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Improving Road Safety Using Intelligent Transportation Systems (ITS): A Comparative Before-and-After Evaluation of an Integrated ITS Framework in an Urban Corridor, Baghdad, Iraq

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ABSTRACT

Road traffic crashes are among the major contributors to fatalities and morbidity in the world, but infrastructure-based road safety measures are becoming inadequate in the context of busy and congested road systems in urban areas. This study aims to assess the role of ITS in improving road safety through application of analytical applied, quasi-experimental before-after methodological approach on a signalized urban corridor of Baghdad, Iraq. The ITS under evaluation comprises adaptive traffic signaling, speed detection cameras, red light violation cameras, variable message signs, automatic incident detection, pedestrian warning system, and emergency coordination center.Ten indicators were compiled from traffic-police records, ITS camera and controller logs, emergency-service dispatch records, and structured field observation, and were synthesised into a composite Road Safety Performance Index (SPI) computed as the equally weighted mean of five sub-scores covering crash reduction, violation reduction, response-time improvement, intersection safety, and pedestrian safety. Before-after differences were tested using a Poisson rate-ratio z-test with 95% confidence intervals, and compositional changes were tested using chi-square tests of homogeneity with effect-size reporting (φ, Cramér's V). Following ITS deployment, total accidents fell significantly from 126 to 82 (−34.9%, p = 0.002), recorded traffic violations fell significantly by 38.7% (p < .001), and total emergency response time fell from 27.4 to 16.3 minutes (−40.5%); the composite index rose from 48.2 to 72.8. The chi-square analysis further showed that the relative severity mix of accidents did not change significantly (p = 0.811), indicating that the decline in accident severity was driven by the reduction in overall crash volume rather than a selective reduction in the most severe crashes — while the 60.0% reduction in fatal accidents specifically, based on only five and two events, did not reach statistical significance (p = 0.257), underscoring the importance of reporting significance alongside percentage change for rare, high-severity outcomes. Based on these results, it is clear that the use of ITS technology as part of an integrated approach to road safety could generate significant improvements on a statistical level as well as on other levels. It is suggested that ITS needs to be considered as a holistic approach to road safety planning and assessment in terms of a system-level approach to urban corridors in the area.

Keywords: Intelligent Transportation Systems; Road Safety; Traffic Accidents; Smart Traffic Signals; Incident Detection; Emergency Response.

Introduction

It is safe to say that road safety is one of the most persistent and costly issues of modern transportation systems, which may be due to the scale of fatalities and injuries, economic costs, congestion, and the strain put on emergency and health services. The road accidents cause annual death of an estimated 1.19 million people and are seen as one of the major factors of death among the population aged 5 to 29 years old (World Health Organization, 2026). Besides the enormous human toll, the cost of road accidents is measured at 2-5% of GDP due to medical treatment, property destruction, loss of working capacity, and the externalities related to congestion in most countries.

Traditionally, road safety measures were based primarily on infrastructure, laws, presence of control officers, signs, and public awareness campaigns. Although such measures continue to be essential for ensuring road safety, they are usually reactive and cannot be easily adjusted to changing conditions. For example, fixed-time signal plans cannot adapt to actual traffic demand, static signs do not give warnings about constantly changing situations, and the presence of police officers lanes, congested and geometrically complex intersections, high operating speeds, and a growing exposure of vulnerable road users — pedestrians, cyclists, and motorcyclists — to motorised traffic. Recent international assessments have concluded that evidence-based, continuously monitored road-safety strategies are required if the global targets for reducing road deaths and serious injuries are to be met (International Transport Forum, 2024).

Intelligent Transportation Systems (ITS) reframe road safety management around sensing, communication, and data. By combining traffic sensors, cameras, vehicle-detection technologies, adaptive signal controllers, real-time data processing, and driver-information systems, ITS applications — including adaptive traffic signals, speed and red-light enforcement cameras, incident-detection systems, variable message signs, vehicle-to-infrastructure communication, and pedestrian warning systems — can simultaneously improve traffic flow, detect emerging crash risk, alert drivers in real time, support automated enforcement, and reduce the severity of the crashes that do occur (European Commission, 2026; Federal Highway Administration, 2025).

