in person and in the mother tongue of the Rwandan people. For future surveys like this we recommend multiple rounds of pilot testing to assure that questions are clear and not amenable to interpretation. Our household sample was derived from the same frame used for the 2012 census in order to be representative, but a new census conducted in 2022 (not yet published at the time of our data collection) includes some significant shifts in population demographics and urban migration. This could leave our sample to be less representative than we intended and shorten the duration of time for which our findings should be considered relevant by some margin. We also did not apply weighting to the data collected. The decision to select our sample from households was motivated in part by our lack of a reliable national database from which to sample a population of drivers and motorcyclists, but we hope that the geographic diversity represented in our sample helped us to achieve a sample representing all Rwandans.

Recommendations

While our team advocates for effective and continuous communication to achieve sensitization of the public before and during the implementation of ASE program we also suspect that our findings support alternatives to this approach. Our results are somewhat discordant in that there was broad support for ASE, correct understanding of the road safety benefits ASE can generate but also report of limited communication about

ASE to the public. Informants of our study to document the Rwandan ASE program design and implementation processes corroborated the idea that there was an inadequate public sensitization campaign and the Rwandan National Police enthusiastically responded to this. Much of their response was grounded in the logic that if you simply don't driver over the speed limit or violate other traffic laws you won't have any problem with ASE. Further, they commented on the need to adopt a safe systems approach to something as mission critical as improving the safety of Rwandan roads. People will always be at risk of making errors that end up harming or killing them, and the police feel a duty to keep the people safe. Rwanda is full of evidence that the government cares for the people first, and is constantly seeking investments in their future prosperity and well-being. The trust and goodwill this generates in a population perhaps obviates the benefits that would otherwise be achieved from specific campaigns to sensitise the public to controversial policy.

This study was an opportunity to collect a tremendous amount of data from the population relevant to African road safety and ASE. We also learned so much by engaging in this study. Therefore, we recommend that especially countries planning an ASE program should conduct a survey of this kind to understand the public perception as it helps identify possible gaps but is also one of the ways to evaluate the impact. Surveys from different countries can be adapted to the local context such that direct comparisons of findings across borders is possible. The countrywide survey should be well prepared ahead of time with appropriate design of the data collection tool, adequate training of enumerators, piloting and subsequent adjustment, timely involvement of local leaders and ensuring the availability of all needed approvals. During this survey, random sampling of households was conducted but villages not visited before the start of data collection which caused significant challenges related to accessibility and field logistics. Better understanding of the field by visiting or using enumerators who know the selected areas is highly recommended for a smooth exercise. Dedicating enough resources and time to the activity is mandatory to ensure the accuracy of the collected data.

Finally, we recommend recruiting crucial stakeholders from institutions like the police and various community members at the research design stage to engage in co-production of data collection tools and analysis planning. Decision focused evaluations methods are excellent ways to assure that the right questions are considered in the right context by researchers so that they can generate results that directly answer the questions of policy makers and support prioritisation of regulations and interventions (46). These methods require upfront investment of time and resources from the research team but their outputs can often pay much larger dividends than research methods that aim to be generalizable to other contexts for the sake of knowledge generation.

Conclusion

According to the findings of the survey, the public perception of automated speed enforcement in Rwanda is not significantly different between different categories of the population. Most people living in Rwanda think ASE was initiated with positive intent and acknowledge its impacts such as reduction of road crashes and deaths, prevention of corruption and making roads safer. The public correctly knows that speeding is a risk factor for crashes and that cameras are used to monitor speed. Even though the vast majority of drivers have been issued a citation by the cameras at some point, only a small percentage of individuals regard ASE as a method for generating revenues and impoverishing drivers. Even though some may feel inconvenienced by the fines, which may create controversy, majority of road users agree that speed cameras and the delivery of citations are fair, which confirm the importance of ASE as a tool for improving public safety, a sign of country development and a government that works for the people.

Synthesized Recommendations Across the Study

We are grateful for the support from the World Bank for our team to engage in this overall ASE research project in Rwanda that would inform a follow up publication to the "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement," aimed specifically at African LMIC's where the highest burden of road traffic crashes, injuries, and deaths are experienced. Once a country has determined they are ready to pursue their own ASE program using the aforenoted guide, they can examine this case study from Rwanda to support their own design and implementation strategies. We have adapted the checklist with our assessments of Rwanda's specific readiness as reported by our respondents. Notable achievements include substantial political support for ASE, strong regulatory and enforcement frameworks that promote vehicular registration, and linking national identification to a unique mobile phone number that facilitates real-time, digital feedback to vehicle owners of an over-speeding infraction. A table of the specific assessments of Rwanda can be found in the executive summaries.

Below we present recommendations from our team rooted in the literature and guided by our experience in Rwanda. We have synthesized these recommendations into a "Checklist for ASE program design, implementation, maintenance and evaluation" and imagined that this publication can work in concert with the "Guide for Determining Readiness for Speed Cameras and Other Automated Enforcement" to provide a full package to support other African LMIC in their ASE considerations.

Briefly, the checklist outlines activities within four sections: 1) program preparation and coordination, 2) program design steps, 3) program implementation steps, and 4) program maintenance and evaluation. We synthesize our experience and lessons into tangible check list items. For example, in the program preparation, we recommend updates to traffic laws to ensure speed limits are updated prior to ASE implementation, as was done in Rwanda.

In addition to this checklist found in the executive summaries we provide cross-cutting recommendations for Rwanda, countries considering implementation ASE, and researchers hoping to conduct evaluations of ASE in similar contexts.

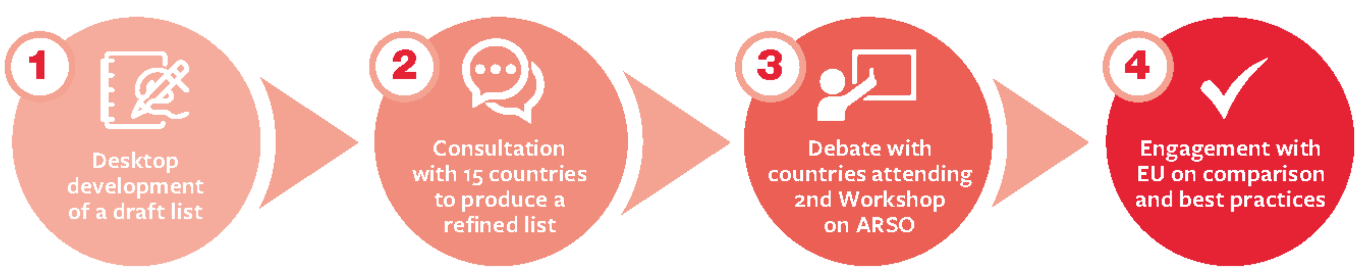
Co-production and collaboration with in-country partners is essential.

One key lesson from this work was the importance of co-creation and collaboration with in-country partners. We developed a strong partnership within our research team (HPR and TIRF) and with the RNP during the study. However, the police were not engaged in proposal writing, planning, and design. As such, we had written the proposal to assess implementation and impact without a complete understanding of the data limitations and confidentiality concerns which affected numerous components of this project. In retrospect, if the RNP were fully invested co-creators from the outset, we could have better communicated the importance of conducting high-quality and rigorous research, which would benefit their road safety efforts in country. A few examples in which we saw potential opportunities for improvement in this regard include during the qualitative interviews, in which we could have better communicated to emphasize the importance of transparency and the importance of including the right stakeholders (i.e., those that were involved with the design, planning and implementation of ASE). We ultimately addressed this challenge by conducting several participatory feedback sessions. Another example is the issues with obtaining precise locations of ASE units. We had initially intended on measuring the impact for precise locations but found that the police were not able to share this confidential information with us. As noted above, this could have been avoided if we had included them from the outset and agreed to access and store this information. This also would have protected us from time- and resource-constraints associated with making requests of a police force that may have dramatic and rapidly shifting priorities. Importantly, co-production could also ensure that the evaluation is directly answering questions which are relevant for their policy and implementation efforts and contribute to reductions in road traffic injuries and deaths, the ultimate goal of this work.

High-quality data systems need to be developed, maintained, and used for rigorous research.

Another notable lesson from this work is the importance of high-quality data systems. Through our entire study the overarching challenge we faced as researchers was limited data on road traffic crashes, injuries, and deaths, and limited specificity of the data (i.e., no locations, times, factors). Although we acknowledge that it is not possible for any police department to capture all data on crashes, particularly those which are never reported to them without diligent searching of other data sources. The lack of digitized and cross-linked databases resulted in substantial time- and resource-intensive data compiling and quality checking processes. Certain quality issues we found were impossible to overcome and resulted in use of alternate analyses that were less valuable than we hoped to be able to perform.

