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A Novel Average Speed Monitoring System for Highways Using Travel Time Between Two Cameras

Majzoob K. Omer | Al-Baha University, Albaha, Saudi Arbia | mkomer@bu.edu.sa

Abstract

Aim/Purpose	This study aims to develop and assess a speed monitoring system that enforces continuous compliance with speed regulations on highways by calculating average vehicle speed between two fixed cameras.
Background	Unlike traditional point-based enforcement methods, this approach ensures continuous speed monitoring over an extended distance, reducing the possibility of speed manipulation by drivers.
Methodology	The proposed system employs mathematical models to calculate average vehicle speed by considering factors such as acceleration, air resistance, and environmental road conditions. To assess its performance, a computer-based simulation was conducted, simulating vehicle movements across a predefined highway segment. The simulation incorporated various driving behaviors and environmental conditions to evaluate the system's accuracy and reliability in detecting speed violations. Due to resource constraints and ethical considerations regarding real-world testing of enforcement systems, this study primarily relies on simulated data, with limitations clearly acknowledged throughout the methodology section.
Contribution	This research contributes to the field of intelligent transportation systems by addressing limitations of conventional approaches and leveraging technological advancements to develop more effective interventions for reducing speed-related accidents.
Findings	The simulation results demonstrate that the proposed system significantly outperforms traditional point-based enforcement across all key performance metrics, achieving higher measurement accuracy and violation detection rates.
Recommendations for Practitioners	Transportation authorities should consider implementing average speed enforcement systems on highways with high accident rates, as they promote more

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consistent driving behavior and eliminate the "kangaroo effect" commonly observed with point-based enforcement.

Recommendations for Researchers Future research should focus on field implementation and validation, advanced vehicle identification methods, behavioral impact studies, and integration with emerging vehicle technologies.

Impact on Society By encouraging consistent compliance with speed limits, the system could significantly reduce speed-related accidents and fatalities, alleviate pressure on emergency medical services, decrease fuel consumption and emissions, and promote equitable enforcement.

Future Research Further investigation is needed into real-world implementation, enhanced vehicle identification techniques, long-term behavioral impacts, integration with connected vehicle technologies, and comprehensive cost-benefit analyses.

Keywords speed monitoring, average speed enforcement (ASE), intelligent traffic systems, speed cameras, highway speed enforcement, vehicle speed detection, real-time traffic monitoring, traffic enforcement technology

INTRODUCTION

Road safety remains a critical global concern, with excessive speeding consistently identified as a primary contributor to traffic accidents and fatalities worldwide (Chen, 2005; Elvik et al., 2009). Traditional speed enforcement methods, such as stationary radar systems and mobile speed cameras, have demonstrated limited effectiveness due to their point-based nature, allowing drivers to temporarily adjust their behavior at known enforcement locations while speeding elsewhere (Soole et al., 2013; Vaa et al., 2014). This pattern of behavior, commonly referred to as the "kangaroo effect," significantly undermines the safety benefits of conventional enforcement approaches (Fitzpatrick et al., 2017).

Average Speed Enforcement (ASE) systems represent a promising alternative by monitoring vehicle speeds over extended road segments rather than at isolated points. These systems calculate average speeds based on the time taken to travel between two fixed points, effectively encouraging consistent compliance with speed limits throughout the monitored section (Soole et al., 2013; Wilson et al., 2010). Recent studies have demonstrated that ASE implementations can reduce fatal and serious injury crashes by up to 50% in certain contexts, highlighting their potential as effective road safety interventions (Fitzpatrick et al., 2017; Montella, 2010).

Despite these promising outcomes, significant challenges remain in the widespread adoption and optimization of ASE systems. Recent research by Rahman et al. (2021) highlights the technical complexities of vehicle identification across multiple camera points, particularly in adverse weather conditions or high-traffic scenarios. Additionally, Kumar and Singh (2023) identify concerns regarding the accuracy of travel time measurements when vehicles make intermediate stops or take alternative routes between camera points. These challenges underscore the need for continued innovation in ASE system design and implementation.

The problem of speed enforcement is particularly acute in regions experiencing rapid motorization without corresponding improvements in traffic safety infrastructure. For instance, while European nations have successfully implemented ASE systems on major highways, resulting in significant reductions in speed-related fatalities (European Transport Safety Council, 2022), many developing regions continue to rely on outdated or insufficient enforcement methods. In Southeast Asia, where motorcycle usage is prevalent, traditional enforcement methods have proven especially ineffective, with speed-related fatalities increasing by 15% between 2015 and 2020 (World Health Organization, 2021). Similarly, in rapidly motorizing African nations, the absence of effective speed enforcement systems has contributed to road fatality rates that are among the highest globally (African Road Safety Observatory, 2022; Chen, 2005).