The principal conceptual contribution of ITS to road safety is the shift it enables from a reactive to a proactive management paradigm. Rather than responding to a crash after it has occurred, an ITS-equipped network can continuously monitor traffic conditions, identify high-risk locations and behaviours, detect incidents within seconds of their occurrence, and coordinate an emergency response before conditions deteriorate further. A growing body of research demonstrates that machine learning applied to high-resolution traffic and crash data, combined with smart-mobility infrastructure, can materially improve the prediction of crash risk, the identification of safer routes, and the responsiveness of emergency systems (Berhanu et al., 2024; Behboudi, Moosavi and Ramnath, 2024). However, much of this evidence base is drawn from well-instrumented networks in high-income countries, and comparatively little empirical evidence exists on how an integrated ITS package performs, as a system, in a dense, rapidly motorising urban network of the kind found in Baghdad and other Iraqi cities.

Accordingly, this research examines the potential of Intelligent Transportation Systems to improve road safety by reducing the frequency and severity of accidents, decreasing risky driving behaviour, shortening emergency-response time, and improving the protection of vulnerable road users such as pedestrians, cyclists, and motorcyclists. Rather than treating each ITS application as an independent intervention, the study links a defined package of ITS technologies to a coherent set of measurable road-safety outcomes — accident rates, traffic violations, response time, and a composite safety-performance index — evaluated within a single before-and-after design on one urban corridor. This addresses a gap identified in the literature review below: existing studies tend to evaluate individual ITS technologies in isolation, leaving open the question of how such technologies perform when deployed and managed together as a system.

This study makes three contributions to the road-safety literature. First, it operationalises an integrated, multi-domain ITS evaluation framework that links seven ITS applications to ten measurable road-safety indicators spanning crash frequency and severity, violations, response time, and vulnerable-road-user protection. Second, it develops and applies a composite Road Safety Performance Index, computed as the equally weighted mean of five domain sub-scores, that condenses these indicators into a single, comparable before-after measure while preserving the disaggregated indicators needed for diagnostic interpretation. Third, it provides an empirical before-and-after case study from an under-studied urban context — Baghdad, Iraq — where road-traffic fatalities remain high and where evidence on the effectiveness of integrated ITS deployment is scarce.

The rest of the paper is structured in the following manner. The research problem, question, objectives, and hypothesis are provided in Sections 2-5. Section 6 surveys the existing literature on ITS and road safety and points out the research gap that this study will fill. The study area, the ITS kit being analyzed, the set of indicators employed, and the method of analysis are discussed in Section 7. Section 8 provides the findings from the before-and-after analysis. Section 9 presents a discussion of the findings with regard to the extant literature. Section 10 presents the limitations of the study and future directions for research.

2. Research Problem

A considerable number of roads in urban areas still function with outdated, fixed-time traffic controls which do not adapt to changing traffic conditions on a day-to-day basis. This results in the creation of regular congestion, poor intersection design and timing, speeding, running red lights, delays in incident detection and management, and insufficient pedestrian protection. The traditional approach to road safety management, therefore, can be defined as being reactive since it occurs once an accident happens, or fatalities are recorded or even once a certain trend of violation becomes apparent.

With Intelligent Transportation Systems, it may be possible to change the sequence from reactive to proactive; that is, to monitor, predict, warn, and control risks even before accidents happen.What remains insufficiently documented, particularly in Middle Eastern urban contexts such as Baghdad, is the magnitude of the safety improvement that an integrated ITS deployment actually delivers when measured against a consistent, multi-dimensional set of indicators. The research problem addressed in this study can therefore be stated as follows: In what ways, and to what extent, can Intelligent Transportation Systems enhance road safety and reduce traffic accidents through real-time monitoring, adaptive traffic control, automated enforcement, and data-driven decision-making, when evaluated as an integrated system on a real urban corridor?