In 2021 the Africa Transport Program published a guide entitled "Road Safety Data in Africa: A Proposed Minimum Set of Road Safety Indicators for Data Collection, Analysis, and Reporting" that our research team believes could serve as an excellent guide and benchmark that governments preparing for ASE programs can use to improve their road safety data quality (47). They describe the rigorous design process of their recommended indicators that have been integrated into the African Road Safety Charter from the African Road Safety Observatory (ARSO) and African Union: "The minimum set of indicators can serve as a powerful tool, making it possible to identify and quantify road safety problems throughout Africa, evaluate the efficiency of road safety measures, determine the relevance of community actions, and facilitate the exchange of experience in this field. It is accepted that more variables and values may be necessary to better describe and analyze the road crash phenomenon than is provided in the minimum set of indicators. The flexibility of the set makes it possible for countries to add more variables should their management systems require it. A minimum set of standardized data elements has been developed which allow for comparable road crash data to be available nationally, regionally, and internationally. The number of indicators varies depending on the level of reporting. The figure below summarizes these steps:"



Source | Road Safety Data in Afraic: A prposed minimum set of raod safety indicators for data collection, analysis and reporting. Figure 6, Steps to derive consensus on ARSO crash-related variables.

Additionally, these indicators can all be digitally collected, stored, visualized in a graphical dashboard and continuously analysed through the Data for Road Incident Visualization Evaluation and Reporting (DRIVER) open-source system by the GRSF(48). Maintaining data in this manner would facilitate higher quality spatial and spatiotemporal analyses of ASE and other road safety interventions.

Research should be conducted more frequently to determine the most effective implementation strategies and road user perceptions.

Another notable lesson, and strength of this work, was the gap in research for this topic area in Rwanda and other LMICs. Although components of the study could be improved in future work, we are proud to contribute insights to this notable research gap. Throughout each study, we realized that when comparing our findings on the implementation, impact, and the public perceptions to prior studies, nearly all were from high-resource settings. This matches macro research trends which indicate that less than 10% of all road safety research takes place in LMICs (9). Beyond this well-known and documented gap, we also noted that there was not an existing culture of conducting research and generating evidence on how to implement such an intervention. In our qualitative study, one of our key takeaways was the need for the RNP and in-country partners to conduct research studies to better understand the best way to implement the cameras, including the visibility, signs associated with the cameras, and potential dynamic feedback that can be included. Such an advanced system, densely blanketing Rwandan roads, with the ability to collect traffic count data, there are numerous possible ways to use these systems to get a better understanding of road traffic patterns and to conduct studies testing various implementation strategies.

Such research could also inform certain decisions (e.g., covert versus overt cameras, no warning signs) and address potential controversies which are typically associated with ASE programs (43). Closely related to this is the recommendation to conduct research on public perceptions. This study was an opportunity to collect a tremendous amount of data from the population relevant to African road safety and ASE. We also learned much by engaging in this study. We recommend that countries planning an ASE program should conduct a survey of this kind to understand the public perception as it helps identify possible gaps but is also one of the ways to evaluate the impact. Surveys from different countries can be adapted to the local context such that direct comparisons of findings across borders is possible. The countrywide survey should be well prepared ahead of time with appropriate design of the data collection tool, adequate training of enumerators, piloting and subsequent adjustment, timely involvement of local leaders and ensuring the availability of all needed approvals. Dedicating enough resources and time to the activity is mandatory to ensure the accuracy of the collected data.

Data on baseline speeds, traffic, and road safety indicators is necessary to understand the impact of ASE.

Closely related to the two prior lessons, we also found that the lack of routine data on traffic counts, speed distribution, economic indicators, and other measures associated with road safety hindered our ability to assess the impact of ASE on speed outcomes and injury/death outcomes. First, for the interrupted time series, we were not able to obtain any traffic counts, or fuel consumption measures to estimate exposure. Instead, we used population, which may not be the best proxy for exposure to road traffic crashes and injuries. Unable to obtain data for a control (i.e., a similar country) we tried to capture all time-varying confounders (e.g., COVID-19 restrictions, other road safety policies), which may have affected trends in crashes, injuries, and deaths.

Similarly, for the cross-sectional study, we would have ideally measured baseline estimates and distributions of speed before a unit was implemented to reduce bias. However, given time and resource constraints and a strict schedule for ASE camera installation, we were not able to collect the data prior to overt cameras being installed. Instead, we relied on the expertise of police to determine locations which are matched on road conditions and would be suitable for ASE systems to match existing locations. We would highly recommend that future researchers obtain or collect their own data to meet the study requirements.

Road users should be included and given adequate information about ASE implementation.

Across the studies, we found some indications that certain components of the program may not have adequately prepared road users for the ASE program. For example, in the qualitative study, participants noted some concerns about the length and manner of the sensitization campaign, which may not have been aligned with international recommendations to provide a warning period without citations. In the public perceptions survey, we found that most participants agreed with positive statements about ASE (e.g., "the system makes roads safer"). However, one statement, "the police had a sensitization campaign to sensitize road users about the speed cameras" did not have high levels of agreement, indicating that the campaign was not as extensive and far-reaching as the police may have intended. Informing the public and providing a warning period could greatly reduce negative experiences and controversies.

ASE should not be seen as the silver bullet to solving all road safety issues.

Lastly, although our studies show positive effects, a successful implementation, and positive public perception about the intent and impact of ASE in Rwanda, we still feel that ASE should be treated as one component of a comprehensive speed management system. For example, in our experiment, we found localized impacts of overt cameras on mean speeds, the number of vehicles violating the speed limit, and the number of vehicles exceeding the speed limit by any amount for all vehicles, cars, motorcycles, commercial heavy vehicles, and commercial public transport vehicles. However, this effect was specific to the area of the camera, and the program does not seem to be affecting overall speeds on Rwandan roads. As such, there may be other ways to improve compliance with speed limits, such as including engineering treatments to slow down motor vehicles and separating road users, changing behaviour through campaigns, and implementing speed zones/limits by functions (22).

Conclusion and Next Steps

These studies have produced novel and valuable information about a national ASE program in an African low-income country. Describing the design and implementation processes of ASE, verifying a localized decrease in measured vehicle speeds associated with overt ASE and detailing the public perceptions of Rwandan ASE generated new knowledge and built a foundation for future growth.

We are cognizant of the limited results this research can confidently generate, and further study with more comprehensive data will surely improve the understanding of ASE impacts in Rwanda and other African countries. Specifically, there is potential to compare our findings with the North African, lower-middle income country of Morocco that has a much greater land mass than Rwanda and a longer history with ASE. Additionally, the lack of road use exposure data uncovered in this research can be an effective driver of change to improve data quality and quantity that will support future studies. Rwanda is not unique in our data limitations, contributing to the generally low road safety research productivity across African LMICs. This ASE evaluation, the challenges to road safety research and the recommendations generated from the overall experience could form the basis for a continental working group that generates African solutions to the problem of road safety in Africa. One such solution may be broader incorporation of ASE programs into national road safety strategies in African countries.

We hope that posterity will find this report to be an African road safety case study in humility and effective methods to catalyse rapid development and research quality improvement. If realized, the impacts of this research on the impacts of ASE in Rwanda to develop recommendations for African countries could contribute exponentially greater value than originally anticipated at the launch of this project.

Appendix A

An Interrupted Time Series Analysis of the Impact of Automated Speed Enforcement on Road Traffic Crashes, Injuries and Deaths in Rwanda from 2010-2022

Methods

Objective

The objective of this study was to describe the association of ASE implementation on reduction of road deaths, and fatal and serious injury collisions in the first years of implementation in the provinces and the whole of Rwanda, filling a gap in knowledge regarding the effectiveness of ASE in Africa, and in LMICs. Additionally, we sought to determine if the trend was consistent across provinces. Our hypothesis is that the reduction of road deaths and fatal and serious injury collisions can be associated to the implementation of ASE cameras.

Study description

This study was conducted to quantify the association of ASE cameras, and other concurrent road safety interventions, e.g., campaigns on improving the road safety in Rwanda, by analysing the trend of crashes resulting in death and serious injury. The crash data were collected from the Rwanda National Police (RNP) based on their official reports (49). Additionally, the relation between COVID-19 restrictions and crashes was considered because the implementation period overlaps with the study period.

Data sources and sampling

The RNP investigate and maintain a database of all road traffic crashes that was provided for the study period (49). They are also responsible for the network of ASE across the country and provided the installation and activation dates of each individual camera, as well as the number of cameras installed and activated per district each month during the study period. COVID-19 data were obtained through government publications and the public press. These data were corroborated by study team members present in Rwanda during the period of pandemic-related restrictions. Information on other concurrent interventions aimed at reducing crashes were obtained from press reports and the RNP's and research team's knowledge of such interventions in Rwanda over the study period (e.g., stricter enforcement of drunk driving). Finally, national, annual GDP, and unemployment rate data were gathered from the National Bank of Rwanda and the Institute of Statistics, respectively.

Data collection

This section describes how the data were collected. This includes crash data, ASE implementation information, exposure data, COVID-19 data, and information on additional road safety measures.