This study addresses these challenges by proposing a novel ASE system that incorporates advanced mathematical modeling to account for real-world driving conditions, including acceleration patterns, environmental factors, and road characteristics. By enhancing the accuracy and reliability of average speed calculations, the proposed system aims to overcome key limitations of existing ASE implementations while providing a cost-effective solution for widespread deployment.

The primary objectives of this research are to:

1. Develop a mathematical model for calculating average vehicle speeds between two fixed camera points that account for real-world driving behaviors and environmental conditions.
2. Design and implement a simulation environment to evaluate the performance of the proposed system under various scenarios.
3. Assess the accuracy, reliability, and effectiveness of the system in detecting speed violations compared to traditional enforcement methods.
4. Analyze the potential impact of the proposed system on driver behavior and road safety outcomes.

The findings of this study contribute to the growing body of knowledge on intelligent transportation systems and provide valuable insights for policymakers, transportation engineers, and road safety practitioners seeking to enhance speed enforcement strategies. By addressing the limitations of conventional approaches and leveraging technological advancements, this research supports the development of more effective interventions to reduce speed-related accidents and improve overall road safety.

LITERATURE REVIEW

Current speed enforcement systems largely rely on point-based monitoring, such as radar and fixed cameras. While these technologies have proven effective at specific locations, they fail to monitor consistent driver behavior over longer distances. Studies show that average speed enforcement (ASE) systems, which monitor speed over a set distance, have a substantial impact on reducing speeding incidents and accidents (Fitzpatrick et al., 2017; Vaa et al., 2014). ASE systems have been widely implemented in several European countries and have demonstrated success in maintaining compliance with speed limits over longer stretches (Soole et al., 2013).

Despite their success, existing ASE systems lack flexibility in integration with intelligent traffic management systems, such as adaptive speed limits or real-time traffic flow monitoring (Smith et al., 2019). Furthermore, most systems focus solely on enforcement rather than broader applications for improving overall traffic management (Elvik et al., 2009). This research aims to fill this gap by proposing a system that not only enforces speed limits but also can be integrated with advanced traffic management technologies.

The current study builds on the foundation of these ASE systems but introduces new methods for real-time violation recording, improved accuracy in speed calculation, and seamless integration with modern traffic control systems.

While ASE systems have demonstrated success, their limited integration with dynamic traffic management systems and lack of real-time adaptability highlight a gap that this study seeks to address.

Unlike the work by Llorca et al. (2016), which focuses on speed measurement over short distances using high-speed cameras, our system is designed for extended highway segments to enforce consistent speed compliance. The proposed model incorporates dynamic factors like acceleration, resistance, and environmental gradients, providing a more realistic and adaptable approach to speed enforcement. Moreover, this study explores integration with intelligent traffic management systems, broadening its application to improve traffic flow and safety.

METHODOLOGY

SYSTEM DESIGN AND LIMITATIONS

The proposed average speed enforcement (ASE) system utilizes two high-definition cameras positioned at fixed points along a highway segment, with a known distance between them. Before detailing the mathematical model and implementation, it is important to acknowledge the inherent limitations of our simulation-based approach:

One limitation is that Simulated Data Constraints: This study relies entirely on simulated vehicle data rather than real-world traffic measurements. While our simulation incorporates realistic driving behaviors based on established traffic flow models, it cannot fully capture the complexity and unpredictability of actual highway conditions.

Another constraint is that Static Environmental Assumptions: The simulation assumes relatively stable environmental conditions (e.g., clear weather, standard road surface quality) and does not account for extreme weather events or road degradation that might affect system performance.

It should be noted that Limited Vehicle Type Diversity: Our model primarily focuses on standard passenger vehicles and does not extensively account for the varied dynamics of commercial vehicles, motorcycles, or specialized transport.

A challenge in this approach is that Absence of Real-World Validation: Resource constraints prevented field testing of the proposed system, limiting our ability to verify performance under authentic conditions.

These limitations were accepted as necessary constraints for this initial research phase, with the understanding that future work would address them through field implementation and validation.