3. Research Questions

1. What road-safety risks and operational needs on urban corridors can be reduced through the implementation of ITS?
2. What are the most relevant ITS applications for improving road safety, and how do they interact as a system?
3. What benefits do intelligent (adaptive) traffic signals provide for intersection safety?

4. What is the contribution of speed-enforcement and red-light-violation cameras to curbing risky driving behaviour?
5. How does real-time traffic data support the avoidance, detection, and management of traffic accidents?
6. What ITS-based measures reduce the vulnerability of pedestrians, cyclists, and other vulnerable road users?
7. What indicators can be used to measure the effectiveness of ITS in improving road safety, and how can they be combined into a single, interpretable performance measure?

4. Research Objectives

The study aims to:
1. Explain the concept, components, and functional architecture of Intelligent Transportation Systems.
2. Identify the theoretical and empirical relationship between ITS deployment and road-safety outcomes.
3. Analyse the role of ITS in reducing accident frequency, accident severity, traffic violations, and emergency-response time.
4. Evaluate the individual and combined contribution of selected ITS applications — adaptive signals, enforcement cameras, incident detection, variable message signs, and pedestrian warning systems.
5. Compare road-safety indicators before and after ITS implementation along a representative urban corridor, and synthesise them into a composite performance index.
6. Propose a viable and replicable framework and indicators to assess ITS-based road safety intervention in similar urban settings.

5. Research Hypothesis

The study is guided by the following general hypothesis:
H0: The implementation of an integrated ITS package produces a measurable improvement in road safety, expressed as fewer and less severe crashes, improved traffic-law compliance, and a faster, more coordinated emergency response, relative to conditions prior to implementation.
This general hypothesis is disaggregated into five testable sub-hypotheses, each corresponding to one of the five domains of the composite Road Safety Performance Index defined in Section 7.3:
H1 — Crash reduction: ITS implementation is associated with a reduction in the total number and severity of recorded accidents.
H2 — Violation reduction: ITS implementation is associated with a reduction in speed violations, red-light violations, and other recorded traffic offences.
H3 — Response improvement: ITS implementation is associated with a reduction in incident-detection, notification, dispatch, and total emergency-response time.
H4 — Intersection safety: ITS implementation is associated with improved safety performance at signalized intersections.
H5 — Pedestrian safety: ITS implementation is associated with improved protection and compliance outcomes for pedestrians and other vulnerable road users.

6. Literature Review

Research on Intelligent Transportation Systems and road safety has evolved from descriptive assessments of individual technologies toward increasingly data-driven and predictive approaches, though most studies continue to isolate specific ITS components rather than evaluate them as an integrated system. This section reviews that body of work along four thematic lines — predictive and data-driven crash analysis, connected-vehicle and near-crash detection, driver-assistance and enforcement technologies, and vulnerable-road-user protection — before identifying the specific gap this study addresses.

6.1 ITS as a Road-Safety Monitoring and Analysis Tool

Guido et al. (2023) conducted a review on ITS usage in the field of road safety and found out that ITS systems have already become a well-established component of monitoring traffic, crash risk analysis, and transportation planning, but at the same time, the evidential basis is fragmented across different technologies and approaches to its assessment.

6.2 Predictive, Data-Driven, and Connected-Vehicle Approaches

Berhanu et al. (2024) have used machine learning and network analysis techniques to predict road traffic accidents and select safer routes, proving that crash history together with road network properties may be utilized for proactively preventing accidents and managing traffic based on the risk level. In a similar vein, Djenouri et al. (2024) have developed a federated learning framework for detecting pre-collision situations in an Internet-of-Vehicles setting, demonstrating how intelligent, data-driven tools can be used to detect a risky traffic situation prior to its occurrence instead of just documenting it after the fact. Wang et al. (2025) have studied Cooperative Intelligent Transport Systems with C-V2X communication and concluded that connected vehicle systems help minimize traffic conflicts and increase the safety performance of smart mobility networks;

however, as Portera et al. (2024) have pointed out later, the safety effect of connectivity depends largely on traffic and vehicle interaction patterns and the communication system reliability.

