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Road Safety Impacts of Automated Speed Enforcement in Saudi Arabia and the Gulf Cooperation Council: A Severity-Based Review of Compliance, Crash Reduction, and Engineering Integration

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Abstract

Automated speed enforcement has become a central road safety measure in Saudi Arabia and other Gulf Cooperation Council (GCC) countries as governments respond to traffic growth, high operating-speed environments, and the continued burden of fatal and serious injury crashes. This review examines automated speed enforcement in Saudi Arabia, the United Arab Emirates (UAE), Qatar, and Kuwait, with emphasis on localized speed compliance, crash reduction, severity-specific outcomes, and engineering integration. Among the sources reviewed for the four countries, Saudi Arabia provides the most detailed direct camera-effectiveness evidence through the corridor-level evaluation of mobile enforcement associated with the SAHER/ATVAM program, while Kuwait provides evidence on localized speed compliance and speed recovery near fixed cameras. The reviewed UAE and Qatar sources support the discussion of technology-enabled safety management but do not provide directly comparable, severity-disaggregated estimates of camera effectiveness. The paper argues that speed cameras should not be treated as stand-alone safety solutions. They can improve compliance, but sustainable reductions in fatal and serious injury crashes require risk-based deployment, road safety audits, infrastructure countermeasures, roadside protection, governance aligned with safety outcomes, and severity-based performance monitoring.

Keywords

Automated Speed Enforcement, Speed Camera Systems, Crash Severity Analysis, Fatal and Serious Injury Reduction, Risk-Based Enforcement Deployment, Driver Behavioral Adaptation, Road Safety Audits (RSA), Traffic Safety Engineering, Saudi Arabia and GCC Road Safety

1. Introduction

Road traffic crashes remain a major public safety and economic challenge across Saudi Arabia and the wider Gulf Cooperation Council (GCC). Rapid traffic growth, urban expansion, high-capacity highway network development, and increased intercity mobility have created transport networks where exposure to high-speed travel is substantial. In this regional context, road safety strategies have increasingly shifted from general crash-count reduction toward the prevention of fatal and serious injury outcomes, because severe crashes impose disproportionate social, medical, and economic consequences on the public and government sector.

Excessive and inappropriate speed remains one of the most important factors influencing both crash occurrence and crash severity. From an engineering and biomechanical perspective, the relationship between vehicle speed and impact severity is nonlinear, because kinetic energy increases with the square of vehicle velocity. This means that even moderate reductions in operating speed can produce meaningful reductions in collision energy and injury potential. This principle provides the technical basis for speed management policies and explains why automated speed enforcement has become a central tool in modern road safety programs.

Saudi Arabia represents an important GCC case because automated speed enforcement was deployed at large scale in 2010 through the Automated Traffic Violations Administering and Monitoring (ATVAM) system, locally known as SAHER, including fixed and mobile camera applications [1] [2]. Evidence from Saudi Arabia also includes a corridor-level evaluation of mobile enforcement operated under an earlier Private Finance Initiative (PFI) model. This provides severity-specific crash estimates and a basis for discussing the authors' proposed explanation concerning deployment incentives, without establishing a causal effect of governance arrangements [1].

However, the safety impact of automated speed enforcement cannot be evaluated only by whether cameras reduce speeding violations near monitored locations. Improved compliance is important, but it does not automatically translate into sustained reductions in fatal and serious injury crashes. Crash outcomes are also affected by roadway geometry, roadside hazards, traffic composition, exposure growth, enforcement visibility, driver adaptation, and the quality of site-selection criteria. These factors require a severity-based and system-

based interpretation rather than a simple before-and-after comparison of total crashes.

This review examines the road safety impacts of automated speed enforcement in Saudi Arabia and selected GCC countries, with emphasis on compliance effects, crash reduction patterns, severity-specific outcomes, and engineering integration. The paper argues that speed cameras should not be treated as a stand-alone safety solution. Instead, automated enforcement should be understood as one layer within a broader road safety system that includes risk-based deployment, road safety audits, infrastructure design improvements, roadside protection, and severity-based performance monitoring.

2. Review Methods

This study is a narrative review of automated speed enforcement and related road-safety evidence in Saudi Arabia, Kuwait, the United Arab Emirates, and Qatar. The country coverage emerged from the publications identified during literature collection, rather than from a predefined geographic eligibility criterion. Literature identification began on 8 February 2026, with the search updated on 5 November 2026. Sources were identified through Google Scholar and AI-assisted searches. Only English-language sources were considered, with no restriction on publication year. Exact search terms and combinations were not recorded, which limits the reproducibility of the search.

Sources were selected for their relevance to automated speed-enforcement deployment, driver speed behaviour, camera-related collision outcomes, or severity-based safety planning and traffic-monitoring applications in the four countries. International reviews and methodological publications were also included to support interpretation of enforcement effects and evaluation methods. Non-English sources and publications outside these topics were excluded. Both authors read the included sources in full. Reference lists within the included publications were not searched for additional sources. The review followed a narrative approach and does not claim an exhaustive or systematic identification of all relevant literature.

Direct evaluations of camera effectiveness were distinguished from contextual studies of safety planning and traffic monitoring. Findings were synthesized narratively, considering study design, geographic and operational context, severity classifications, reported uncertainty, and limitations affecting comparisons across studies.

3. Automated Speed Enforcement Deployment across Saudi Arabia and the GCC

This narrative review examines Saudi Arabia, Kuwait, the United Arab Emirates, and Qatar. The geographic scope developed around the relevant publications identified during literature collection, rather than through a predefined country-selection procedure. Bahrain and Oman were not represented in the selected evidence base and were therefore not included in the country-specific discussion.

Their omission should not be interpreted as evidence that relevant research or automated-enforcement programs are absent in those countries. Among the sources included, Saudi Arabia provides the most detailed direct camera-effectiveness evaluation, while Kuwait contributes evidence on driver behaviour and fatal-collision patterns near cameras. The UAE and Qatar sources principally address severity-based safety planning and technology-supported traffic monitoring. Statements about evidence availability refer to the four countries examined and the sources reviewed, rather than to the GCC as a whole.

3.1. Saudi Arabia: SAHER Deployment and Governance Models

Saudi Arabia represents the most developed case in the reviewed regional evidence. In 2010, the Kingdom launched one of the largest fixed and mobile automated speed enforcement programs in the world through the Automated Traffic Violations Administering and Monitoring (ATVAM) system, locally known as SAHER. The system was introduced to reduce speeding violations and speed-related collisions across major road networks, with early deployment in major cities including Madinah, Makkah, Dammam, Riyadh, Buraydah, Tabuk, Jeddah, and Abha [1] [2].

A distinctive feature of the Saudi experience is that the automated enforcement program and its traffic enforcement equipment were operated through a Private Finance Initiative (PFI) model from 2010 to 2015 [1]. This governance arrangement makes Saudi Arabia especially important for this review because it introduces a question beyond camera technology itself: whether enforcement locations are selected based on crash-risk reduction or violation-generation potential. Alamry and Hassan [1] proposed that revenue incentives under the PFI arrangement might have encouraged placement at locations with high speeding-violation potential rather than high collision-reduction potential. This was a possible explanation for the findings, rather than a directly tested deployment mechanism.

The Saudi evaluation focused on a 210-km section of the Madinah-Makkah Expressway, locally known as Al-Hijra Road, where mobile speed enforcement was applied after speed-camera and warning signs were installed along the highway [1]. This case is important because it provides corridor-level evidence rather than only a general description of system deployment.