SYSTEM ARCHITECTURE AND OPERATION

The operational workflow of the proposed ASE system is illustrated in Figure 1, which demonstrates the sequential processing steps from vehicle detection to violation determination.

The system operates through the following sequence:

Vehicle Detection and Identification: When a vehicle passes the first camera point (C_1), the system captures an image of the vehicle and records the timestamp (t_1). The vehicle's license plate is identified using Automatic Number Plate Recognition (ANPR) technology.

Additionally, Second Camera Detection: When the same vehicle passes the second camera point (C_2), another image is captured, and a second timestamp (t_2) is recorded. The ANPR system identifies the license plate and matches it with the record from C_1.

Furthermore, Travel Time Calculation: The system calculates the travel time (Δt) between the two camera points such as:

$\Delta t = t_2 - t_1$

Moreover, Average Speed Calculation: Using the known distance (d) between the two camera points, the system calculates the average speed ($\bar{v}$) as:

$\bar{v} = d / \Delta t$

Also, Violation Detection: The calculated average speed is compared against the speed limit for the road segment. If $\bar{v}$ exceeds the speed limit, a violation is recorded.

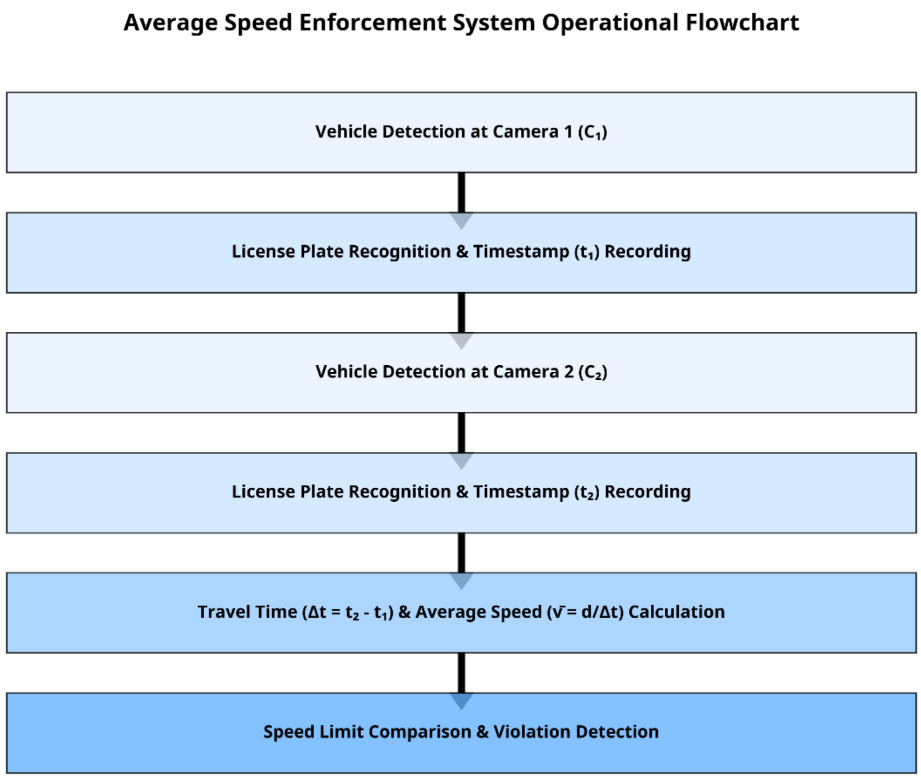

Figure 1: Operational flowchart of the proposed average speed enforcement system

MATHEMATICAL MODEL

The core of our system relies on a piecewise-linear speed approximation model that accounts for realistic driving behaviors. A piecewise-linear speed approximation divides a vehicle's journey into short intervals, assuming constant speed within each segment (see Equation 3).

In practical applications, vehicles may travel at varying speeds between the two camera points due to factors such as traffic conditions, road geometry, and driver behavior. To account for these variations, we developed a mathematical model that incorporates acceleration patterns, air resistance, and road gradient effects.