Crash data

This study utilizes data on the number of road deaths, crashes with at least one death plus serious injury crashes for all provinces in Rwanda (the City of Kigali (COK), Northern, Southern, Western, Eastern provinces) within the timespan detailed in Table 5. Note that the number of road deaths were presented as an incidence rate. The incidence rate was calculated as the ratio of the number of monthly road deaths to the monthly population (per

100,000 people). The investigating police officers collected these data on a paper form up until 2022 at which point, they began collecting nearly the same variables but on a tablet device. The form fields can be found in the Supplementary Materials.

Table 5 | Police crash investigation data availability

Time series	Timespan of Data
Number of Road Deaths	Jan 2010 - Dec 2022
Number of Death Crashes	Oct 2014 - Dec 2022
Number of Serious Injury Crashes	Jan 2010 - Dec 2022

Data were not uniform as the reporting system changed over time, but available data were organized per district per month. A police officer was tasked to extract data from archives register books and share them with the HPR research team. Before the year 2022, crash data were collected by trained crash investigation police officers on paper then aggregated data was sent to the central level where they were kept in registers while from January 2022, electronic individual crash data were sent to the central level where a designated team continuously organize them in a database. Generally, crash data are categorized into crashes and victims. Before 2014, crashes were only categorized as serious and minor injuries. After 2014, the crash category was expanded to include death, serious, minor injuries, and property damage-only crashes. Definitions for injury severity are as follows: all RTIs involving a loss of body part and severely/moderate sick victims are initially counted as serious, and all others are counted as minor injuries. The victims' category constantly contains deceased and injured victims. Thirty days post-crash, the hospital is contacted to find out the outcomes for the victims. If the victim has died, he/she is considered a death injury, those that resulted in permanent disability are counted as serious. For instance, if an individual was in a crash on January 15, 2022, and passed away on February 15, 2022, as a result of that same crash, this would be considered a death occurring in January 2022. It was not uncommon to find delays to inclusion in the database sometimes of many months while paper reports may be held in the judicial system, but this was remedied by the initiation of digital, individual crash data transfer in 2022.

ASE implementation data

Table 6 presents information on the date and number of installed ASE cameras in the provinces of Rwanda, as provided by the RNP (49). Note that ASE cameras include fixed cameras, semi-fixed cameras, mobile cameras, enforcement fine cameras, and red-light cameras. The installation dates of ASE cameras were designated as ASE Cameras-location-n, with location indicating province or the whole of country and n indicating the counter of the set of cameras installed on sequential dates. An instance of this can be seen in the label ASE Cameras-COK-03, where it indicates that 10 ASE cameras were set up at COK in April 2021 and the label itself refers to the third row of table 2 for COK.

Table 6 | Number of ASE cameras installed in provinces of Rwanda on different dates

Province	Date	Label	Number of ASE Camera
City of Kigali (COK)	30-Jul-19	ASE Cameras-COK-01	1
	30-Jan-21	ASE Cameras-COK-02	2
	30-Apr-21	ASE Cameras-COK-03	10
	30-Jun-21	ASE Cameras-COK-04	2
	30-Aug-21	ASE Cameras-COK-05	4
	30-Sep-21	ASE Cameras-COK-06	12
	30-Oct-21	ASE Cameras-COK-07	2
	30-Nov-21	ASE Cameras-COK-08	2
	30-Dec-21	ASE Cameras-COK-09	6
	30-Jan-22	ASE Cameras-COK-10	39
	28-Feb-22	ASE Cameras-COK-11	1
	30-Mar-22	ASE Cameras-COK-12	2
	30-May-22	ASE Cameras-COK-13	6
	30-Nov-22	ASE Cameras-COK-14	4
North	30-Jun-21	ASE Cameras-Northern-01	7
	30-Jul-21	ASE Cameras-Northern-02	5
	30-Sep-21	ASE Cameras-Northern-03	19
	30-Jan-22	ASE Cameras-Northern-04	1
	30-Mar-22	ASE Cameras-Northern-05	6
	30-Aug-22	ASE Cameras-Northern-06	2
West	30-Sep-21	ASE Cameras-Western-01	43
	30-Jun-22	ASE Cameras-Western-02	10
	30-Aug-22	ASE Cameras-Western-03	3
	30-Dec-22	ASE Cameras-Western-04	4
South	30-Jul-19	ASE Cameras-Southern-01	1
	30-Aug-21	ASE Cameras-Southern-02	31
	30-Sep-21	ASE Cameras-Southern-03	7
	30-Nov-21	ASE Cameras-Southern-04	4
	30-Mar-22	ASE Cameras-Southern-05	16
	30-Aug-22	ASE Cameras-Southern-06	1
	30-Dec-22	ASE Cameras-Southern-07	7

Province	Date	Label	Number of ASE Camera
East	30-Jul-19	ASE Cameras-Eastern-01	3
	30-Jan-21	ASE Cameras-Eastern-02	2
	30-Sep-21	ASE Cameras-Eastern-03	25
	30-Nov-21	ASE Cameras-Eastern-04	10
	30-Jan-22	ASE Cameras-Eastern-05	1
	28-Feb-22	ASE Cameras-Eastern-06	32
	30-Jun-22	ASE Cameras-Eastern-07	1
	30-Nov-22	ASE Cameras-Eastern-08	2
Cumulative National Total	30-Jul-19	ASE Cameras-Rwanda-01	5
	30-Jan-21	ASE Cameras-Rwanda-02	4
	30-Apr-21	ASE Cameras-Rwanda-03	10
	30-Jun-21	ASE Cameras-Rwanda-04	9
	30-Jul-21	ASE Cameras-Rwanda-05	5
	30-Aug-21	ASE Cameras-Rwanda-06	35
	30-Sep-21	ASE Cameras-Rwanda-07	106
	30-Oct-21	ASE Cameras-Rwanda-08	2
	30-Nov-21	ASE Cameras-Rwanda-09	16
	30-Dec-21	ASE Cameras-Rwanda-10	6
	30-Jan-22	ASE Cameras-Rwanda-11	41
	28-Feb-22	ASE Cameras-Rwanda-12	33
	30-Mar-22	ASE Cameras-Rwanda-13	24
	30-May-22	ASE Cameras-Rwanda-14	6
	30-Jun-22	ASE Cameras-Rwanda-15	11
	30-Aug-22	ASE Cameras-Rwanda-16	6
	30-Nov-22	ASE Cameras-Rwanda-17	6
	30-Dec-22	ASE Cameras-Rwanda-18	11

Exposure data

As commonly used exposure data, e.g., Vehicle Kilometres Travelled (VKT) or Annual Average Daily Traffic (AADT), were not accessible in this study, other exposure variables such as annual GDP, Quarterly GDP (50), the annual unemployment rate from 2010 to 2022, and population (51) as national-level data were used as available surrogates to add context to crash rates.

COVID-19 data

Table 7 provides the start and end dates of COVID-19 restrictions in Rwanda. This includes lockdowns, a curfew at 7:00 pm, a ban of inter-district movement, and closing of schools and bars (52). These restrictions were implemented in all provinces, except the COK, which did not implement the second curfew at 7:00 pm. Noting that the official start date of the COVID-19 pandemic in Rwanda was March 2020, which we used as an intervention in our time series analysis.

Additional road safety measures

Table 8 describes other road safety measures that were implemented during the study period. These include the Gerayo Amahoro campaign, traffic month, launches of new unmarked patrol vehicles, Breathalyzer use, and speed governor along with their effective dates. We obtained this information from different publications including the official National gazette, RNP's website, magazine, local newspapers, official social media sources and detailed information on these policies and sources can be found in Table A.1 (see the Supplementary Materials).