3.2. Kuwait: Fixed Cameras, Driver Adaptation, and Site-Selection Risk

Among the reviewed sources, Kuwait contributes directly relevant evidence on behavioural responses to fixed speed cameras. Earlier work on automated speed-monitoring cameras in Kuwait found that vehicle speeds were lower at camera locations but higher before and after the camera sites [3]. This pattern supports the concern that fixed cameras may generate localized compliance while allowing speed recovery outside the immediate enforcement zone.

Kuwait is also relevant because fatal collision frequencies within a 2-km radius of speed cameras were reported to be statistically higher than in comparable areas without speed cameras [4]. However, this finding should not be interpreted as evidence that cameras caused higher fatal crash occurrence. The original interpretation is more cautious: the observed pattern may reflect pre-existing site risk, where cameras were installed at already collision-prone locations.

Kuwait therefore strengthens one of the central methodological points of this paper: automated enforcement must be evaluated with attention to site-selection bias, spatial risk redistribution, and before-after comparison quality. This finding applies to non-intersection collisions involving a death at the time of the collision; the study did not use a 30-day fatality follow-up criterion or evaluate nonfatal injury and PDO outcomes [4].

3.3. United Arab Emirates: Severity-Based Safety Planning and Technology Integration

The UAE is useful in this review as a regional example of technology-supported and severity-oriented road safety planning, rather than as a direct source of camera-effectiveness evidence. Recent Dubai-based research using severity weighted hotspot analysis identified spatial and temporal crash-severity patterns and proposed targeted countermeasures including enhanced automated enforcement, lighting improvement, speed-limit management, and pedestrian-focused treatments [5]. This supports the broader argument that enforcement should be connected to risk diagnosis and engineering treatment rather than applied as an isolated measure. The study used High/Low incident-severity labels, which should not be interpreted as directly equivalent to fatal and serious-injury classifications [5].

The UAE evidence therefore contributes to the systems interpretation of automated enforcement. It shows that speed management is part of a wider road safety framework involving hotspot identification, infrastructure conditions, night time risk, pedestrian exposure, and targeted intervention planning. However, the UAE sources included in this review did not provide a corridor-level evaluation isolating speed-camera effects on fatal, serious-injury, minor-injury and PDO collisions.

3.4. Qatar: Technology-Supported Traffic Monitoring and Safety Modernization

Qatar is best treated as a regional case of traffic monitoring and safety-data modernization rather than as a direct source of automated speed enforcement effectiveness evidence. Published work on Qatar's traffic monitoring environment has proposed Internet of Things (IoT)-based systems for collecting vehicle trip data, Global Positioning System (GPS) coordinates, minimum, average and maximum speed, and driver-behavior indicators to support crash prediction and road infra-

structure improvement [6]. This aligns with the wider GCC trend toward digital traffic monitoring and data driven safety management.

For the purpose of this review, Qatar's relevance is not that it provides strong published evidence of speed-camera crash reduction. Rather, Qatar supports the regional observation that traffic safety programs are increasingly moving toward technology-enabled monitoring, behavioral data collection, and infrastructure-linked safety analysis. The Qatar source included in this review does not provide severity-disaggregated estimates of automated-enforcement effectiveness, limiting direct comparison with the Saudi and Kuwaiti camera studies.

3.5. Maintaining the Integrity of the Specifications

Across the reviewed GCC cases, automated speed enforcement and technology-supported traffic safety systems are present, but the maturity of published evaluation differs significantly. Among the included sources, Saudi Arabia provides the most detailed direct evaluation through the corridor-level study of PFI-operated mobile cameras [1], supported by deployment context from [2]. Kuwait contributes directly relevant evidence on localized compliance, speed recovery, and site-selection uncertainty around fixed camera locations [3] [4]. The UAE contributes broader evidence on severity-based hotspot analysis and integrated countermeasure planning, including enforcement as one element among infrastructure and operational treatments [5]. Qatar contributes evidence on traffic monitoring, speed-related data collection, and technology-supported safety modernization, but not on direct camera-specific crash reduction [6].

The included sources provide uneven coverage of camera effectiveness across the four countries. This reflects the composition of the reviewed evidence and should not be interpreted as a comprehensive assessment of all available GCC research. Therefore, the GCC comparison should not be framed as a simple country-by-country ranking of speed-camera success. Direct cross-country performance comparisons should therefore be avoided unless outcomes are normalized for traffic exposure, roadway length, functional road classification, and speed environment; where available, vehicle-kilometers traveled should be considered rather than raw crash totals alone. It should be interpreted as an evidence-maturity comparison: cameras may improve compliance, but sustainable fatal and serious injury reduction depends on whether enforcement is deployed through risk-based site selection, integrated with road safety audits, driver behavior analysis, infrastructure design and maintenance, road geometry review, and severity-specific performance monitoring.

This structural convergence establishes a regional enforcement ecosystem with comparable deterrence mechanisms but variable evaluation maturity. An overview of enforcement implementation characteristics and publicly available severity-based evaluation maturity across selected GCC countries is presented in **Table 1**.

Table 1. Automated-enforcement deployment and related safety evidence represented in the sources reviewed for the four selected GCC countries.

Country	Role in this review	Enforcement/technology deployment evidence	Severity-based evaluation represented in the reviewed sources
Saudi Arabia	Main empirical case	Large-scale automated enforcement through SAHER/ATVAM, including fixed and mobile systems; early operation included a Private Finance Initiative model [1] [2].	High relative to other reviewed GCC cases. Corridor-level evaluation is available, including property-damage-only (PDO), serious-injury, fatal, and total collision outcomes [1].
Kuwait	Behavioral adaptation and site selection caution	Fixed automated speed-monitoring camera studies are available, including evidence of lower speeds at camera sites and higher speeds before/after camera locations [3].	Moderate. Kuwait has direct camera-related studies, including fatal-collision spatial analysis near speed-camera locations [3] [4].
United Arab Emirates	Severity-based planning and integrated countermeasure context	Dubai-based safety research Supports severity-weighted hotspot analysis and targeted countermeasures, including automated enforcement as one element among lighting, speed management, and pedestrian treatments [5].	Moderate to limited for camera specific evaluation. Evidence supports severity-based planning, but not isolate speed-camera crash-effectiveness by severity.
Qatar	Technology-supported traffic monitoring and safety-data modernization	Published Qatar work supports IoT based traffic monitoring, trip data, GPS coordinates, speed data, driver-behavior indicators, crash prediction, and infrastructure improvement logic [6].	Limited for camera-specific evaluation. Evidence supports technology-based monitoring but not direct automated-enforcement crash reduction.

4. Enforcement Mechanisms and Evaluation Considerations

Automated speed enforcement operates primarily through deterrence. By increasing the actual and perceived certainty of detection, speed cameras are intended to reduce excessive speeding and shift driver behavior toward posted speed limits. However, the safety effect of automated enforcement depends on more than the presence of cameras. Camera type, visibility, location selection, enforcement consistency, driver adaptation, and evaluation methods all influence whether improved speed compliance translates into measurable reductions in crashes and injury severity.

4.1. Compliance Effects and Deterrence Logic

The most direct effect of automated speed enforcement is behavioral compliance. A camera system can reduce speeding at or near monitored locations because drivers recognize that violations can be detected without direct police presence. This makes automated enforcement attractive in high-speed environments, long corridors, and locations where conventional enforcement is difficult, unsafe, or resource intensive [7].

However, compliance should be treated as an intermediate safety outcome rather than the final measure of success. A reduction in speeding violations or operating speed near enforcement points is useful, but it does not automatically

prove a reduction in fatal and serious injury risk. Compliance measures describe driver response; safety measures require crash and injury outcomes. For this reason, enforcement programs should be evaluated using a hierarchy of outcomes: speed behavior, violation frequency, total crashes, crash type, and crash severity.