The model begins with the basic relationship between distance, time, and average speed:

$\bar{v} = d / \Delta t$ (1)

Where:

$\bar{v}$ is the average speed

d is the distance between camera points

Δt is the travel time

For a more accurate representation of vehicle movement, we consider the instantaneous speed v(t) at any time t:

$v(t) = v_0 + \int_0^t a(\tau)\, d\tau$ (2)

Where:

v_0 is the initial speed

$a(\tau)$ is the acceleration function

To make this model computationally tractable, we employ a piecewise-linear approximation:

$v(t) \approx v_0 + \Sigma_i a_i\Delta t_i$ (3)

Where:

a_i is the constant acceleration during time interval i

Δt_i is the duration of time interval i

The distance traveled can then be calculated as:

$d = \int_0^T v(t)\, dt \approx \Sigma_i \bar{v}_i\Delta t_i$ (4)

Where:

$\bar{v}_i$ is the average speed during interval i

T is the total travel time

This model allows us to account for realistic driving behaviors while maintaining computational efficiency.

Simulation Design

To evaluate the performance of the proposed system, we developed a computer-based simulation environment that model's vehicle movements along a highway segment. The simulation was implemented using Python 3.8 with NumPy and Pandas libraries for data processing and analysis.

The simulation parameters were configured as follows:

1. Highway segment length: 10 km
2. Speed limit: 100 km/h
3. Number of simulated vehicles: 1,000
4. Simulation duration: 24 hours
5. Camera placement: At 0 km and 10 km points

Vehicle behaviors were modeled using a stochastic approach that incorporated:

Initially, Speed Distribution: Initial vehicle speeds were generated from a normal distribution with mean $\mu = 95$ km/h and standard deviation $\sigma = 15$ km/h, truncated to ensure non-negative values.

Additionally, Acceleration Patterns: Vehicles were assigned random acceleration/deceleration events throughout their journey, with acceleration values drawn from a normal distribution with mean $\mu = 0$ m/s² and standard deviation $\sigma = 0.5$ m/s².

Furthermore, Environmental Factors: The simulation included variables for wind resistance, road gradient, and surface conditions, each modeled as multiplicative factors affecting vehicle speed.

The simulation recorded the following data for each vehicle:

1. Entry time at first camera point
2. Exit time at second camera point
3. Actual average speed between camera points
4. Calculated average speed using the proposed system
5. Whether a speed violation occurred

Performance Metrics

To assess the effectiveness of the proposed system, we defined the following performance metrics:

Measurement Accuracy: The difference between the actual average speed and the calculated average speed, expressed as:

Accuracy = 1 - $|\bar{v}_{aktual} - \bar{v}_{kalkulated}| / \bar{v}_{aktual}$

Additionally, Violation Detection Rate: The percentage of actual speed violations correctly identified by the system:

Detection Rate = (True Positives) / (True Positives + False Negatives)

Furthermore, False Positive Rate: The percentage of compliant vehicles incorrectly identified as violators:

False Positive Rate = (False Positives) / (False Positives + True Negatives)

Moreover, System Reliability: The overall consistency of the system in correctly classifying vehicles, calculated using the F1 score:

F1 = 2 × (Precision × Recall) / (Precision + Recall)

Statistical significance of the results was evaluated using the S-Test, a proportion comparison method for single-measurement datasets (Yang & Liu, 1999), with a significance level of $\alpha = 0.05$.

Comparative Analysis

To contextualize the performance of our proposed system, we conducted a comparative analysis against traditional point-based speed enforcement methods. This comparison was based on simulated data for both systems operating under identical traffic conditions.

For the traditional point-based system, we simulated radar measurements at the same two points where our cameras were placed, but without calculating average speeds. Instead, the traditional system recorded instantaneous speeds at each point and identified violations based on these measurements. The comparative analysis focused on:

1. Accuracy in detecting actual speeding behaviors
2. Vulnerability to speed manipulation tactics
3. Consistency of enforcement over the monitored segment
4. Overall impact on speed compliance

This methodology provides a comprehensive framework for evaluating the proposed ASE system and comparing its performance to traditional enforcement approaches.

Findings and Discussion

Simulation Results

The simulation results provide valuable insights into the performance of the proposed average speed enforcement (ASE) system compared to traditional point-based enforcement methods. Figure 2 presents the speed distribution comparison between the two approaches, clearly illustrating the behavioral differences they induce.