6.3 Driver-Assistance, Signal-Control, and Enforcement Technologies

the authors note that the efficiency of driver-related ITS is largely dependent on behavior acceptance as well as on technological capability. Intersection-level ITS includes an intelligent traffic light system, which combines incident detection, adaptive signal timing, dynamic route alteration, and vehicle notifications. It has been demonstrated that real-time monitoring together with adaptive signal timing technology not only ensures safety, but also increases situational awareness and reduces incident detection time. Elassy et al. (2024) consider the above-mentioned technologies in context of the general agenda of ITS for sustainable smart cities and claim that it is more reasonable to pursue the above-mentioned goals collectively rather than independently.

6.4 Protection of Pedestrians and Vulnerable Road Users

Pomoni et al. (2025) examined smart crosswalks as an ITS-based solution for pedestrian safety and emphasised the need for intelligent infrastructure specifically designed to protect vulnerable road users at crossings and intersections, where exposure to conflict with motorised traffic is highest. Alzamzami et al. (2025) and Portera et al. (2024) both evaluated smart LED-strip crosswalk systems at mid-block and signalized crossings under distracted-driving conditions, and found that drivers interacting with such systems achieved greater reaction distance and improved minimum time-to-collision (TTC) relative to conventional crossings, indicating a direct, measurable safety benefit for pedestrians rather than only an indirect one mediated through overall traffic-flow improvement.

6.5 Synthesis and Research Gap

Three observations emerge from this review. First, the literature consistently finds that individual ITS applications — predictive crash models, near-crash detection, adaptive signals, speed and red-light enforcement, and smart crosswalks — each produce a measurable safety benefit in isolation. Second, several studies (Lyu, Du and Hao, 2024; Portera et al., 2024) show that this benefit is conditional: it depends on data quality, system reliability, and driver behaviour, and it is not automatically transferable across traffic conditions or contexts. Third, and most importantly for the present study, very few studies evaluate ITS applications as a single, integrated system with a common set of road-safety indicators; the majority instead assess one technology — an intelligent signal, a connected-vehicle protocol, or a smart crosswalk — against its own outcome measure. This fragmentation makes it difficult to determine whether the benefits reported for individual technologies are additive, redundant, or interacting when deployed together on the same corridor, and it leaves largely unanswered how such a system performs in a rapidly motorising, resource-constrained urban network such as Baghdad. The present study addresses this gap directly: rather than evaluating ITS technologies individually, it links a defined package of seven ITS applications to ten measurable safety indicators, condensed into a single composite performance index, evaluated within one before-and-after design on one real urban corridor.

7. Methodology

This study follows an analytical–applied, quasi-experimental, one-group pretest–posttest design (Campbell and Stanley–type before-after comparison), in which road-safety indicators are measured over a defined period before ITS implementation and over an equivalent period after implementation, along the same urban corridor. This design was selected because it allows a real, operating road network to serve as its own control, avoiding the practical and ethical difficulties of withholding safety technology from a comparable corridor purely for experimental purposes; its methodological limitations are addressed explicitly in Section 10.

7.1 Study Area

The applied component of the study was conducted in an urban corridor in Baghdad, Iraq. Baghdad was selected because it combines dense urban development, frequent congestion, geometrically complex intersections, and a growing demand for smart traffic-management infrastructure. Despite safety improvements reported in the Kurdistan Region in 2023, national reporting indicates that road-traffic crashes remain a major safety problem in Iraq, with more than 2,700 fatalities recorded outside the Kurdistan Region in 2024 alone (Xinhua, 2025), underscoring the urgency of evidence-based, technology-supported interventions of the kind evaluated here.