Table 7 | Effective period of different types of COVID-19 restrictions implemented in Rwanda

COVID-19 Restriction Type	Description	First Effective Period	Second Effective Period	Third Effective Period	Fourth Effective Period
Lockdown	Public transport and outdoor movements are not permitted. Public and private businesses and schools closed. Personal transportation continues, motorcycles/bicycles are not permitted to carry passengers.	March 2020 - April 2020	January 2020 - February 2021	July 2021	-
Curfew at 6:00 pm	Countrywide day-time curfew results in closing shops/businesses at 6:00 pm	July 2021 - August 2021	-	-	-
Curfew at 7:00 pm	Countrywide day-time curfew results in closing shops/businesses at 7:00 pm	February 2021	April 2021 - June 2021	-	-
Inter-district Movement	Movement between districts was prohibited	March 2020 - April 2020	August 2020 - September 2020	January 2021 - March 2021	July 2021
School Closure	Schools closed/remain closed and remote learning begins	March 2020- October 2020	January 2021 - February 2021	July 2021	-
Bar Closure	Bars closed/remained closed	March 2020 - September 2020	January 2021 - October 2021	-	-

Table 8 | Effective dates of other road safety policies implemented in Rwanda

Road Safety Policy	Description	Date of Effectiveness
Gerayo Amahoro Campaign	Rwandan road safety campaign to educate road users on safety and precautionary measures to reduce the number of crashes	Start: May 2019 (phase 1) End: March 2020 (39^{th} week)
Traffic week	Road safety campaigns were conducted codenamed traffic week	April and August - September 2014
Launches new unmarked patrol vehicles	Dispatch of unmarked police cars equipped with overhead removable traffic lights that are dispatched across the country with plain-clothed police officers.	Start: September 2016 End: Ongoing
Breathalyzer use in Rwanda	Incorporated additional measures, such as implementing stricter penalties for drunk driving, in addition to alcohol testing.	Start: March 2010 End: Ongoing
Speed Governor	Speed limit measures were initiated in public service and commercial vehicles to limit speed to 60km/hr using a speed governor installed in the vehicle.	Start: February 2016 End: Ongoing

Statistical analysis: interrupted time series regression

The time series used in this study are the monthly incidence of road deaths per 100,000 people, and the frequency of crashes resulting in deaths, and serious injuries for both the individual provinces and the entirety of Rwanda. Note that crash locations as well as data on camera locations are not available for the whole study period (2010-2022), which is detailed in the study limitations section. Therefore, a controlled before and after study cannot be used to evaluate the effect of installed cameras in this study on crashes and injuries. Please see the additional report of the experimental data we collected to assess changes in vehicle speeds in response to overt cameras that adds some additional information on the impacts of ASE in Rwanda.

This study conducted interrupted time series regression to measure the association of ASE cameras on reduction of road traffic crashes. This methodology has been used previously to evaluate interventions like law enforcement programs to estimate their effectiveness in improving road safety and forecasting traffic crashes (53-57).

An interrupted time series (ITS) model including Seasonal Autoregressive Integrated Moving Average (SARIMA) error was used to assess the association of ASE cameras on reduction of road traffic crashes. Confounders including regression to the mean were controlled for through the SARIMA method. The analysis evaluated the association of ASE cameras on changes in the number of crashes while controlling for other explanatory variables including available exposure factors (e.g. GDP, population), the start of COVID-19 and its associated restrictions (e.g., lockdown and curfew), and other factors such as the use of unmarked patrol vehicles, Breathalyzer implementation, and road safety campaigns.

SARIMA represents a special case of time series modelling, as it can be applied to non-stationary data and data containing seasonality (58, 59). It consists of seasonal (S), autoregressive (AR), integrative (I), and moving average (MA) components (60). In this study, SARIMA with the following formula was used to mathematically identify trends and seasonal components using the Box-Jenkins method (for details see (58, 61)).

$$Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i X_t + N_t$$

Where Xt, Yt, and Nt represent the explanatory variables, the response variable, and a SARIMA model, respectively. Under the assumption that an intervention occurs in 'u' time, a dummy variable equal to 0 before the intervention (e.g., start of COVID-19) and 1 after that can be applied (62). The method employed for selecting explanatory variables in the model was backward stepwise regression, which involves starting with all predictor variables in the model and only variables with lowest p-values were retained to ensure that our best selected models accurately represented the data and were well-fitted to actual data (58, 61). The Akaike Information Criterion (AIC) is utilized to compare different possible models, models better fit to the data will result in a lower AIC score (58, 59). Another important step for choosing the best model is checking if the residuals are white noise. White noise is a type of stationary random process commonly used in time series analysis that is distinguished by two key features: a mean of zero and the absence of autocorrelation. The residual plots were examined for zero-mean and the white noise (Wntestq) test was conducted to test for autocorrelation. The null hypothesis of the test is that the residuals of ITS models are uncorrelated.

Results

Descriptive Statistics and Temporal Trends

Rwanda experienced 7,835 police-reported road deaths over 13 years (an average of 603 deaths per year), resulting in an average of 5.43 annual deaths per 100,000 people from 2010 to 2022. In this regard, the city of Kigali had the largest number of all types of crashes from 2010 to 2022, e.g., an incidence of 123.71 road deaths (total of 1,666) per 100,000 people.

The annual incidence of road death exhibited an initial reduction, declining from 3.46 in 2010 to 3.12 in 2011. Nevertheless, from 2011 onward, an increasing trend with slight variations persisted until the year 2022, as illustrated in Figure 3. This consistent pattern is mirrored in the count of fatal crashes spanning from January 2015 to the conclusion of 2022 (refer to Figure 5).

Figure 3 | Incidence of Annual Road Deaths per 100,000 people in Rwanda | 2010 - 2020

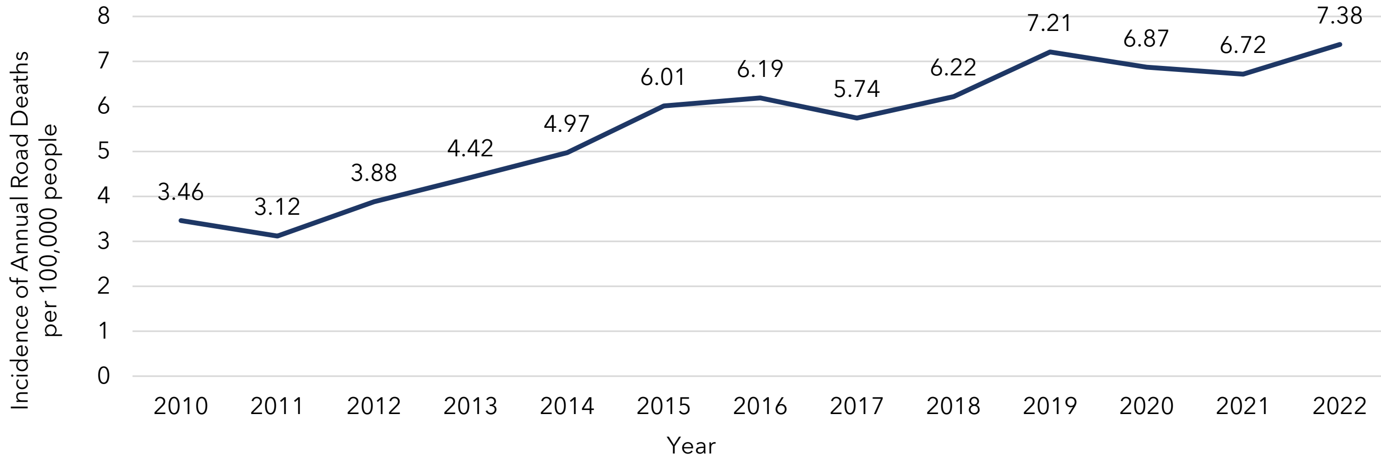


Figure 5 | Number of Annual Road Fatal Crashes in Rwanda | 2015 - 2022

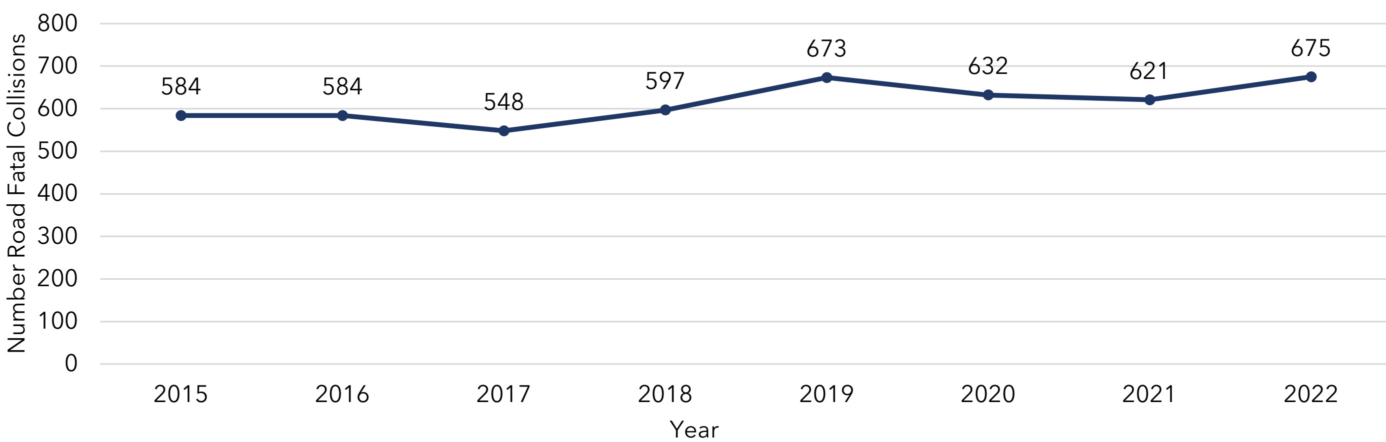
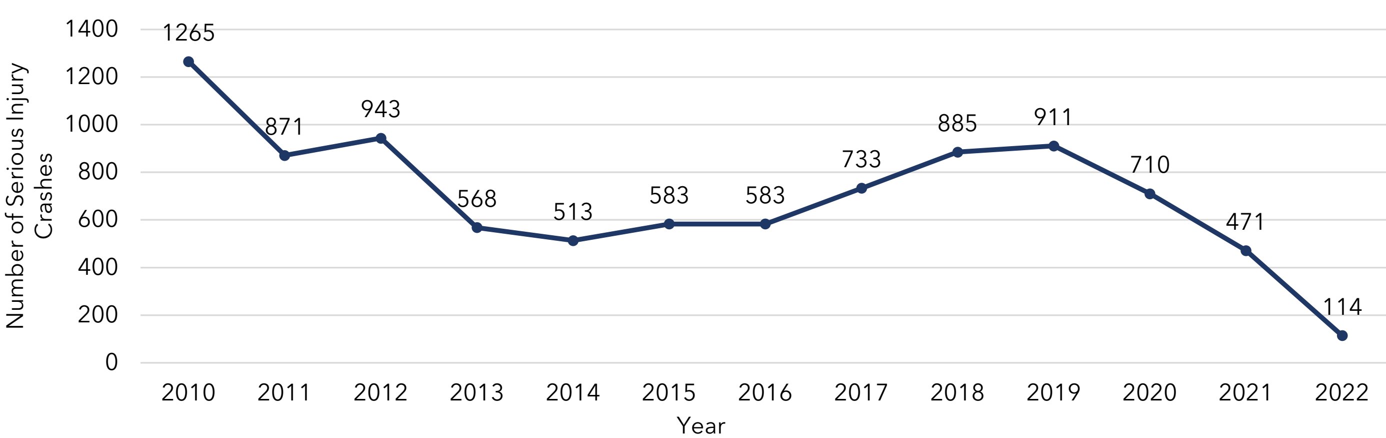