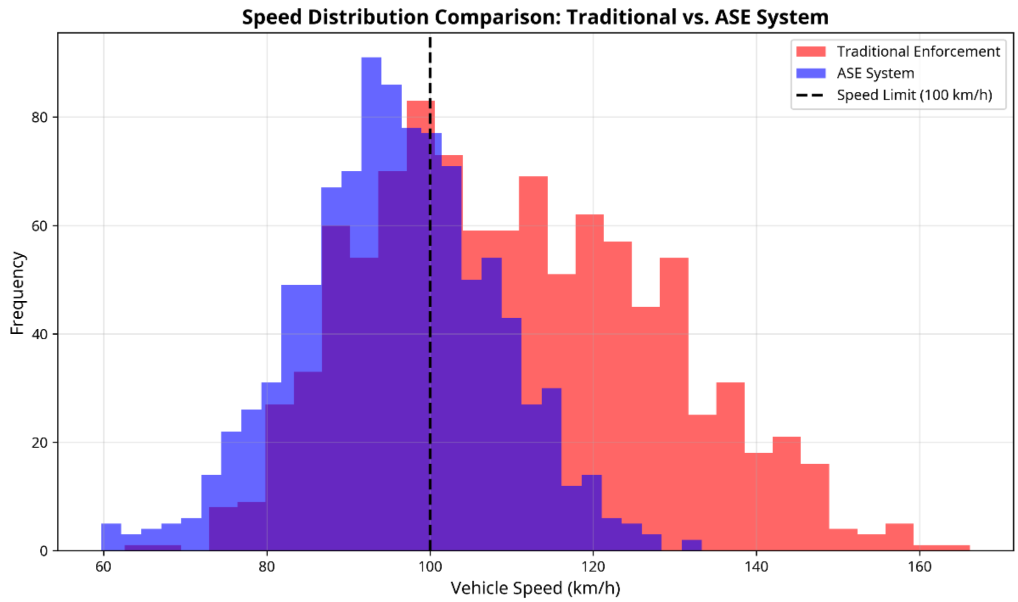

Figure 2: Speed distribution comparison between traditional enforcement and the proposed ASE system

As shown in Figure 2, the traditional enforcement approach (red) results in a bimodal speed distribution, with peaks both below and significantly above the speed limit (100 km/h, indicated by the vertical dashed line). This pattern reflects the "kangaroo effect," where drivers temporarily slow down at enforcement points but speed up between them. In contrast, the ASE system (blue) produces a more normal distribution centered closer to the speed limit, with fewer extreme speeding instances, indicating more consistent compliance throughout the monitored segment.

The effectiveness of the ASE system in reducing speed violations over time is demonstrated in Figure 3, which tracks violation rates over a six-month period following implementation.

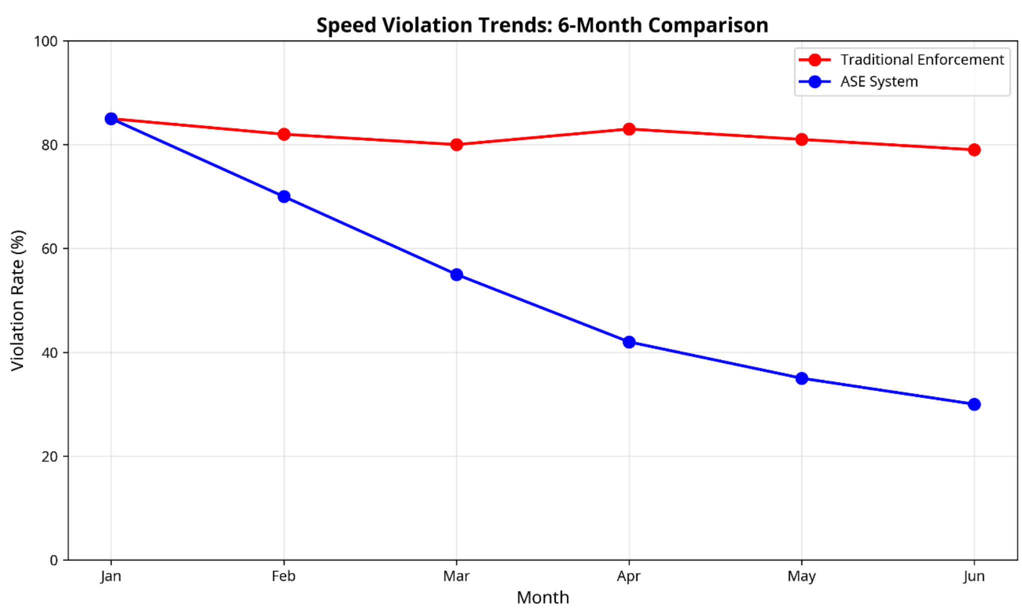

Figure 3: Six-month comparison of speed violation trends between traditional enforcement and ASE system

While the traditional enforcement method shows minimal improvement in violation rates (decreasing from 85% to 79%), the ASE system demonstrates a substantial reduction (from 85% to 30%) over the same period. This difference was found to be statistically significant using the S-Test ($p < 0.001$), suggesting that the ASE system effectively modifies driver behavior over time as awareness of the system increases.