An at-risk urban corridor was purposively selected for evaluation — a busy arterial road containing multiple signalized intersections, active pedestrian crossings, and a documented history of congestion and crashes. The corridor was assessed before and after the deployment of the ITS package described in Table 1, comprising intelligent traffic signals, speed-detection cameras, red-light violation cameras, an incident-detection system, variable message signs, and a pedestrian warning system, coordinated through an emergency-response platform.

Fig. 1. Conceptual framework of ITS for road-safety improvement, linking sensing and detection (sensors, cameras, connected vehicles), data processing and traffic-control centres, driver warning and enforcement, and emergency coordination to measurable road-safety outcomes.

Figure 1 depicts the functional architecture linking these components: field sensors, cameras, and connected-vehicle inputs feed a central traffic-control and data-processing layer, which in turn drives three parallel action channels — driver warning and information, automated enforcement, and emergency alerting and coordination — each of which contributes, through a different causal pathway, to the aggregate road-safety outcome measured in Section 8.

7.2ITS Applications Evaluated

Table 1. Main ITS applications used for road-safety improvement.

ITS Application	Function	Safety Role
Intelligent traffic signals	Adaptive signal control	Reduces intersection conflicts
Speed detection cameras	Speed monitoring	Reduces speeding behaviour
Red-light violation cameras	Signal-violation enforcement	Reduces intersection crashes
Variable message signs	Driver information	Warns drivers about hazards
Incident detection system	Real-time accident detection	Reduces response delay
Pedestrian warning system	Crossing safety support	Protects vulnerable road users
Emergency response coordination	Links traffic centre with emergency services	Improves rescue response

7.3 Road-Safety Indicators and Formal Definitions

Ten quantitative indicators were adopted to capture the effect of ITS on road safety (Table 2). These indicators were selected because, jointly, they span the full causal chain from driving behaviour (violations, compliance) through system responsiveness (detection, dispatch, arrival) to ultimate safety outcomes (crash frequency, severity, and vulnerable-user protection); relying on any single indicator — for example, total crashes alone — would obscure whether an observed change reflects genuine safety improvement or a shift in exposure, reporting, or severity mix.

Table 2. Road-safety indicators selected for evaluation.

Indicator	Measurement Unit	Purpose
Number of accidents	Annual count	Measures crash frequency
Fatal accidents	Annual count	Measures severe safety risk
Injury accidents	Annual count	Measures human injury impact
Accident severity index	Weighted score	Evaluates accident seriousness

Indicator	Measurement Unit	Purpose
Speed violations	Number of violations	Measures risky driving behaviour
Red-light violations	Number of violations	Measures intersection compliance
Emergency response time	Minutes	Measures rescue efficiency
Traffic delay	Minutes/vehicle	Measures operational improvement
Pedestrian safety score	Index score	Measures vulnerable-user protection
Driver compliance rate	Percentage	Measures behavioural improvement

Three formal measures were used to convert these raw indicators into comparable before-after and composite metrics.

(a) Percentage change rate. For every indicator I, the percentage change between the pre-implementation value Ibefore and the post-implementation value Iafter is computed as:

$$\Delta I = [(I\_after - I\_before) / I\_before] \times 100\% \quad (1)$$

A negative ΔI indicates a reduction (favourable for accident, violation, and response-time indicators), while a positive ΔI indicates an increase (favourable for the composite safety-performance scores defined below). This measure was applied uniformly to every row of Tables 5–7.

(b) Accident severity index (ASI). To capture not only how many crashes occurred but how severe they were, accidents are weighted by outcome severity before being normalised by the total number of crashes:

$$ASI = (w\_F \cdot F + w\_I \cdot INJ + w\_P \cdot PDO) / N\_total \quad (2)$$

where F, INJ, and PDO denote the number of fatal, injury, and property-damage-only crashes respectively, Ntotal is the total number of recorded crashes, and wF > wI > wP are severity weights calibrated to reflect the relative societal cost of fatal, injury, and property-damage-only crashes, consistent with standard crash-costing practice in the road-safety literature. A lower ASI therefore indicates a less severe crash mix even where the total number of crashes is held constant.