4.2. Fixed and Mobile Camera Effects

Automated speed enforcement systems are commonly categorized as fixed or mobile and may also be operated as overt or covert enforcement. Fixed cameras can provide continuous monitoring at known locations and are useful where repeated speeding or crash risk is concentrated. Their limitation is that drivers may learn camera locations and modify behavior only within the immediate enforcement zone [7].

This localized response is central to the concern known as the kangaroo effect, where drivers slow down before or at the camera and then accelerate after passing it. Kuwait evidence supports this concern, with measured speeds before and after fixed-camera locations reported to be higher than speeds at the camera sites [3]. International meta-analysis also identifies speed recovery and spatially uneven behavior as important issues in fixed-camera and section-control evaluation [8]. Therefore, fixed cameras should not be interpreted as corridor-wide speed management tools unless downstream and upstream behavior is also monitored.

Mobile cameras can reduce some of the predictability associated with fixed enforcement because their locations can be rotated. In principle, this can increase general deterrence by making drivers less certain about where enforcement will occur. However, mobile cameras also require disciplined deployment logic. If camera locations are selected mainly for high violation potential rather than high crash or severity risk, enforcement may increase detection activity without producing proportional safety improvement. This issue is especially important in the Saudi PFI case, where the concern was that private-sector operating incentives may have favored high-speeding locations rather than high-collision-risk locations [1].

Average-speed, or section-control, enforcement should be distinguished from point-based fixed cameras because it measures mean speed over a defined road segment. Its objective is sustained corridor-level speed moderation and therefore it can reduce the incentive for localized braking and downstream acceleration associated with known point enforcement locations [8].

4.3. Compliance, Crash Reduction, and Severity Outcomes

Evaluation of automated speed enforcement should distinguish between three outcome levels: compliance improvement, crash-frequency reduction, and severity reduction. Compliance improvement refers to changes in speed behavior or violation rates. Crash-frequency reduction refers to changes in the number of reported collisions. Severity reduction refers to changes in fatal, serious-injury, minor-injury, or property-damage-only outcomes.

These outcomes do not always move in the same direction. A camera may improve local compliance but have limited corridor-wide effect if drivers accelerate after the enforcement point. A program may reduce total crashes but produce unclear effects on fatal crashes because fatal events are rarer, more variable, and strongly influenced by roadway geometry, roadside hazards, vehicle type, restraint use, emergency response, and time of day. Conversely, property damage-only crashes may be more sensitive to reporting practices and enforcement-related changes in driver behavior. This is why severity-disaggregated evaluation is essential.

The Saudi corridor evidence illustrates this distinction. In the PFI mobile-camera evaluation, Negative Binomial regression and Empirical Bayes before-and-after analysis were applied to all reported collisions and to property damage-only, serious-injury, and fatal collision categories. The study found higher frequencies of property-damage only, serious-injury, and total collisions associated with the mobile camera treatment, while fatal collision effects were mixed and weaker [1]. The importance of this finding is not that automated enforcement is inherently ineffective. Rather, it shows that enforcement impact must be interpreted by severity level and deployment context.

4.4. Site Selection, Exposure, and Regression-to-the-Mean

A central evaluation challenge is site-selection bias. Cameras are often installed at locations with known speeding problems, high crash history, public complaints, or operational convenience. If a site already has unusually high crash frequency before camera installation, a simple before-and-after comparison may incorrectly attribute later crash changes to the camera rather than to natural fluctuation, exposure changes, or regression-to-the-mean.

Comparative evaluations should also account for traffic exposure, functional road classification, and the posted and operating-speed environment so that enforcement effects are not confounded by fundamentally different roadway conditions [9]-[11].

For this reason, robust automated-enforcement evaluation should account for traffic volume, temporal trends, reference sites, and regression-to-the-mean. Empirical Bayes before-and-after methods are commonly used in road safety evaluation because they estimate what the crash frequency would likely have been without the treatment, using reference-site information and safety performance functions [9] [10]. The Saudi PFI study applied this logic by using treated and untreated expressway segments, dividing crash data into before and after periods, and developing crash modification factors by severity category [1].

The quality of the evaluation still depends on data quality and reference-site suitability. If reference sites differ substantially from treated sites in traffic volume, geometry, enforcement exposure, or reporting practices, the estimated camera effect may remain uncertain. Therefore, methodological rigor cannot be separated from engineering judgment. A statistically sophisticated study can still produce

limited conclusions if site comparability, crash reporting, and exposure data are weak.

4.5. Implications for This Review

This review therefore interprets automated speed enforcement through four evaluation filters. First, whether the system improves speed compliance. Second, whether compliance is localized or sustained across the corridor. Third, whether crash outcomes improve by severity category, especially fatal and serious injury crashes. Fourth, whether enforcement deployment is integrated with engineering diagnosis, including roadway geometry, roadside hazards, traffic composition, and road safety audit findings.

This framework is necessary because automated speed enforcement is a behavioral intervention, not a complete road safety system. Cameras can influence driver behavior, but they cannot by themselves correct geometric deficiencies, remove fixed-object hazards, improve pedestrian protection, redesign high-risk intersections, or compensate for weak post-crash response. The following sections therefore examine not only whether automated enforcement is associated with safety improvement, but whether it is deployed as part of a broader engineering and policy framework aimed at fatal and serious injury reduction.

5. Behavioral Adaptation and Spatial Risk Redistribution

Automated speed enforcement does not influence all driver behavior uniformly across a road network. Its effect may be strongest at or near the enforcement point, especially where camera locations are fixed, visible, or widely known. This creates an important distinction between local deterrence, where drivers slow down near a camera, and general deterrence, where drivers reduce speeding across a wider corridor or network because they perceive enforcement as unpredictable and consistently applied.

5.1. Localized Compliance around Fixed Cameras

Fixed speed cameras can produce clear localized compliance because drivers learn camera locations and adjust speed before reaching them. This response can reduce speeds within the immediate enforcement zone, but it may not indicate sustained corridor-level speed management. If drivers slow down only near the camera and then accelerate downstream, the safety benefit remains spatially limited.

This behavior is especially important in GCC highway and urban arterial environments, where long straight segments, high operating speeds, and multilane roadways can allow rapid speed recovery after the enforcement point. The Kuwait evidence is directly relevant here. Reported speed observations showed that vehicle speeds before and after fixed camera locations were higher than speeds at the camera sites [3]. This pattern is conceptually illustrated in **Figure 1**, where speed decreases near the enforcement point and then rises again after the camera zone.

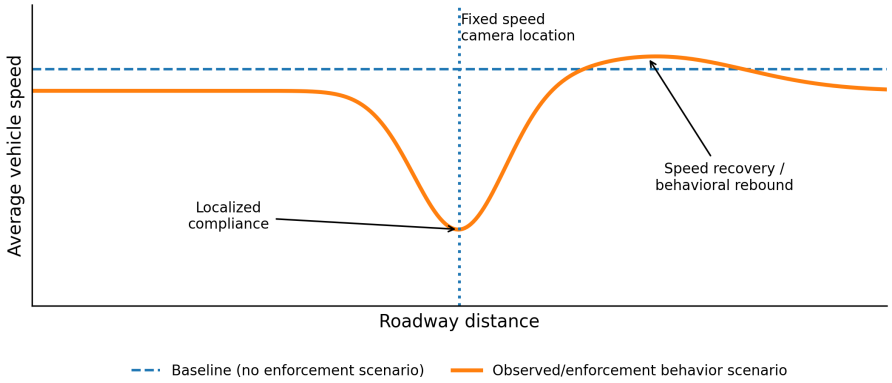


Figure 1. Conceptual illustration of localized speed compliance and behavioral adaptation near fixed au-tomated enforcement locations.