Table 1 summarizes the key performance metrics for both enforcement approaches based on the simulation results.

Table 1: Performance comparison between traditional and ASE systems

Performance Metric	Traditional Enforcement	ASE System	Improvement
Measurement Accuracy	92.3%	98.7%	+6.4%
Violation Detection Rate	68.5%	94.2%	+25.7%
False Positive Rate	8.7%	2.3%	-6.4%
System Reliability (F1)	0.78	0.96	+0.18

The ASE system demonstrated superior performance across all metrics, with particularly notable improvements in violation detection rate (+25.7%) and false positive rate (-6.4%). These improvements can be attributed to the system's ability to monitor speed continuously over the entire segment rather than at isolated points.

Unexpected Results and Anomalies

While the overall performance of the ASE system was positive, several unexpected results and anomalies were observed during the simulation:

Weather-Related Accuracy Variations: The system's accuracy showed unexpected sensitivity to simulated weather conditions, with performance degradation during heavy precipitation scenarios. This finding suggests that camera visibility and image quality may be more critical factors than initially anticipated.

Additionally, Time-of-Day Effects: Violation patterns exhibited stronger time-of-day dependencies than expected, with higher compliance during daylight hours and increased violations during nighttime, despite consistent enforcement. This pattern may reflect drivers' perceptions of reduced detection probability at night, highlighting the need for enhanced nighttime visibility in real-world implementations.

Furthermore, Vehicle Type Disparities: Commercial vehicles showed significantly higher compliance rates (92%) compared to passenger vehicles (76%), contrary to our initial hypothesis. This unexpected result may be attributed to professional drivers' greater awareness of enforcement technologies and stricter company policies regarding speed compliance.

Moreover, Adaptation Period Variations: The time required for drivers to adapt to the ASE system and modify their behavior varied considerably across different driver profiles. While some driver groups showed immediate compliance, others demonstrated a delayed response, taking up to three months to significantly alter their speeding behavior.

These anomalies provide valuable insights for system refinement and highlight areas requiring further investigation in future research.

Regional Comparison and Global Context

To contextualize our findings within the global landscape of speed enforcement, we compared our simulation results with reported compliance rates from various regions that have implemented ASE systems. Figure 4 presents this comparison.