Figure 6 | Number of Annual Serious Injury Crashes in Rwanda | 2015 - 2022



There was a total of 9,150 serious injury crashes in Rwanda. Figure 6 shows a reduction in annual serious injury crashes from 1,265 in 2010 to 114 in 2022, with fluctuations, particularly in the last five years of the study period.

The highest frequency of all types of crashes, constituting 28% of fatalities, coincided with the extended dry season from June to August. This period corresponds to increased vacation travel. Rwanda experiences four climatic seasons encompass the lengthy rainy season from March to May, a short rainy season from September to November, alternating with the long dry season from June to August, and the short dry season from December to February.

The following results in Table C1-C3 (see Appendix C) were obtained from the ITS analysis for incidence of traffic deaths per 100,000 people from 2010 to 2022 and fatal crashes and serious injury crashes in Rwanda between 2014 and 2022.

Primary Analyses: The Impact of ASE

The primary outcome, road deaths, in Table 9 shows implementation of ASE cameras throughout Rwanda in April 2021 was linked to a significant 0.142 (95% CI [0.212, 0.072]) reduction of monthly incidence of deaths per 100,000 people over the period of April 2021 to December 2022, taking into account the exposure variable of quarterly GDP, measured at one unit in billions of Rwandan Francs, and COVID-19 measurements. This intervention was associated with a monthly mean decrease in deaths from 49.206 (January 2010-March 2021) to 30.431 (April 2021-December 2022), equating to a monthly 38.156% reduction from the rate before the implementation of ASE cameras. Furthermore, the implementation of ASE cameras in the Southern province in September 2021 was linked to a substantial reduction of 0.247 (95% CI [0.458, 0.036]) in the monthly incidence of deaths per 100,000 people. Acknowledging a significant association, an increase in quarterly GDP of one unit corresponds to a monthly rise in the incidence of deaths by 0.00027 (95% CI [0.00025, 0.00028]) across Rwanda and 0.001 (95% CI [0.000, 0.002]) in Northern province.

An important finding in the analysis of fatal crashes, shows in Table 10, is the significant correlation between ASE camera installations and a notable reduction of 11.797 (95% CI [23.389, 0.204]) and 16.257 (95% CI [30.269, 2.246]) fatal crashes per month in June 2019 and September 2021 across the entire country of Rwanda. This signifies that the installation of 106 cameras led to a more significant decrease in fatal crashes compared to the installation of 5 cameras, indicating a potentially dose-dependent association. Also, each one-unit increase in quarterly GDP corresponds to a monthly increase of 0.027 (95% CI [0.011, 0.043]) in fatal crashes throughout Rwanda. Furthermore, the deployment of ASE cameras in the Western and COK provinces was linked to a reduction in fatal crashes, exemplified by a decrease of 4.02 (95% CI [7.387, 0.654]) fatal crashes per month in COK.

In the analysis of serious injury crashes (refer to Table 11), it becomes evident that the installation of ASE cameras had a significant association with monthly reduction of serious injury crashes in the whole of Rwanda, and Eastern and Western provinces with 45.307 (95% CI [79.651, 10.963]), 6.798 (95% CI [11.036, 2.56]) and 11.288 (95% CI 18.168, 4.409]), respectively.

Secondary Analyses: The Impact of COVID-19 and Other Non-ASE Road Safety Measures

The start of the COVID-19 pandemic in the Southern province of Rwanda was associated with a significant monthly increase in the incidence of deaths by 0.188 (95% CI [0.004, 0.372]). However, the implementation of lockdown measures was associated with a significant decrease in the monthly incidence of deaths in Rwanda, the city of Kigali, and the Western province by 0.161, 0.817, and 0.255, respectively. Also, the closure of bars was associated with a 0.288 reduction in the incidence of deaths in the Southern province per month (95% CI [-0.505, -0.071]).

The start of COVID-19 in the Southern and COK provinces resulted in a significant monthly rise in fatal crashes, with an increase of 5.601, and 4.212, respectively, while the Northern provinces experienced a reduction of 3.931 in such crashes. And the start of COVID-19 in the Southern province led to a significant monthly decrease of 7.172 serious injury crashes (95% CI [11.034, 3.311]). The implementation of lockdown measures led to notable decreases in fatal crashes in Rwanda and COK and Southern provinces, with monthly reductions of 18.767 (95% CI [32.623, 4.91]), 13.366 (95% CI [18.962, 7.77]) and 4.496 (95% CI [8.906, 0.086]), respectively. Furthermore, the closure of bars and school was linked to a 4.085 (95% CI [7.055, 1.115]) and 2.994 (95% CI [5.312, 0.676]) decrease in the Southern and Western provinces, respectively. And restrictions on interdistrict movement were found to be associated with a 5.461 increase in fatal crashes in COK. Moreover, the implementation of lockdown measures was significantly associated with a 20.222 (95% CI [40.311, 0.133]) reduction in serious injury crashes per month in the whole of Rwanda.

In addition to the COVID-19 measures, the launch of the unmarked Patrol Vehicles policy in Southern province and entire of Rwanda was associated with a 0.102 (95% CI [0.170, 0.034]) and 0.091 (95% CI [0.129, 0.053]) reduction in the incidence of deaths in the entire country per month, respectively. Additionally, traffic month campaigns in the Eastern province were associated with a 0.233 (95% CI [0.334, 0.132]) decrease in the incidence of deaths per month. The implementation of Breathalyzer testing was associated with a significant monthly increase in the incidence of deaths in the city of Kigali by 0.434 (95% CI [0.243, 0.625]). Moreover, the GA campaign was linked to a monthly increase of 0.081 (95% CI [0.008, 0.155]) in the incidence of traffic deaths in the Western province.

The launch of the unmarked Patrol Vehicles policy in Southern province and entire of Rwanda was associated with a 3.622 (95% CI [6.186, 1.059]) and 5.555 (95% CI [9.343, 1.767]) reduction in the fatal crashes per month, respectively. Moreover, the launch of the unmarked Patrol Vehicle policy was significantly associated with 3.776 increase in the serious injury crashes of the Western provinces. In the Northern province, GA campaigns were associated with a monthly reduction of 2.222 (95% CI [4.429, 0.015]) in fatal crashes, while in the Eastern province, GA campaigns were associated with an increase of 4.087 (95% CI [0.265, 7.909]) in fatal crashes per month. Additionally, the implementation of speed governors in the Northern province was associated with a monthly decrease of 2.682 (95% CI [4.765, 0.599]) in fatal crashes.