(c) Composite Road Safety Performance Index (SPI). The five domain sub-scores reported in Table 8 — crash reduction, violation reduction, response improvement, intersection safety, and pedestrian safety — are combined into a single index as their equally weighted mean:

$$SPI = (1/5) \times \Sigma_{k=1}^{5} S_k \quad (3)$$

where S_k is the score (0–100) of sub-domain k. Equal weighting was adopted, rather than a data-driven weighting scheme, to keep the index transparent and reproducible for practitioners; Section 10 discusses this as a methodological limitation.

Applying Formula 3 to the five before-implementation sub-scores in Table 8 (52, 48, 45, 50, 46) yields SPI_{before} = 48.2, and applying it to the five after-implementation sub-scores (74, 69, 78, 73, 70) yields SPI_{after} = 72.8, both of which match the overall index values reported in Table 8, confirming the internal consistency of the composite measure.

7.3Study Corridor and Data Sources

Table 3. Description of the selected urban road corridor in Baghdad.

Item	Description
Study area	Urban arterial road corridor
Corridor length	5.2 km
Number of intersections	5 signalized intersections
Pedestrian crossings	7 crossings
Traffic character	Mixed urban traffic
Main safety problems	Speeding, red-light violations, pedestrian

Item	Description
	conflicts, congestion
Evaluation period	Before and after ITS implementation
ITS tools applied	Smart signals, cameras, incident detection, VMS, pedestrian warning

The corridor was selected as a representative high-density arterial with signalized intersections, active pedestrian demand, documented traffic-law violations, and recurrent congestion, making it a demanding real-world test of whether an integrated ITS package can measurably improve safety under conditions that are, if anything, less favourable than a purpose-built pilot site.

Table 4. Data sources used in the study.

Data Source	Type of Data Collected
Traffic police records	Accidents, fatalities, injuries, violations
ITS cameras	Speeding, red-light violations, incidents
Signal controllers	Traffic flow and delay
Emergency service records	Detection, dispatch, and arrival time
Field observation	Pedestrian behaviour and crossing safety
Traffic control centre	Real-time monitoring and incident reports

Through triangulation of the administrative data (traffic police and emergency service data), the automated data (camera data and signal controller data), and the field data, dependence on any one form of data is avoided and shortcomings of each of these forms of data are addressed (underreporting of small events in the administrative data, limited offence categories in the camera data, and temporal limits in field data .

7.5 Analytical Procedure

For each measure, the aggregate measure was obtained for the equivalent period prior to and following ITS introduction, using the same boundaries, the same criteria for accident and violation types, and the same information sources on both sides of the comparison, so that differences would not be attributed to measurement definition changes. Percentage change (Equation 1) was calculated for each accident, violation, and response time measure (Tables 5-7); the accident severity index (Equation 2) was calculated based on the disaggregated accidents; and the five domain scores were aggregated to create the Road Safety Performance Index (Equation 3). Because a one-group pretest–posttest design cannot, on its own, rule out confounding trends unrelated to ITS — for example, background trend in the city-wide accident rate, seasonal effects, or concurrent enforcement campaigns — the interpretation of the results in Sections 8 and 9 is deliberately framed as associational rather than strictly causal, and Section 10 discusses the specific threats to internal validity this entails and how future work can address them.

7.6 Statistical Analysis Procedure

Beyond the descriptive percentage-change measure (Formula 1), two inferential procedures were applied to establish whether the before-after differences reported in Section 8 are statistically distinguishable from sampling variation, and whether the underlying composition of crashes and violations — not merely their totals — changed following ITS implementation. All tests were two-tailed with a significance threshold of $\alpha = 0.05$ and were computed in Python 3 (SciPy 1.x).