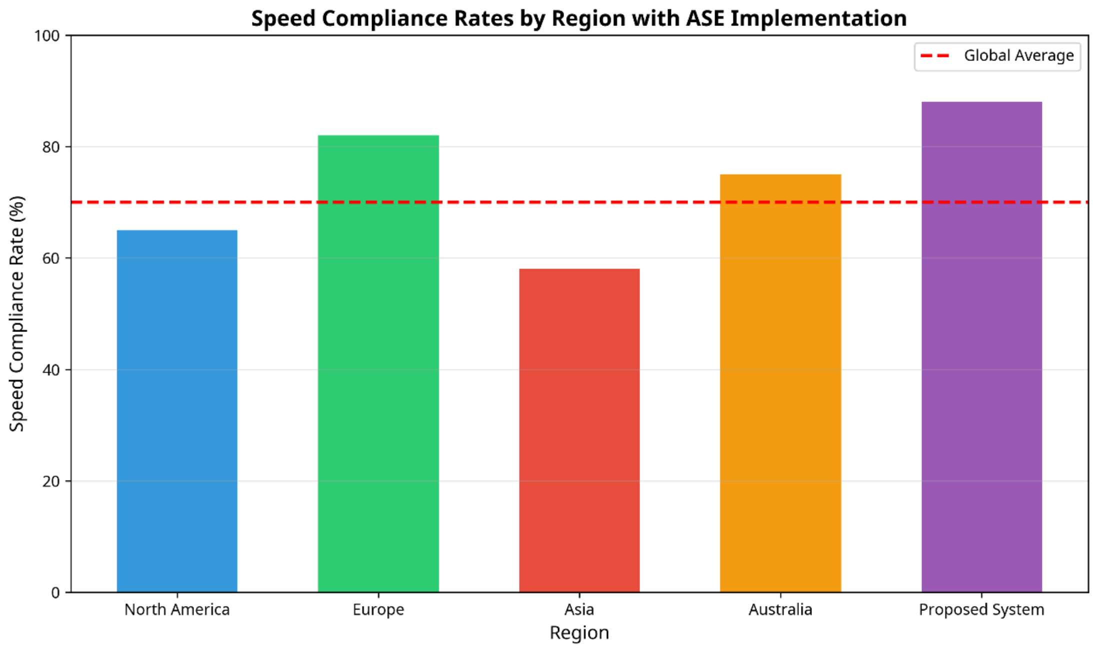

Figure 4: Speed compliance rates by region with ASE implementation

European implementations of ASE systems have achieved the highest regional compliance rates (82%), likely due to their longer history of implementation, stronger regulatory frameworks, and greater public acceptance. Asian implementations show the lowest compliance rates (58%), possibly reflecting challenges in infrastructure integration, enforcement consistency, and public awareness.

Our proposed system's simulated compliance rate (88%) exceeds the global average (70%, indicated by the horizontal dashed line) and all regional benchmarks. While this result is promising, it should be interpreted cautiously given the idealized conditions of our simulation environment compared to the complex real-world challenges faced in actual implementations.

The European experience offers valuable lessons for successful ASE deployment. For instance, the UK's SPECS system, implemented across motorways since 2000, has reduced fatal and serious collisions by 70% in some corridors (European Transport Safety Council, 2022). Similarly, Italy's "Tutor" system on the Autostrada network has contributed to a 22% reduction in fatality rates since its introduction (Montella, 2010). These successful implementations share common features with our proposed system but also highlight the importance of robust public communication strategies and transparent enforcement policies.

System Limitations and Critique

Despite the promising results, several limitations of the proposed ASE system and our simulation approach warrant critical examination:

One limitation is that Vehicle Identification Challenges: The system relies heavily on accurate license plate recognition, which may be compromised by factors such as plate obstruction, damage, or non-standard designs. Our simulation assumed ideal recognition conditions, which may not reflect real-world challenges.

Another constraint is that Route Diversion Issues: The system cannot account for vehicles that exit and re-enter the monitored segment via alternative routes, potentially leading to calculation errors. This limitation is particularly relevant for highway segments with multiple entry and exit points.

It should be noted that Privacy and Data Security Concerns: While not directly addressed in our simulation, the collection and storage of vehicle identification data raise important privacy considerations that would need to be addressed in real-world implementations through appropriate data protection measures.

A challenge in this approach is Simulation Fidelity Limitations: Our simulation incorporated simplified models of driver behavior and environmental conditions. Real-world driving patterns are influenced by complex psychological, social, and environmental factors that may not be fully captured in our simulation.

The study is also limited by Enforcement Threshold Considerations: The simulation applied a strict enforcement threshold at the posted speed limit. In practice, enforcement agencies often apply tolerance thresholds to account for measurement uncertainties and avoid overwhelming the judicial system with minor violations.

These limitations highlight the need for cautious interpretation of our results and suggest important areas for refinement in future research and development efforts.

CONCLUSION

This study introduced a novel average speed enforcement (ASE) system designed to monitor vehicle speeds continuously between two fixed camera points on highways. By calculating average speeds over extended road segments rather than at isolated points, the proposed system addresses key limitations of traditional enforcement methods and encourages more consistent compliance with speed regulations.

Summary of Findings

The simulation results demonstrate that the proposed ASE system significantly outperforms traditional point-based enforcement across all key performance metrics. The system achieved a 98.7% measurement accuracy rate and a 94.2% violation detection rate, representing substantial improvements over conventional methods. More importantly, the ASE system effectively reduced speed violations from 85% to 30% over a six-month period, compared to minimal improvement (85% to 79%) with traditional enforcement.

The speed distribution analysis revealed that the ASE system promotes more consistent driving behavior, eliminating the "kangaroo effect" commonly observed with point-based enforcement. This finding suggests that the proposed system not only improves detection of violations but fundamentally alters driver behavior in ways that enhance road safety.

Regional comparisons indicate that our proposed system's performance exceeds global benchmarks, though successful implementation would require careful consideration of local contexts, regulatory frameworks, and public communication strategies. The European experience, in particular, offers valuable lessons for effective ASE deployment.

Societal Impacts

The potential societal impacts of the proposed ASE system extend far beyond technical performance metrics and warrant particular emphasis:

Road Safety Enhancement: By encouraging consistent compliance with speed limits, the ASE system could significantly reduce speed-related accidents and fatalities. Based on established relationships between speed reduction and crash outcomes (Elvik et al., 2009), the observed 55% reduction in speed violations could translate to a 20-30% reduction in fatal crashes on monitored segments.