Table 9 | Results of ITS analysis for incidence of traffic deaths in Rwanda, 2010-2022

	Variable	Coefficient	Standard Error	Z value	P>|z|	95% CI
Rwanda National Data	QGDP	0.00027	0.000	37.98	0.000	0.00025
	ASE Cameras-Rwanda-01	-0.047	0.026	-1.82	0.069	-0.098- -0.004
	ASE Cameras-Rwanda-03	-0.142	0.036	-3.97	0	-0.212- -0.072
	Unmarked Patrol Cars	-0.091	0.019	-4.68	0	-0.129- -0.053
	Lockdown	-0.161	0.053	-3.05	0.002	-0.264- -0.058
	Curfew 6pm	0.105	0.096	1.1	0.273	-0.083-0.293
	Noise	SARIMA(3 ,0,0)(1,0,0,12)				
	AIC[1]	-303.8253				
	Wntestq[2]	0.5645				
City of Kigali	Unmarked Patrol Cars	-0.191	0.1	-1.91	0.056	-0.387-0.005
	Breathalyzer Test	0.434	0.097	4.46	0	0.243-0.625
	Lockdown	-0.817	0.412	-1.98	0.048	-1.626- -0.009
	Interdistrict restrict	0.505	0.278	1.82	0.069	-0.039-1.05
	Constant	0.624	0.026	24.35	0	0.574-0.675
	Noise	SARIMA(4,0,0)(1,0,0,15)				
	AIC[1]	83.34476				
	Wntestq[2]	0.6651				
Eastern Province	ASE Cameras-Eastern-03	-0.043	0.065	-0.660	0.511	-0.171
	GA Campaign	0.047	0.043	1.080	0.280	-0.038
	Traffic month Campaign	-0.233	0.052	-4.510	0.000	-0.334
	Interdistrict Restrict	-0.075	0.087	-0.860	0.389	-0.244
	Constant	0.420	0.023	18.580	0.000	0.375
	Noise	SARIMA(0,0,0)(1,0,0,12)				
	AIC[1]	-145.085				
	Wntestq[2]	0.662				

	Variable	Coefficient	Standard Error	Z value	P>|z|	95% CI
Northern Province	QGDP	0.001	0.000	3.380	0.001	0.000
	GA Campaign	-0.073	0.071	-1.020	0.306	-0.213
	Start COVID-19	-0.105	0.060	-1.760	0.079	-0.222
	Speed Governor	-0.055	0.048	-1.150	0.251	-0.149
	Constant	-0.418	0.242	-1.730	0.084	-0.893
	Noise	SARIMA(0,0,0)(0,0,0,12)				
	AIC[1]	-84.604				
	Wntestq[2]	0.684				
Western Province	ASE Cameras-Western-01	-0.102	0.06	-1.71	0.088	-0.218-0.015
	Campaign	0.081	0.037	2.18	0.029	0.008-0.155
	Unmarked Patrol Cars	-0.065	0.06	-1.09	0.274	-0.182-0.052
	Breathalyzer Test	0.108	0.06	1.8	0.073	-0.01-0.226
	Lockdown	-0.255	0.079	-3.24	0.001	-0.409- -0.101
	Constant	0.332	0.021	15.77	0	0.291-0.373
	Noise	SARIMA(0,0,0)(1,0,0,12)				
	AIC[1]	-163.184				
	Wntestq[2]	0.3578				
Southern Province	Population	3.380e-07	1.620e-07	2.080	0.037	1.960e-08
	ASE Cameras-Southern-03	-0.247	0.108	-2.300	0.022	-0.458
	Start of COVID-19	0.188	0.094	2.000	0.046	0.004
	Unmarked Patrol Vehicles	-0.102	0.035	-2.940	0.003	-0.170
	Bar close	-0.288	0.111	-2.600	0.009	-0.505
	Noise	SARIMA(3,0,0)(2,1,0,12)				
	AIC[1]	-81.613				
	Wntestq[2]	0.114				
1. Akaike information criterion						
2. Kolmogorov Smirnov test						

Number of crashes resulting in deaths

The following results in Table 10 are obtained from the ITS analysis for number of crashes that resulted in at least one death in Rwanda between 2014-2022 representing the available range of data. It includes the estimated coefficients, standard errors, z-values, p-values, and confidence intervals (CI). Additionally, each model has a noise following a SARIMA model, along with an AIC and white noise test (Wntestq) result which confirms the white noise for all models.

Exposure variables

An increase in quarterly GDP of one unit (measured in billions of Rwandan Francs) is significantly associated with a corresponding monthly increase in death crashes by 0.027 (95% CI [0.011, 0.043]) in the whole of Rwanda.

ASE camera interventions

The installation of ASE cameras is significantly associated with a 11.797 (95% CI [23.389, 0.204]) and 16.257 (95% CI [30.269, 2.246]) reduction in death crashes per month on June 2019 and September 2021 in the whole of Rwanda, respectively. This shows the different effects of the dosage of cameras on death crashes. The absolute value of the ASE Cameras_07 coefficient is more than the ASE Cameras_01 coefficient for the whole of the country. This means the installation of 106 cameras reduced the number of death crashes more than the installation of 5 cameras. However, it's important to note that the relationship between camera dosage and the reduction of crashes is not linear. As the dosage increases, we cannot necessarily expect a proportional decrease in the number of crashes. Furthermore, we did not find any locations with higher fatality rates, like COK, that had a larger reduction (higher coefficient) after the installation of cameras in our results. Specifically, the coefficient for fatal collisions resulting from the installation of cameras in COK and the western provinces was -4.02. Moreover, the installation of ASE cameras in the Eastern, Western and COK provinces are associated with reductions in death crashes. For instance, 4.02 (95% CI [7.387, 0.654]) reduction of death crashes per month were observed in COK.

COVID-19 restrictions

The start of COVID-19 in the Southern provinces and COK resulted in a significant monthly rise in death crashes, with an increase of 6.237 and 4.212, respectively, while the Northern provinces experienced a reduction of 3.288 in such crashes. The implementation of lockdown measures led to notable decreases in death crashes in Rwanda and COK province, with monthly reductions of 18.767 (95% CI [32.623, 4.91]) and 13.366 (95% CI [18.962, 7.77]), respectively. Furthermore, the closure of bars was linked to a 3.952 increase in death crashes in the Eastern province but a 5.709 decrease in the Southern province. Additionally, restrictions on interdistrict movement were found to be associated with a 5.461 increase in death crashes in COK but a 4.468 decrease in the Eastern province.

Table 10 | Results of ITS analysis for death crashes in Rwanda, 2014-2022

	Variables	Coefficient	Standard Error	Z value	P>|z|	CI (95%)	
						L	U
Rwanda	QGDP	0.027	0.008	3.23	0.001	0.011	0.043
	ASE Cameras-Rwanda-01	-11.797	5.914	-1.99	0.046	-23.389	-0.204
	ASE Cameras-Rwanda-07	-16.257	7.149	-2.27	0.023	-30.269	-2.246
	Campaign	9.122	5.676	1.61	0.108	-2.003	20.246
	Start of COVID	18.654	8.835	2.11	0.035	1.338	35.97
	Unmarked Patrols	-5.555	1.933	-2.87	0.004	-9.343	-1.767
	Lockdown	-18.767	7.07	-2.65	0.008	-32.623	-4.91
	Bars close	-7.425	6.606	-1.12	0.261	20.373	5.523
	Noise	SARIMA(0,0,0)(1,1,0,12)					
	AIC[1]	650.5437					
	Wntestq[2]	0.1476					

	Variables	Coefficient	Standard Error	Z value	P>|z|	CI (95%)	
						L	U
COK	ASE Cameras-COK-02	-4.02	1.718	-2.34	0.019	-7.387	-0.654
	ASE Cameras-COK-12	2.953	2.014	1.47	0.143	-0.995	6.9
	Start of COVID-19	4.212	1.132	3.72	0	1.993	6.43
	Lockdown	-13.366	2.855	-4.68	0	-18.962	-7.77
	Curfew 6pm	5.016	2.739	1.83	0.067	-0.354	10.385
	Interdistrict restrict	5.461	1.893	2.88	0.004	1.75	9.172
	Constant	11.213	0.323	34.74	0	10.58	11.845
	Noise	SARIMA(0,0,0) (1,0,0,15)					
	AIC[1]	539.3085					
	Wntestq[2]	0.4443					
Eastern Province	ASE Cameras-Eastern-02	3.995	5.578	0.720	0.474	-6.938	14.928
	ASE Cameras-Eastern-03	-3.727	4.341	-0.860	0.391	-12.235	4.780
	GA Campaign	4.087	1.950	2.100	0.036	0.265	7.909
	Interdistrict Restrict	-4.494	4.536	-0.990	0.322	-13.384	4.397
	School close	4.416	2.426	1.820	0.069	-0.339	9.170
	Bar close	-0.670	3.076	-0.220	0.828	-6.699	5.360
	Noise	SARIMA(5,1,0)(0,0,0,12)					
	AIC[1]	556.225					
	Wntestq[2]	0.882					
Northern Province	Population	8.070e-05	2.540 e-05	3.170	0.002	3.080e-05	1.306e-04
	GA Campaign	-2.222	1.126	-1.970	0.048	-4.429	-0.0153
	Start of COVID-19	-3.931	1.426	-2.760	0.006	-6.726	-1.136
	Speed Governor	-2.682	1.063	-2.520	0.012	-4.765	-0.599
	Constant	-136.577	45.293	-3.020	0.003	-225.350	-47.805
	Noise	SARIMA(0,0,0)(0,0,0,12)					
	AIC[1]	485.33					
	Wntestq[2]	0.917					