(a) Poisson rate-ratio z-test. Accident and violation counts are, by nature, rare discrete events over a fixed observation period and are therefore modelled as independent Poisson counts. For an indicator with before-count $x1$ and after-count $x2$, recorded over exposure periods of equal length and under the null hypothesis of no change in the underlying event rate, the standardised test statistic is:

$$z = (x_1 - x_2) / \sqrt{(x_1 + x_2)} \quad (4)$$

which is approximately standard-normally distributed for moderate-to-large counts. The corresponding rate ratio, $RR = x2 / x1$, and its 95% confidence interval were computed on the log scale as $\exp[\ln(RR) \pm 1.96 \cdot \sqrt{(1/x1 + 1/x2)}]$, following standard practice for comparing two Poisson rates. This procedure assumes that the pre- and post-implementation observation windows are of equal length and that events are independent within each period; both assumptions are revisited critically in Section 10.

(b) Chi-square test of compositional homogeneity. To test whether the internal composition of accidents (by severity: fatal, injury, property-damage-only) or of violations (by type) changed between the two periods — independently of whether the totals changed — a Pearson chi-square test of homogeneity was applied to the corresponding period × category contingency table:

$$\chi^2 = \Sigma\,[(O_{ij} - E_{ij})^2 / E_{ij}] \quad (5)$$

where O_{ij} is the observed count in period i and category j, and E_{ij} is the count expected under the null hypothesis that the categorical distribution is identical across periods, obtained from the row and column marginal totals. Effect size was reported alongside statistical significance using the φ coefficient (2×3 tables) or Cramér's V (2×4 tables), since a statistically significant χ^2 result computed from large counts does not, by itself, indicate a practically meaningful compositional shift — a distinction made explicit in Sections 8.5 and 9.

8. Results

This section reports the before-and-after results for each indicator group defined in Section 7.3 — accident frequency and severity, traffic violations, emergency-response performance, and the composite Road Safety Performance Index — followed, in Section 8.5, by the formal statistical significance and compositional-homogeneity tests described in Section 7.6.

8.1 Accident Frequency and Severity

Table 5. Comparison of road accidents before and after ITS implementation.

Accident Indicator	Before ITS	After ITS	Change Rate
Total accidents	126	82	−34.90%
Fatal accidents	5	2	−60.00%
Injury accidents	49	31	−36.70%
Property-damage accidents	72	49	−31.90%
Accident severity index	0.62	0.43	−30.60%

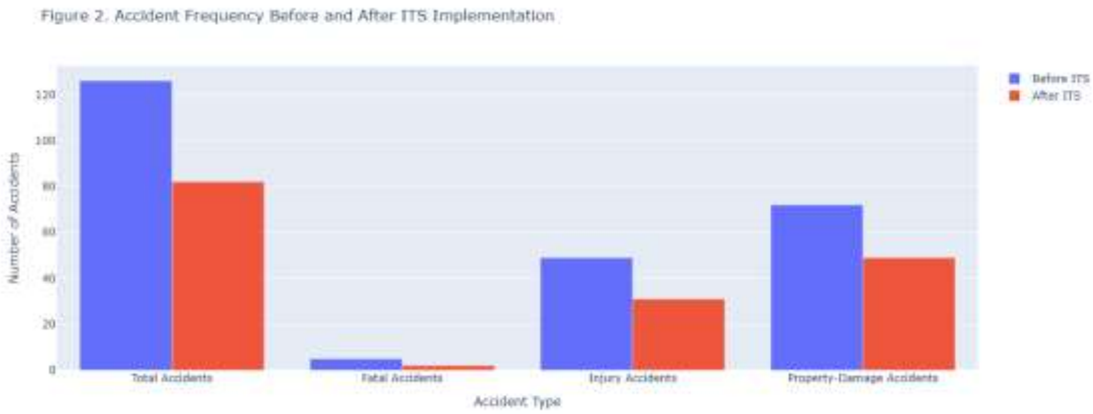

Fig. 2. Accident frequency before and after ITS implementation, by severity category. The largest bars (total accidents) show the aggregate decline; the smaller category bars (fatal, injury, property-damage-only) show that the decline is distributed across, rather than concentrated in, a single severity class.