5.2. Kangaroo Effect and Speed Recovery

The localized speed-reduction pattern is commonly described as the kangaroo effect, where drivers decelerate before the camera and accelerate after passing the monitored zone [8]. This behavior reduces the reliability of camera-site speed measurements as indicators of broader safety performance. A speed survey at the camera location may show compliance, while the same corridor may still experience high-risk speeds upstream or downstream.

This effect has two implications. First, enforcement evaluation should not rely only on spot speeds measured at camera locations. Second, camera deployment should be designed to reduce predictability where appropriate, either through rotating mobile enforcement, corridor-based enforcement strategies, or average-speed enforcement systems where feasible. The objective is to shift behavior across the road section, not only at one visible enforcement point.

5.3. Spatial Risk Redistribution and Collision Migration

Behavioral adaptation may also affect where risk occurs. If drivers change routes to avoid camera locations, or if they speed up after passing known enforcement points, crash risk may be redistributed rather than removed. This does not mean that speed cameras cause crashes, but it means that camera effects must be interpreted spatially. Risk displacement may be spatial, temporal where enforcement is intermittent, or route-based, while behavioral adaptation may confine compliance to known enforcement zones [7] [8].

Kuwait provides a useful example of this problem. Fatal collision frequencies within a 2-km radius of speed cameras were reported to be statistically higher than in similar areas without cameras, but the study could not confirm whether cameras contributed to the higher fatal collision frequency or whether cameras had been installed at already collision prone locations [4]. This uncertainty is central to automated enforcement evaluation. Without knowing the original risk profile of camera sites, a spatial crash pattern near cameras may reflect site-selection bias rather than a treatment effect.

Alamry and Hassan [1] proposed that operational incentives might have en-

couraged camera placement at locations with high speeding-violation potential rather than high collision-reduction potential. This explanation was not directly tested, and the observed collision outcomes do not establish that these incentives determined deployment or caused the estimated changes.

5.4. Implications for Deployment Strategy

The behavioral adaptation evidence supports a risk-based deployment approach. Cameras should be placed and evaluated based on crash history, severity potential, operating-speed profiles, geometric conditions, roadside hazards, pedestrian exposure, and traffic composition. Deployment based only on violation volume is insufficient because high speeding frequency does not always correspond to the highest fatal and serious injury risk.

A system-based strategy should therefore combine enforcement with corridor diagnosis. This includes before-and-after speed monitoring upstream, at, and downstream of camera locations; crash analysis by severity and crash type; review of alternative route behavior; and road safety audits to identify whether infrastructure conditions are contributing to severe crash risk. In this framework, automated enforcement becomes one part of a wider speed-management system rather than a stand-alone compliance tool.

5.5. Authors and Affiliations

Behavioral adaptation also explains why severity-based evaluation is necessary. A camera may reduce speed at a point but fail to reduce fatal and serious injury crashes if high-risk behavior simply shifts downstream, to parallel routes, or to untreated segments. Conversely, a camera may reduce the most severe crashes even if total reported crashes do not fall, because lower impact speeds can reduce injury severity.

For this reason, the next stage of the review focuses on crash severity. The key question is not only whether automated enforcement reduces violations or total crashes, but whether it contributes to sustained reductions in fatal and serious injury outcomes.

6. Severity-Based Evaluation of Automated Speed Enforcement

Automated speed enforcement is often evaluated through changes in violations, operating speed, or total crash frequency. These indicators are useful, but they are not sufficient for judging the real safety value of enforcement. The central road safety question is whether automated enforcement contributes to reducing fatal and serious injury outcomes. A program that reduces minor violations but has limited effect on severe crashes should not be interpreted in the same way as a program that measurably reduces fatal and serious injury risk.

6.1. Why Severity-Based Evaluation Is Necessary

Crash severity matters because not all crashes impose the same social, medical,

and economic burden. Fatal and serious injury crashes represent the highest consequence events and are the primary focus of modern road safety systems. Property-damage-only crashes, minor injury crashes, serious injury crashes, and fatal crashes should therefore be analyzed separately wherever data allow.

For clarity, this review uses severity categories in the following sense. A fatal crash refers to a crash resulting in one or more deaths, commonly counted within 30 days of the crash when the death results from injuries sustained in that event. A serious-injury crash refers to a crash resulting in major injury requiring substantial medical treatment, hospitalization, or producing lasting functional consequences. A minor-injury crash refers to a crash resulting in injury of lower medical severity, while a property-damage-only (PDO) crash refers to a reported crash without recorded physical injury.

These categories provide an interpretive framework and do not imply that the reviewed studies used harmonized recording rules. In the Saudi evaluation [1], Traffic Police Department records classified minor injuries treated at the scene without hospitalization as PDO collisions. Consequently, that study's PDO category is broader than the no-recorded-injury definition adopted above, and minor-injury outcomes cannot be separated from its reported PDO results. The study does not establish that its fatal collision records followed a 30-day death-registration rule, nor does it document a standardized clinical threshold demonstrating equivalence with this review's serious-injury definition.

The Kuwait fatal-collision study [4] used a narrower fatality-recording criterion: it examined non-intersection collisions involving at least one death at the time of the collision, rather than deaths occurring within a 30-day follow-up period. Its fatal collision outcome is therefore not directly equivalent to the 30-day definition described above. The study did not investigate nonfatal injury or PDO collisions.

The Dubai hotspot study [5] used binary High/Low incident-severity labels without establishing their correspondence to the fatal, serious-injury, minor-injury and PDO categories adopted here. Its severity-weighted findings are therefore interpreted within the original classification, without treating High severity as equivalent to fatal or serious injury. The Kuwait speed-behaviour evidence [3] and Qatar monitoring-system evidence [6] are used for behavioural and technological context, respectively, rather than as comparable severity-specific crash-effect estimates. Accordingly, this review retains source-specific outcome labels and does not assume that severity categories are interchangeable across studies.

This distinction is especially important for automated speed enforcement because compliance effects and crash-severity effects may differ. A camera may reduce speeding at a specific location but produce unclear effects on fatal crashes if severe crash risk is mainly controlled by other factors, such as roadside hazards, median protection, curve geometry, intersection conflicts, pedestrian exposure, vehicle mix, and emergency response time. Conversely, enforcement may reduce impact speed enough to reduce injury severity even if the total number of reported crashes does not decline substantially.

6.2. Speed, Impact Energy, and Injury Severity

Speed is directly linked to crash severity because impact energy increases nonlinearly with vehicle speed. In basic mechanical terms, kinetic energy is proportional to the square of velocity. This means that a small increase in speed can produce a much larger increase in collision energy. The reverse is also important: moderate reductions in operating speed can meaningfully reduce the energy transferred during impact.

This relationship is conceptually illustrated in Figure 2. The figure should not be presented as field-measured data. Its purpose is to show why speed management is technically connected to fatal and serious injury reduction.