	Variables	Coefficient	Standard Error	Z value	P>|z|	CI (95%)	
						L	U
Western Province	Population	0.00002	0	2.43	0.015	0.000004	0.00004
	ASE Cameras-Western-01	-4.002	1.443	-2.77	0.006	-6.83	-1.174
	Unmarked Patrols	-2.018	1.183	-1.71	0.088	-4.337	0.301
	School close	-2.994	1.183	-2.53	0.011	-5.312	-0.676
	Bar close	-1.927	1.048	-91.84	0.066	-3.982	0.127
	Noise	SARIMA(0,0,0)(0,1,1,12)					
	AIC[1]	438.8646					
	Wntestq[2]	0.8377					
Southern Province	Population	0.001	0.000	3.050	0.002	0.000	0.002
	Start of COVID-19	5.601	1.869	3.001	0.003	1.937	9.265
	Unmarked Patrol Vehicles	-3.622	1.307	-2.770	0.006	-6.186	-1.059
	Lockdown	-4.496	2.250	-2.000	0.046	-8.906	-0.086
	Bar close	-4.085	1.515	-2.700	0.007	-7.055	-1.115
	Constant	-54.799	18.158	-3.020	0.003	-90.389	-19.210
	Noise	SARIMA(0,0,0)(2,1,0,12)					
	AIC[1]	488.876					
	Wntestq[2]	0.407					
1. Akaike information criterion							
2. Kolmogorov Smirnov test							

Serious injury crashes

There was a reduction in annual serious injury crashes from 1,265 in 2010 to 114 in 2022, with fluctuations, particularly in the last five years of the study period (detailed in the Supplementary Materials). The following presents the ITS analysis conducted on serious injury crashes in Rwanda between 2014 and 2022, as shown in Table 11. It includes the estimated coefficients, standard errors, z-values, p-values, and confidence intervals (CI). Additionally, each model has a noise following an SARIMA model, along with an AIC and Wntestq result which confirms the white noise for all models.

ASE Camera Interventions

The analysis shows that the installation of ASE cameras had a significant association with monthly reduction of serious injury crashes in the whole of Rwanda, and Eastern and Western provinces with 45.307 (95% CI [79.651, 10.963]), 6.798 (95% CI [11.036, 2.56]) and 11.288 (95% CI 18.168, 4.409]), respectively.

COVID-19 Restrictions

The implementation of lockdown measures was significantly associated with a 20.222 (95% CI [40.311, 0.133]) reduction in serious injury crashes per month in the whole of Rwanda.

Other Road Safety Policies

The launch of the unmarked Patrol Vehicle policy was significantly associated with 3.776 and 5.466 increases in the serious injury crashes of the Western and Southern provinces.

Table 11 | Results of ITS analysis for serious injury crashes in Rwanda, 2014-2022

	Variables	Coefficient	Standard Error	Z value	P>|z|	CI (95%)	
						L	U
Rwanda	ASE Cameras-Rwanda-07	-45.307	17.523	-2.59	0.01	-79.651	-10.963
	Lockdown	-20.222	10.25	-1.97	0.049	-40.311	-0.133
	Constant	64.262	5.166	12.44	0	54.138	74.387
	Noise	SARIMA(1,0,0)(0,0,0,12)					
	AIC[1]	1345.752					
	Wntestq[2]	0.5312					
COK	ASE Cameras-COK-03	-12.975	14.335	-0.91	0.365	-41.071	15.122
	Lockdown	-10.25	9.952	-1.03	0.303	-29.756	9.257
	Constant	25.314	6.947	3.64	0	11.698	38.929
	Noise	SARIMA(2,0,0)(0,0,0,12)					
	AIC[1]	1267.28					
	Wntestq[2]	0.8419					
Eastern Province	ASE Cameras-Eastern-03	-6.798	2.162	-3.14	0.002	-11.036	-2.56
	Interdistrict restrict	-2.704	2.213	-1.22	0.222	-7.042	1.634
	Constant	10.2	0.552	18.47	0	9.118	11.283
	Noise	SARIMA(1,0,0)(0,0,0,12)					
	AIC[1]	843.4991					
	Wntestq[2]	0.2727					
Northern Province	ASE Cameras-Nothern-02	-6.123	3.178	-1.93	0.054	-12.351	0.106
	Bars close	-1.74	1.739	-1	0.317	-5.149	1.668
	Constant	7.565	0.62	12.21	0	6.35	8.779
	Noise	SARIMA(2,0,0)(1,0,0,12)					
	AIC[1]	764.9434					
	Wntestq[2]	0.3733					

	Variables	Coefficient	Standard Error	Z value	P>|z|	CI (95%)	
						L	U
Western Province	ASE Cameras-Western-01	-11.288	3.51	-3.22	0.001	-18.168	-4.409
	Unmarked Patrols	3.776	0.624	6.05	0	2.552	4.999
	curfew6pm	-8.822	4.638	-1.9	0.057	-17.912	0.269
	School close	-3.683	1.442	-2.55	0.011	-6.509	-0.857
	Constant	8.888	0.398	22.34	0	8.108	9.667
	Noise	SARIMA(0,0,0) (0,0,0,12)					
	AIC[1]	841.4358					
	Wntestq[2]	0.7235					
Southern Province	Start of COVID-19	-7.172	1.970	-3.640	0.000	-11.034	-3.311
	Unmarked Patrol Vehicles	2.525	1.471	1.720	0.086	-0.357	5.408
	Constant	10.552	0.921	11.460	0.000	8.747	12.357
	Noise	SARIMA(0,0,4) (0,0,0,12)					
	AIC[1]	878.264					
	Wntestq[2]	0.926					
1. Akaike information criterion							
2. Kolmogorov Smirnov test							

Discussion

The purpose of this study was to assess the association of ASE cameras on reduction of road traffic crashes resulting in deaths and injuries in Rwanda. In doing so, we accounted for external influences on crash rates, including other concurrent road safety interventions. Our findings indicate that the installation of ASE cameras is associated with a significant decrease in death and serious injury crashes either in certain provinces or throughout the entire country. The results are in-line with the literature review study conducted on speed enforcement on crashes, which concluded that enforcement measures can lead to a reduction in death and serious injury crashes (63). Another study found reductions in average speed ranging from 1% to 15% and reductions in proportion of vehicles speeding ranging from 14% to 65% by reviewing 35 studies. Furthermore, this study reported that near camera sites, pre-post reductions ranged from 8% to 49% for all crashes and 11% to 44% for death and serious injury crashes. In comparison with controls, the relative improvement in pre-post injury crash proportions ranged from 8% to 50% (64).

Moreover, this study found that COVID-19 restrictions, such as lockdowns, were associated with a decrease in crashes. This may be due to the reduction in traffic volume and inter-district movements during the lockdown period. Not all of the COVID-19 restrictions positively correlated with road safety improvements. It was found that curfews had the opposite effect and were linked to an increase in crashes.

Figure 13 | Availability and quality of the covariate data sources used in the WHO model

Independent variables	Description	Source of information
In (GDP)	World Development Indicators (2017) and WHO estimates of Gross Domestic Product (GDP) per capita (international dollars or purchasing power parity dollars, 2011 base)	World bank and WHO database
In (vehicles per capita)	Total vehicles per 1000 persons	GSRRS surveys and WHO database
Road density	Total roads (km) per 1000 hectares	International Futures database
National speed limits on rural roads	The maximum national speed limits on rural roads (km/h) from WHO questionnaire	GSRRS survey
National speed limits on urban roads	The maximum national speed limits on urban roads (km/h) from WHO questionnaire	GSRRS survey
Health system access	Health system access variable (principal component score based on a set of coverage indicators for each country)	Institute for Health Metrics and Evaluation dataset
Alcohol apparent consumption	Liters of alcohol (recorded plus unrecorded) per adult aged 15+	WHO database
Population working	Proportion of population aged 15–64 years	World Population Prospects 2017 revision
Percentage motorbikes	Per cent of total vehicles that are motorbikes	GSRRS survey
Corruption index	Control of corruption index (units range from about -2.5 to +2.5 with higher values corresponding to better control of corruption	World Bank (Kaufmann et al 2009), International Futures database
National policies for walking /cycling	Existence of national policies that encourage walking and / or cycling	GSRRS survey
Population	Total population (used as offset in negative binomial regression	World Population Prospects 2017 revision (UNDESA)

There are a few important limitations to note. Firstly, there are a possibility of underreporting for severe crashes resulting in death or serious injury, which were included in this study. Under-reporting is known to compromise determination of the accurate epidemiology of road traffic crashes across virtually all different statuses of income and geographies (65-69). However, we have no reason to believe that underreporting is biased, directional, or non-uniform throughout the study period in Rwanda which allows us to conduct these analyses but requires thoughtful consideration of the potential impacts of reporting incorrect results. We found an average annual road death incident rate over our study period to be fewer than 6 deaths/100,000 population in Rwanda, a stark contrast to the WHO modelled incidence of 29/100,000 annual road deaths in Rwanda (2). These models are applied systematically and based on objective criteria that the WHO has determined to be associated with a high likelihood of low-quality or otherwise insufficient data that is not amenable to documentation of the reality on the ground in many countries. The full description of the criteria that is used to determine how to apply these models in each country can be found in Explanatory Note 3 of the 2018 Global Road Safety Status Report (2). The algorithm applied is complex and further limited by availability and quality of the covariate data sources considered as shown in Figure 13 that we adapted from the WHO report. These calculations and the covariate data collection is painstaking but engaged in for the purpose of appropriate allocation of resources intended to reduce the human costs of road traffic crashes.