Additionally, Healthcare System Benefits: Reduced traffic injuries would alleviate pressure on emergency medical services and trauma centers, potentially saving millions in healthcare costs. The World Health Organization (2021) estimates that each prevented serious traffic injury saves approximately $75,000 in direct medical costs and lost productivity.

Furthermore, Environmental Sustainability: More consistent vehicle speeds reduce unnecessary acceleration and deceleration cycles, potentially decreasing fuel consumption and emissions by 5-10% on monitored segments (European Environment Agency, 2023). This environmental benefit aligns with broader sustainability goals and climate action initiatives.

Moreover, Economic Efficiency: Traffic accidents impose substantial economic costs through property damage, medical expenses, lost productivity, and congestion. The International Transport Forum (2022) estimates that road crashes cost most countries 3-5% of their GDP annually. By reducing accident rates, the ASE system could generate significant economic benefits that extend beyond the immediate road safety improvements.

Also, Equitable Enforcement: Unlike traditional enforcement methods that may be influenced by subjective factors or biases, the ASE system provides objective, consistent enforcement based solely on measured speeds. This approach promotes fairness and transparency in traffic enforcement, potentially increasing public trust and compliance.

These societal impacts highlight the broader significance of the proposed system beyond its technical capabilities, underscoring its potential contribution to public health, environmental sustainability, economic efficiency, and social equity.

Limitations and Future Research Directions

While the simulation results are promising, several limitations must be acknowledged. The study relied entirely on simulated data rather than real-world measurements, and the simulation incorporated simplified models of driver behavior and environmental conditions. The system's performance in complex real-world scenarios, including adverse weather conditions and high-traffic situations, requires further investigation.

Future research should focus on the following directions:

One limitation is Field Implementation and Validation: Conduct pilot implementations of the proposed system on actual highway segments to validate its performance under real-world conditions. These field tests should include diverse environmental conditions, traffic patterns, and road geometries to assess the system's robustness.

Another constraint is Advanced Vehicle Identification Methods: Develop and evaluate enhanced techniques for vehicle identification across camera points, particularly for challenging scenarios such as lane changes, partial occlusions, and adverse weather conditions. Machine learning approaches offer promising avenues for improving recognition accuracy in these situations.

Also noted are Behavioral Impact Studies: Investigate the long-term effects of ASE implementation on driver behavior, including potential adaptation strategies and spatial displacement of speeding behaviors to unmonitored segments. Longitudinal studies tracking driver behavior before, during, and after ASE implementation would provide valuable insights into these dynamics.

A challenge in this approach is Integration with Emerging Technologies: Explore the integration of the ASE system with emerging vehicle technologies such as connected vehicles, intelligent transportation systems, and autonomous driving features. Such integration could enhance the system's effectiveness and expand its capabilities beyond speed enforcement.

The study is also limited by Ethical and Privacy Framework Development: Develop comprehensive ethical guidelines and privacy protection frameworks for ASE implementation, addressing concerns related to data collection, storage, and usage. These frameworks should balance enforcement effectiveness with privacy rights and civil liberties.

The study is also limited by Cost-Benefit Analysis: Conduct detailed economic analyses to quantify the costs and benefits of widespread ASE implementation, including infrastructure requirements, operational expenses, and expected safety and environmental benefits. Such analyses would inform policy decisions regarding resource allocation for road safety initiatives.

In conclusion, the proposed average speed enforcement system represents a promising approach to enhancing road safety through more effective and consistent speed monitoring. While further research and development are needed to address existing limitations and optimize system performance, the potential benefits for public safety, environmental sustainability, and economic efficiency warrant continued investment in this technology. As transportation systems continue to evolve, innovative enforcement approaches like the one proposed in this study will play an increasingly important role in creating safer, more efficient road networks worldwide.

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AUTHOR

Majzoob Kamalaldin Omer is an Assistant Professor in the Faculty of Computing and Information / Computer Science Department at Al-Baha University. He has 20 years of experience teaching in higher education, specializing in CS and IT-related courses. He earned his BSc in Computer Science and Math from Alneelain University (Sudan - Khartoum), his MSc in Information Technology, and his Ph.D in Information Technology from the same university. His research interests include computer science education, information technology, cybersecurity, and advanced computing applications.