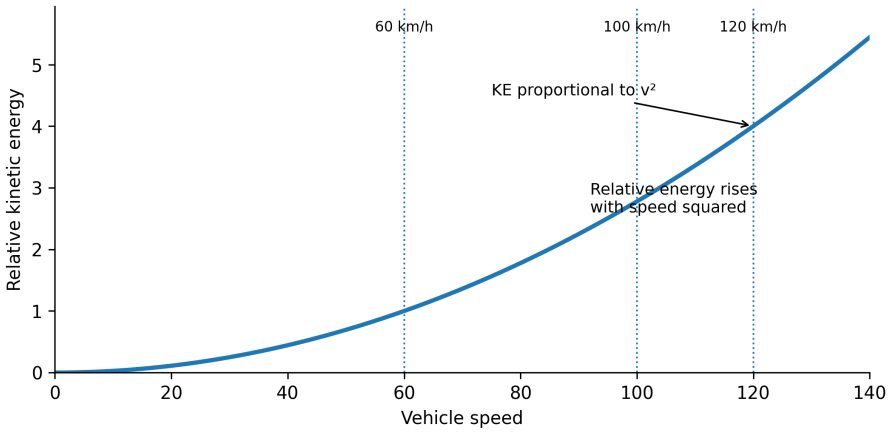


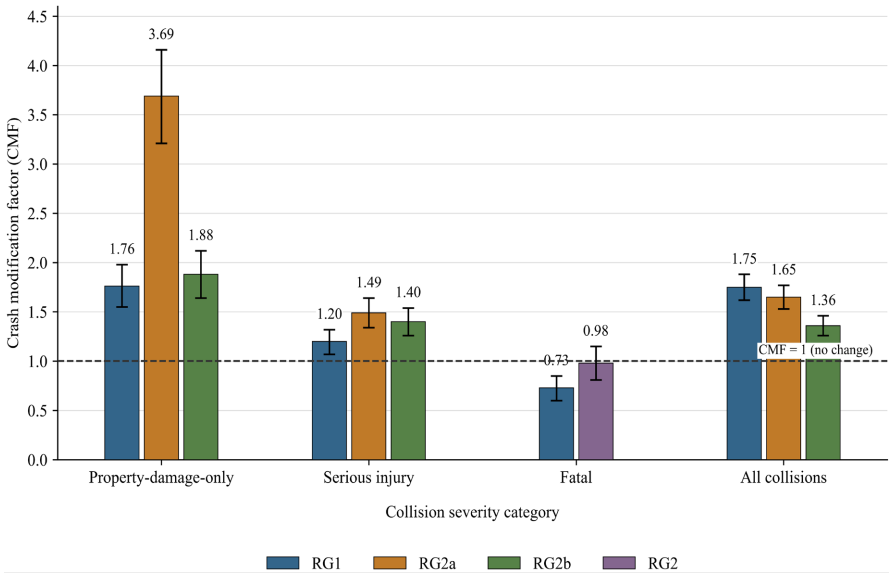
Figure 2. Conceptual relationship between vehicle speed and relative kinetic energy, illustrating the nonlinear increase in impact energy as speed increases.

6.3. Severity Findings from the Saudi PFI Evaluation

The Saudi PFI mobile-camera evaluation is especially useful because it separated crash outcomes by severity. The study evaluated property-damage-only, serious-injury, fatal, and total reported collisions using Negative Binomial regression and Empirical Bayes before-and-after analysis [1]. This is stronger than a simple before-and-after comparison of total crashes because it recognizes that different severity levels may respond differently to enforcement.

The Empirical Bayes analysis estimated statistically significant increases in reported PDO, serious-injury, and total collision frequencies across the reference-group specifications, with increases of 76.36% - 268.96%, 19.72% - 49.07%, and 36.24% - 75.20%, respectively [1]. All corresponding 95% confidence intervals excluded CMF = 1. Fatal collision findings depended on the reference group: RG1 yielded a CMF of 0.73 (95% CI: 0.60 - 0.85), corresponding to a reported 27.40% reduction, whereas RG2 yielded 0.98 (95% CI: 0.81 - 1.15), which was not statistically significant. The Negative Binomial analysis likewise reported significant increases for PDO, serious-injury, and total collisions at the 1% significance level, but did not identify a statistically significant camera effect for fatal collisions. These findings describe the evaluated corridor and operating period and should not be generalized to all Saudi automated enforcement.

Figure 3 summarizes the severity-specific crash modification factors (CMFs) reported in the Saudi PFI mobile speed camera evaluation. A CMF represents the estimated collision outcome after treatment relative to the expected condition without treatment; therefore, a CMF below 1.0 indicates a reduction, while a CMF above 1.0 indicates an increase. The figure presents results across the study's reference-group approaches. RG refers to reference group: RG1 used untreated road segments only, while RG2 used untreated road segments and treated road segments during the before period. RG2a and RG2b represent RG2-based model variants developed with and without the Road variable, respectively, where that variable was statistically significant in the safety performance models. The reported 95% confidence intervals for PDO, serious-injury and total collision CMFs were entirely above 1.0. For fatal collisions, the RG1 interval was below 1.0, whereas the RG2 interval included 1.0. This supports the need to interpret automated enforcement by severity category, reference-site selection, and deployment context rather than by aggregate crashes alone.



Note: CMF = crash modification factor; CI = confidence interval; PDO = property-damage-only; SI = serious injury; RG = reference group. Severity categories follow the original study [1]. In particular, its PDO category includes minor injuries treated at the scene without hospitalization and therefore differs from the no-recorded-injury definition used in this review. RG1 includes untreated road segments only; RG2 includes untreated road segments and treated road segments during the before period. RG2a and RG2b denote models including and excluding the Road variable, respectively, where applicable. Error bars represent the reported 95% confidence intervals. CMF = 1 indicates no estimated change; values below and above 1 indicate estimated decreases and increases, respectively. Confidence intervals excluding 1 indicate statistically significant changes at the 5% level. Estimates are from the Empirical Bayes analysis in Table 7 of [1].

Figure 3. mpirical Bayes crash modification factors and reported 95% confidence intervals for the Saudi PFI mobile-camera evaluation, based on Table 7 of [1].

These findings demonstrate variation by severity and reference-group specifi-

cation in the evaluated corridor. Alamry and Hassan [1] proposed that revenue incentives under the PFI arrangement might have encouraged deployment at locations with high speeding-violation potential rather than high collision-reduction potential. This was a proposed explanation, not a directly tested causal mechanism; the reported collision outcomes alone do not establish that contractual incentives caused the observed changes.

6.4. Interpreting Different Severity Outcomes

Fatal crashes are often less frequent than minor or property-damage-only crashes, which makes statistical evaluation more difficult. A short evaluation period or small sample size may fail to detect meaningful fatality changes even when a safety effect exists. Serious injury crashes may provide a more stable indicator than fatalities alone, but they also depend on crash reporting quality, injury classification, hospital linkage, and police reporting practices.

Property-damage-only crashes require additional caution. They may be more sensitive to reporting behavior, congestion, enforcement presence, minor braking events, or rear-end crash patterns. Therefore, a change in property damage-only crashes should not be treated as equivalent to a change in fatal or serious injury crashes.

This is why automated enforcement evaluation should prioritize fatal and serious injury outcomes, while still reporting total crashes and property-damage-only crashes for completeness. A severity-based approach prevents the analysis from being dominated by high-frequency, low-consequence events.

6.5. Severity-Based Interpretation Framework

The severity-based interpretation used in this review is summarized in Table 2. The table is not intended to replace statistical analysis. It provides an analytical framework for interpreting enforcement outcomes by crash severity and identifying the complementary engineering measures required for each severity level.

Table 2. Severity-based interpretation of automated speed enforcement outcomes and required complementary safety measures.