Unfortunately, it is common for road traffic injury and death data to be under-reported or insufficient, particularly in African LMICs (47). It is important to highlight that the RNP are continuously assessing and improving the quality of their road traffic crash reporting, evidenced by the geo-coded and time-stamped digital database that has been in place since 2022. Even with this updated system, it will still pose a challenge to capture data on all crashes, injuries, and deaths in the country. This would require linking police-reported data, hospital records, a trauma registry, and other sources. As it stands now, as an example, an intoxicated driver who crashes into another vehicle may decide to flee the scene to avoid punishment despite suffering an injury. He may present to a hospital later that night due to worsening chest pain and is found to have fractured ribs and blood in the right side of his chest. If he is hospitalized and ultimately develops an infection from the chest drainage tube and dies one week after his initial road traffic injury, this may not be captured in the police-reported data, even if the cause of the injury was documented in the medical record. Often, medical records are still on paper, and there is no system for the hospitals to report data to the RNP. However, it is important to note that if the RNP responded and recorded the crash, they should and would have followed up with the injured to ascertain the outcome of the crash. There are indications that this limitation will be addressed in future studies. Fortunately, just as substantial resources are being directed towards a road safety transformation in Rwanda, the health system is also actively engaged in their own digital health transformation that will radically transform the availability of road traffic crash epidemiological data (70). Many countries have successfully improved their data through cross-linking of digital databases from the health system, vital registries, insurance claims, and police reports (68).

Secondly, our analysis was limited by the data availability and lack of spatial- and temporal-specificity of the crash, injury, and ASE unit data. In this study, we assume that the ASE installation leads to changes in aggregate (province-level) crashes, rather than specific locations since the individual crashes and locations are not accessible. We frame our findings in a way to reduce the risk of ecological fallacy and acknowledge that we can only report aggregate findings on a province-level.

Time series regression was employed to analyse the association of traffic interventions on changes in number of road crashes, while SARIMA was used to model the noise. However, certain variables that may have an effect, but were not collected, remain unknown. For instance, the exact locations of cameras were not disclosed due to confidentiality concerns, and geocoordinates of road traffic outcomes were not routinely recorded until January 2022.

Once we determined we could not get precise locations of crashes, injuries, deaths, and camera locations, we had hoped to conduct this analysis on a district level, but severe injuries and deaths are relatively rare events, so the district-level time series had mostly zeros and ones (e.g., one death), making it unsuitable for using ITS models, which require a normal distribution in the time series. As such, our analysis was aggregated to a large geographical area (provincial level). Ideally, we would have been able to understand the precise locations and times of the crashes, injuries, and deaths in relation to the ASE camera locations to understand the impact of ASE. Similarly, we could not distinguish between the various types of cameras that were present in the studied areas, such as fixed cameras, enforcement fine cameras, and red-light cameras. As a result, our study did not examine the potential differences in driver behaviour based on the type of camera being used for speed limit enforcement.

Relatedly, the implementation of ASE in Rwanda is ongoing, and this was brought directly to our attention by the RNP when we requested certain data. We began this project in 2022 after ASE was implemented and had to conduct a retrospective evaluation using data from 2010 and onwards. Like the experience of our team in documenting the design and implementation processes of ASE with key informant interviews and focus group discussions, we found it challenging to access the required data sources. Overtime this challenged eased with greater collaboration, but there remained some firm limitations on data that could be shared publicly such as the precise geolocations of ASE deployment. Related challenges came from the need for the specific data on crashes needing to be dis-aggregated to the district and monthly level through a manual process that we checked extensively but could be prone to errors. Finally, we lacked a source of our desired exposure data (e.g., traffic counts) and were required to use suboptimal surrogates compared to similarly aimed analyses in other contexts. Additionally, we had considered using another country (e.g., Burundi) as a control. However, we were not able to access these data. If such data were available, we could have analysed how this policy might have reduced the number of crashes or prevented a higher rate of increase.

Without question this exercise has deep value even if our results are limited, as this was the first opportunity to identify differences between the priorities of researchers (accurate and complete data needed to optimize analyses methods and assess the impact) and the police (the safety and security of the Rwandan people). Such priority preferences are critical to identify to successfully conduct research to generate evidence on interventions to meet the needs of all stakeholders. Ultimately, despite differing orders of priorities both the research team and the police share the overarching goal of improving the safety of Rwandan roads to prevent death, disability, and economic losses. Our experience conducting this landmark study of the impacts of ASE in Rwanda generates the recommendations to future researchers that they prioritize obtaining the data sources (e.g., spatially specific data) they need as early as possible.

This raises one additional challenge of this work. Our full study which consisted of four smaller studies, was conducted over one year. With more time in the design and planning phases, the research team can assure that they have explained the reasons for the requests fully and negotiated alternatives as needed, rather than having to do so during the analysis. Research teams need to recognize the potential for and have the time to accommodate the sometimes dramatically and rapidly shifting focus of a national police force. This ability to pivot attention and resources is what supports Rwanda to be commonly regarded as one of the safest and most secure African countries. However, it can make getting the time and attention of the RNP for a research project like this one quite difficult and hampered by delays. In summary, we are grateful for the partnership of the RNP in their accommodations to our many requests for data and look forward to future opportunities to both improve the quality of the research outputs and ultimately strengthen Rwandan road safety and related technical research capacity.

Moreover, the deployment of ASE cameras can enhance drivers' awareness and modify their driving behaviour. Therefore, even though the models demonstrate only a subset of cameras that are linked to a decrease in fatal/serious injury collisions, we cannot determine the percentage of changes in driver behaviour after each set of ASE cameras by deployed models. In other words, there is a possibility that the process of implementing ASE cameras has changed driver behaviour during the studied period, but we are only observing the effectiveness of a specific subset of cameras. This should not imply that other sets of cameras did not have a positive effect and they may improve positively the drivers' behaviours.

To gain a deeper understanding of the reasons behind the changes in crash trends, it is suggested that future studies collect data on contributing factors, actual camera locations, and geocoordinates availability within the dataset. This would enable spatial or spatiotemporal analyses, making it possible to explore the spatial correlation between provinces/areas under study and compare the association of ASE cameras on changes in the number of collisions in areas with and without cameras. The existence of spatial correlation can indicate whether changes in a particular province or location may result in a decline across the entire country or a larger geographical area. And by having information on the location of collisions, we can investigate the effect of specific policies implemented in certain areas, such as breathalyser tests, on road. Closely related, we would recommend that other studies consider designing and conducting the evaluation prospectively, although this would require a longer study period.

This study conducted in Rwanda highlights the positive association of ASE cameras on road safety, with a decrease in death and serious injury crashes reported in certain provinces or throughout the entire country. The findings are consistent with previous studies on speed enforcement, which have also shown a reduction in death and serious injury crashes (63, 64). Such an approach will allow for a more comprehensive assessment of the effectiveness of traffic interventions on crashes. The study has some limitations, including underreporting data, as well as spatial information on recording individual crashes. The study recommends the need for well-designed guidance for ASE cameras, with several data collection points over time, to conduct a more comprehensive assessment (e.g., spatiotemporal analysis) of traffic interventions' effect on crashes in Rwanda. The findings of this study provide valuable insights for policymakers in the development of evidence-based policies and interventions to improve road safety, particularly in implementing traffic interventions such as ASE cameras in LMICs. Other African countries can consider Rwanda's road safety program as an example of improving road safety. It is important to acknowledge that a comprehensive set of safety measures, such as campaigns and education programs, is required to ensure the safety of all individuals on the roads.

Conclusions

The study's findings indicate that the introduction of ASE cameras and other concurrent road safety interventions in Rwanda was significantly associated with reductions in road deaths and severe injuries. The ITS model was used to analyse the association of ASE cameras and other factors on reducing the crashes, revealing that while the association of ASE cameras on reduction of road crashes varied across different provinces, the interventions had a positive association on improving road safety and could shift the severe to minor crash significantly. Furthermore, the study highlighted that COVID-19 restrictions, such as lockdowns and school and bar closures, also contributed to a decrease in crashes. It is recommended that policymakers continue to legislate and implement road safety policies to enhance road safety in Rwanda, including the use of ASE.

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