Outcome category	Enforcement may influence	Main interpretation risk	Required complementary measures
Speed compliance/violations	Operating speed near camera locations; violation frequency; driver perception of detection risk	Local compliance may be mistaken for corridor-wide safety improvement	Upstream/downstream speed monitoring, rotating/mobile enforcement, average-speed enforcement where feasible
Property-damage-only crashes	Low-severity reported crash frequency; minor rear-end or operational events	May be affected by reporting practices, congestion, braking behavior, or enforcement visibility	Operational review, traffic flow assessment, lane-change management, monitoring of rear-end crash patterns
Serious-injury crashes	High-consequence injury outcomes affected by impact speed and crash configuration	May be underreported or inconsistently classified if police/hospital data are not linked	Severity-specific crash analysis, hospital/police data linkage, road safety audits, targeted geometric improvements

Continued

Fatal crashes	Highest consequence outcome; strongly affected by impact energy, roadside hazards, crash angle, and vehicle mix	Small sample size may make results statistically unstable; fatality changes may be hidden in short evaluation windows	Risk-based site selection, median/roadside protection, access control, intersection safety treatment, post-crash response improvement
Total crashes	Overall crash frequency	Aggregate totals can hide severity shifts; reductions in minor crashes may mask no change in fatal/serious injury risk	Always disaggregate by severity, crash type, location, and exposure

6.6. Implications for Automated Enforcement Evaluation

A severity-based perspective changes how automated enforcement should be judged. The objective should not be simply to increase detected violations or reduce total reported crashes. The objective should be to reduce fatal and serious injury risk. This requires enforcement to be placed where excessive speed contributes to high-severity crash potential, not merely where speeding is common or easily detected.

This perspective also links enforcement to engineering. If severe crashes are driven by roadside fixed objects, inadequate median separation, unsafe access points, poor intersection control, pedestrian exposure, or high operating speeds inconsistent with road function, cameras alone cannot resolve the full risk. They may reduce one behavioral factor, but they cannot remove the underlying infrastructure hazard. Therefore, automated speed enforcement should be evaluated and deployed as part of a severity-based safety system.

7. Integration of Automated Enforcement with Road Safety Engineering

The evidence reviewed in the previous sections shows that automated speed enforcement can influence driver behavior, but its safety value depends on how it is integrated into the wider road safety system. Cameras can reduce speeding exposure, but they cannot correct geometric deficiencies, remove roadside hazards, improve median protection, redesign intersections, protect pedestrians, or compensate for weak crash-data systems. For this reason, automated enforcement should be treated as one component of a system-based road safety strategy rather than as a stand-alone countermeasure.

7.1. Enforcement as One Layer of a Safe Road System

A system-based approach recognizes that severe crashes are rarely caused by a single factor. Speeding may be present, but fatal and serious injury outcomes are also shaped by road geometry, roadside environment, traffic mix, access control, road-user vulnerability, vehicle protection, driver experience, training, and post-crash response. This is consistent with the broader Safe System approach, which emphasizes coordinated action across safer roads, safer speeds, safer road users,

safer vehicles, and post-crash care [12].

In GCC urban arterial contexts, this also requires explicit attention to pedestrian and vulnerable-user exposure. Within this framework, automated speed enforcement mainly addresses the safer speeds and safer road users components. It influences driver behavior by increasing the certainty of detection, but it does not remove physical sources of crash severity. Therefore, enforcement should be deployed together with engineering measures that reduce crash likelihood and crash consequence.

7.2. Risk-Based Site Selection

The first engineering implication is that camera locations should be selected based on risk, not only violation frequency. Locations with high speeding rates may not always be the locations with the highest fatal and serious injury potential. Conversely, a site with fewer violations may still deserve enforcement if excessive speed interacts with high severity risk factors such as sharp curvature, poor sight distance, pedestrian exposure, uncontrolled access, roadside fixed objects, or severe run-off-road crash potential.

Alamry and Hassan [1] proposed that PFI-operated mobile cameras might have been placed at locations with high speeding-violation potential rather than high collision-reduction potential. Although this mechanism was not directly tested, it provides a rationale for examining deployment incentives alongside crash severity, exposure, operating speed, geometry, roadside hazards and facility function.

A risk-based site-selection process should therefore include at least four inputs: historical crash data disaggregated by severity, speed and violation data, roadway inventory and geometric characteristics, and field-based safety review. The purpose is to identify locations where speed enforcement can reasonably contribute to fatal and serious injury reduction, not merely locations where violation capture is likely to be high.

7.3. Road Safety Audits and Corridor Diagnosis

Automated enforcement should be accompanied by road safety audits (RSAs) or equivalent engineering safety assessments, especially on high-speed corridors and urban arterials with severe crash history. A camera may identify or control one behavioral problem, but an audit can identify the physical conditions that allow crashes to become severe. These may include inadequate clear zones, rigid roadside objects, unsafe median openings, inconsistent speed environments, poor lighting, weak pedestrian crossing provision, pavement friction issues, or conflicts created by access points and merging areas.

This is particularly important where enforcement results are mixed. If crashes remain severe after camera deployment, the correct response is not simply to add more cameras. The correct response is to ask whether the crash mechanism is actually speed-dominant or whether speed is interacting with unresolved infrastructure risk. This requires corridor-level diagnosis rather than point-based enforce-

ment evaluation.

The UAE evidence supports this integrated logic. Dubai-based severity-weighted hotspot analysis did not treat automated enforcement as an isolated solution; it placed enforcement among other countermeasures such as lighting improvement, speed management, and pedestrian-focused treatments [5]. This is the correct framing for GCC applications: cameras should be one treatment within a broader package of countermeasures selected according to the crash pattern and road environment.

7.4. Complementary Engineering Countermeasures

The type of complementary engineering treatment depends on the dominant crash pattern and severity mechanism. On high-speed intercity roads, fatal and serious injury risk may be strongly affected by run-off-road crashes, median crossover crashes, high-speed rear-end crashes, and impacts with fixed objects. In such cases, enforcement should be combined with median protection, roadside hazard treatment, shoulder and recovery-area improvements, delineation, access management, and geometric consistency review.

On urban arterials, the safety problem may be different. Severe crashes may involve pedestrians, turning conflicts, signal compliance, driveway access, nighttime visibility, or inconsistent speed environments. In these cases, enforcement should be integrated with pedestrian crossing treatments, lighting upgrades, intersection redesign, traffic calming where appropriate, signal timing review, and speed-limit credibility assessment.

This distinction matters because automated enforcement cannot substitute for context-sensitive engineering. A camera may reduce speed at a point, but if the roadway design still encourages high operating speeds or exposes vulnerable users to high-energy conflicts, severe crash risk may remain. Sustainable fatal and serious injury reduction requires both behavioral control and infrastructure conditions that make safe behavior more natural and crash consequences less severe.

7.5. Data, Monitoring, and Feedback

Engineering integration also requires continuous monitoring. A camera program should not be considered successful only because it generates violations or reduces speeds at the camera site. It should be monitored for upstream and downstream speed behavior, crash migration, crash severity, crash type, and changes in exposure. The evaluation should also consider whether drivers divert to parallel routes or accelerate after passing fixed enforcement locations.

Qatar's traffic-monitoring literature is relevant here because it demonstrates the value of technology-supported safety data, including speed, GPS-based movement, driver-behavior indicators, crash prediction, and infrastructure improvement logic [6]. These data systems can strengthen enforcement evaluation if they are linked to crash severity outcomes and engineering asset data.

The Highway Safety Manual framework also supports this type of safety management thinking by emphasizing crash prediction, safety performance functions,

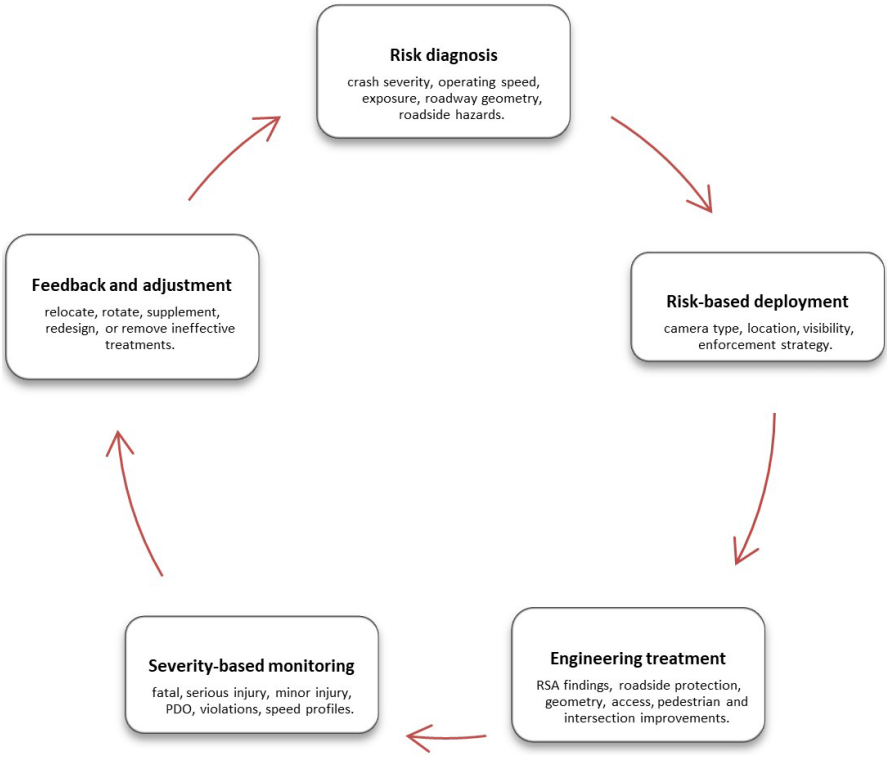


Figure 4. Integrated enforcement-engineering safety framework for severity-based crash-risk reduction.

and crash modification factors as part of roadway safety analysis [11]. For automated enforcement, this means that camera deployment should be embedded in a feedback loop: identify risk, deploy enforcement and engineering measures, monitor behavioral and crash outcomes, adjust treatment, and continue severity-based evaluation.

Figure 4 summarizes this integrated enforcement-engineering framework, linking risk diagnosis, risk-based deployment, engineering treatment, severity-based monitoring, and feedback.

7.6. Implication for GCC Practice

For Saudi Arabia and the GCC, the practical implication is that automated enforcement should be governed by a safety performance logic rather than a violation-count logic. Enforcement locations should be justified by crash severity potential, not only by expected citation volume. Evaluation should be based on fatal and serious injury reduction, not only total crashes or compliance at the enforcement point. Engineering teams should therefore be involved before, during, and after camera deployment.

Practical deployment may also be influenced by jurisdictional responsibilities, funding, power and communications availability, maintenance access, and protection of roadside equipment.

This is especially important in high-speed GCC environments, where operating speeds, wide multilane facilities, long intercity corridors, and roadside exposure

can produce high-energy crashes. In such settings, enforcement can help manage speed, but infrastructure design determines how forgiving the system is when drivers make errors. The central lesson is that cameras can support safer speeds, but only an integrated enforcement-engineering system can reliably target severe crash outcomes.

8. Recommendations for Practice and Policy

The reviewed evidence indicates that automated speed enforcement can support speed management, but its effectiveness depends on deployment logic, engineering integration, governance, and severity-based evaluation. For Saudi Arabia and other GCC countries, the main policy challenge is not whether automated enforcement should be used, but how it should be planned, justified, monitored, and integrated with broader road safety systems.

8.1. Define Success by Fatal and Serious Injury Reduction

Automated enforcement programs should define success primarily by reductions in fatal and serious injury crashes, not by the number of detected violations or the volume of issued citations. Violation counts may indicate enforcement activity, but they do not directly prove safety improvement. Similarly, reductions in total crashes can be misleading if severity shifts are not examined.

Road authorities should therefore report automated enforcement outcomes by severity category: fatal, serious injury, minor injury, property-damage-only, and total crashes. This is especially important in high-speed environments where small changes in operating speed may have large consequences for injury severity. The Saudi PFI evaluation demonstrates why this distinction matters: different severity categories did not produce uniform findings, and fatal crash results were weaker and more mixed than other outcome categories [1].

8.2. Use Risk-Based Site Selection

Camera locations should be selected using crash-risk and severity-risk criteria, not only violation frequency. A site with frequent speeding is not automatically the site where enforcement will produce the greatest reduction in fatal or serious injury risk. Conversely, a site with fewer violations may still require enforcement if excessive speed interacts with severe crash mechanisms, such as roadside fixed objects, median crossover risk, pedestrian exposure, curve geometry, poor sight distance, or uncontrolled access.

A practical risk-based site-selection process should combine several forms of evidence. Historical crash data should be disaggregated by severity to identify fatal and serious injury concentration. Operating-speed profiles should be used to determine whether excessive speed is a contributing risk factor. Exposure data, such as traffic volume and vehicle mix, should be used to normalize risk and avoid overemphasizing locations simply because they carry high traffic volumes. Roadway geometry, roadside hazard inventory, pedestrian exposure, and field-based

safety review should then be used to confirm whether enforcement alone is suitable or whether engineering treatment is also required.

This recommendation is consistent with the concern proposed by Alamry and Hassan [1] that deployment incentives might favour high violation potential over high collision-reduction potential. Their study did not directly establish this mechanism. Risk-based site selection is therefore recommended as a safety-planning principle, rather than as a remedy for a proven contractual cause of the reported collision changes.

8.3. Integrate Cameras with Road Safety Audits and Engineering Treatments

Automated enforcement should be connected to road safety audits, corridor diagnosis, and infrastructure treatment programs. A camera can influence driver behavior, but it cannot remove a roadside hazard, correct poor geometric consistency, improve pedestrian crossing protection, or redesign an unsafe intersection. Therefore, enforcement should be treated as one layer of a broader engineering safety package.

For high-speed intercity roads, complementary measures may include median barriers, roadside hazard removal or shielding, shoulder improvements, access control, delineation, curve warning, pavement friction management, and speed-limit consistency review. For urban arterials, complementary measures may include intersection redesign, pedestrian refuge islands, protected crossings, signal timing improvements, lighting upgrades, traffic calming, driveway/access management, and credible speed-limit setting.

The UAE evidence supports this integrated approach because Dubai severity-weighted safety work placed automated enforcement among other countermeasures such as lighting, speed management, and pedestrian-focused treatments rather than treating cameras as an isolated solution [5].

8.4. Match Enforcement Strategy to the Crash Mechanism

Camera type should be selected according to the risk mechanism. Fixed cameras may be suitable at locations with repeated severe crash history or high-risk point features, but they are vulnerable to localized compliance and speed recovery if drivers know the camera location. Mobile cameras can improve unpredictability and general deterrence, but only if deployment is guided by safety risk rather than ease of violation detection. Average-speed or section-control systems may be more suitable for corridors where the objective is sustained speed moderation rather than point-based compliance.

This distinction is important because different safety problems require different enforcement strategies. A known high risk point may justify fixed enforcement, particularly if the camera is combined with engineering treatment. A long corridor with speed recovery may require average-speed enforcement or rotating mobile enforcement. Temporary risk areas, such as work zones, may require portable

or mobile enforcement. Pedestrian-heavy urban locations may require lower-speed enforcement combined with crossing, lighting, and traffic-calming measures. The enforcement method should therefore follow the crash mechanism, not administrative convenience. Automated systems should also be complemented, where appropriate, by targeted conventional police enforcement at temporary, variable, or high-risk locations where direct intervention may be required. Sustained road-safety communication and awareness programs can provide an additional behavioral layer and should complement, rather than substitute for, risk-based enforcement and engineering treatment [1].

8.5. Strengthen Monitoring, Evaluation, and Data Integration

Evaluation should not rely only on speeds or violations recorded at the camera location. Fixed cameras can produce localized speed reduction while drivers accelerate before or after the monitored zone. Kuwait evidence supports this concern, with vehicle speeds reported to be lower at camera sites and higher before and after the camera locations [3]. For this reason, monitoring should include upstream speed behavior, at-site compliance, downstream speed recovery, corridor crash outcomes, and possible diversion to parallel routes.

Automated enforcement should also be evaluated using methods that account for exposure, time trends, comparison sites, and regression-to-the-mean. Simple before-and-after comparisons can be misleading because cameras are often installed at locations with abnormal crash history, public complaints, or high speeding activity. Where data are available, road authorities should use Empirical Bayes before-and-after methods, safety performance functions, and crash modification factors to evaluate treatment effects by severity category. These methods are already established in road safety evaluation and were applied in the Saudi PFI evaluation [1] [9] [10].

Data integration is essential for this type of evaluation. Police crash records alone may not fully capture injury severity, while hospital data alone may not capture roadway location, crash type, exposure, or engineering context. Road authorities should therefore strengthen linkage between police crash records, hospital injury data, traffic volume, operating speed, violation records, road inventory, and geospatial location data. Qatar's traffic-monitoring literature illustrates the value of technology-supported safety data, including vehicle trip records, GPS coordinates, speed indicators, driver-behavior measures, and crash-prediction logic [6]. For automated enforcement, these data systems become more valuable when connected to crash severity and engineering asset databases.

8.6. Align Governance and Reporting with Safety Outcomes

Governance is a central policy issue. If automated enforcement is managed primarily around violation detection, revenue generation, or equipment productivity, deployment can drift away from safety objectives. This risk is especially important where private-sector operation, outsourcing, or performance-based con-

tracting is involved.

Contracts and performance indicators should therefore prioritize safety outcomes rather than citation volume. Possible safety-based performance indicators include reduction in fatal and serious injury crashes, reduction in high-risk speeding, improved corridor speed consistency, reduced speed variance, and successful treatment of high-risk locations. Citation volume may be tracked as an operational metric, but it should not be the primary measure of program success.

This recommendation is consistent with the explanation proposed by Alamry and Hassan [1] concerning possible revenue-related deployment incentives. Their evaluation did not establish that these incentives determined camera placement or caused the observed collision changes.

More consistent public reporting would support learning across GCC countries. Among the sources reviewed for the four countries, Saudi Arabia contributes corridor-level camera evaluation, Kuwait contributes behavioural and spatial camera studies, and the UAE and Qatar contribute safety-planning and monitoring evidence. These differences in the included evidence limit direct cross-country comparison.

8.7. Summary of Recommendations

The main recommendations are summarized in Table 3.

Table 3. Recommended practice and policy actions for severity-based automated speed enforcement.

Recommendation	Main action	Expected benefit
Define success by fatal and serious injury reduction	Evaluate outcomes by severity, not only violations or total crashes	Aligns enforcement with the real road safety burden
Use risk-based site selection	Select sites using crash severity, exposure, speed, geometry, and roadside hazard risk	Prevents violation-volume logic from dominating
Integrate enforcement with engineering	Combine speed cameras with RSA, roadside, geometric, pedestrian, and intersection treatments	Addresses both behavior and infrastructure risk
Match camera type to safety problem	Use fixed, mobile, or average-speed enforcement based on the risk mechanism	Reduces mismatch between technology and crash pattern
Monitor spatial behavior	Measure upstream, at-site, downstream, and corridor-level speed response	Detects localized compliance and speed recovery
Use robust evaluation methods	Apply reference sites, exposure adjustment, Empirical Bayes methods, and severity-specific CMFs	Reduces bias and improves confidence in results
Improve data linkage	Connect police crash records, hospital injury data, speed data, violation records, traffic volume, and roadway inventory	Enables stronger severity-based analysis
Align governance incentives	Avoid citation-volume performance targets; use safety-performance indicators	Reduces risk of revenue-driven deployment
Standardize GCC reporting	Publish consistent enforcement and safety outcome metrics across GCC countries	Improves regional learning and comparison

9. Conclusions

Automated speed enforcement has become an important road safety tool in Saudi

Arabia and selected GCC countries. The reviewed evidence shows that speed cameras can influence driver behavior by increasing the certainty of detection and improving compliance near monitored locations. However, the safety value of automated enforcement cannot be judged only by violation counts, localized speed reductions, or aggregate crash totals.

Among the sources included for the four countries, the direct camera-related empirical evidence comes principally from Saudi Arabia and Kuwait. Saudi Arabia provides the most developed case through the SAHER/ATVAM system and the corridor-level evaluation of mobile speed enforcement operated under a Private Finance Initiative model. That evaluation demonstrates variation in estimated outcomes by crash severity and reference-group specification. Its authors proposed deployment incentives as a possible explanation, but did not establish that governance or site-selection mechanisms caused the observed changes [1]. Kuwait contributes important behavioral and spatial evidence, showing that fixed cameras may produce localized speed reduction while speed recovery occurs before or after camera locations. These findings support the need to distinguish between local compliance and sustained corridor-level safety improvement.

The UAE and Qatar contribute differently to the review. Their value is not in providing direct camera-effectiveness evidence comparable to Saudi Arabia or Kuwait, but in supporting the broader regional movement toward technology supported safety management, severity-based hotspot analysis, traffic monitoring, and data-driven intervention planning. The included sources provide uneven coverage of severity-disaggregated camera effectiveness across the four countries; this should not be interpreted as a comprehensive statement about evidence availability throughout the GCC.

The central conclusion of this review is that automated speed enforcement should be treated as one layer within a broader road safety system. Cameras can support safer speeds, but they cannot independently correct roadway geometry, remove roadside hazards, improve pedestrian protection, redesign intersections, or resolve weaknesses in crash and injury data systems. Sustainable reductions in fatal and serious injury crashes require risk-based deployment, road safety audits, engineering countermeasures, severity-based monitoring, and governance structures that prioritize safety outcomes over citation volume.

For Saudi Arabia and other GCC countries, the next stage of automated enforcement should therefore focus less on expanding camera presence alone and more on improving the quality of deployment and evaluation. Enforcement locations should be selected using crash severity, operating speed, exposure, roadway geometry, roadside hazard exposure, and vulnerable-user exposure. Evaluation should separate fatal, serious-injury, minor-injury, property damage-only, and total crash outcomes. Regional reporting should also become more consistent so that GCC countries can compare enforcement performance, learn lessons, and improve safety outcomes rather than relying on technology adoption alone.

In summary, automated speed enforcement remains a valuable road safety

measure, but it is not a stand-alone solution. Its greatest value emerges when it is integrated with engineering diagnosis, infrastructure treatment, data systems, and severity-based performance monitoring. The appropriate policy question is therefore not simply whether speed cameras reduce speeding, but whether they are deployed and managed in a way that contributes to sustained fatal and serious injury reduction.

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Author Contributions

Conceptualization, W.K.; methodology, A.A.G.; investigation, A.A.G.; writing—original draft preparation, A.A.G.; writing—review and editing, W.K. and A.A.G. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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