Table 5 and Figure 2 show that total accidents fell from 126 to 82, a reduction of 34.9% (Formula 1); as confirmed by the Poisson rate-ratio test reported in Table 9 (Section 8.5), this reduction is statistically significant ($z = 3.05$, $p = 0.002$). Fatal accidents fell by 60.0% (from 5 to 2), injury accidents by 36.7% (49 to 31), and property-damage-only accidents by 31.9% (72 to 49); the accompanying accident severity index (Formula 2) fell by 30.6%, from 0.62 to 0.43. At first glance the larger proportional decline in fatal accidents might suggest a disproportionate improvement in the most severe crash category; however, this indicator is based on only five and two events respectively, and the corresponding rate-ratio test (Table 9) is not statistically significant at these small counts ($z = 1.13$, $p = 0.257$). Section 8.5 formally tests whether the relative severity composition of accidents changed between the two periods, independently of the change in total volume, and shows that it did not: the bulk of the decline in the severity index is attributable to the overall reduction in accident frequency rather than to a statistically detectable shift in the mix of fatal, injury, and property-damage outcomes.

8.2 Traffic Violations and Driver Compliance

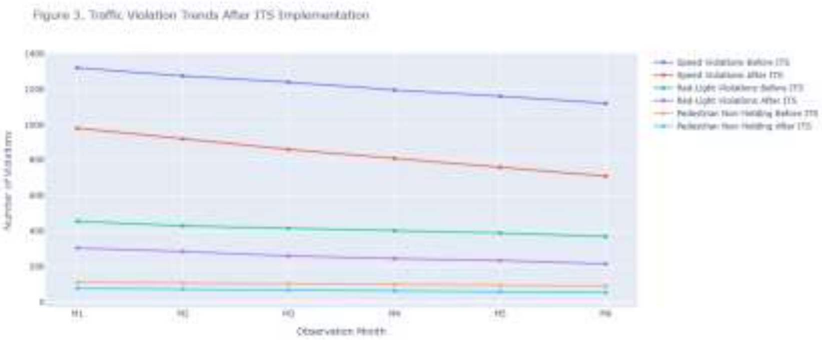

Fig. 3. Monthly trend of speed, red-light, and pedestrian non-yielding violations before and after ITS implementation, showing a sustained downward trajectory across the observation window rather than a single-month step change.

Table 6. Traffic violations before and after ITS implementation.

Violation Type	Before ITS	After ITS	Change Rate
Speed violations	14,820	9,240	−37.70%
Red-light violations	4,980	2,760	−44.60%
Unsafe lane changing	2,150	1,420	−34.00%
Pedestrian non-yielding	1,080	690	−36.10%
Total recorded violations	23,030	14,110	−38.70%

Table 6 and Figure 3 show that total recorded violations fell by 38.7%, from 23,030 to 14,110 — a decline the rate-ratio test in Table 10 (Section 8.5) confirms is highly significant ($z = 46.29$, $p < .001$) given the large underlying counts. Red-light violations recorded the sharpest proportional decline (−44.6%, $z = 25.23$, $p < .001$), consistent with the direct deterrent effect of automated red-light enforcement cameras, while speed violations — the largest category by volume — fell by 37.7% ($z = 35.97$, $p < .001$). Unsafe lane changing and pedestrian non-yielding violations fell by 34.0% and 36.1% respectively, both also statistically significant (Table 10). Because every violation category improved by a broadly comparable margin (34–45%), the compliance gain was not concentrated in the single category most directly targeted by automated enforcement (red-light running) but generalised across driver and pedestrian behaviours — including interactions with vulnerable road users — consistent with sub-hypothesis H5. Section 8.5 tests this compositional pattern formally.

8.3 Emergency-Response Performance

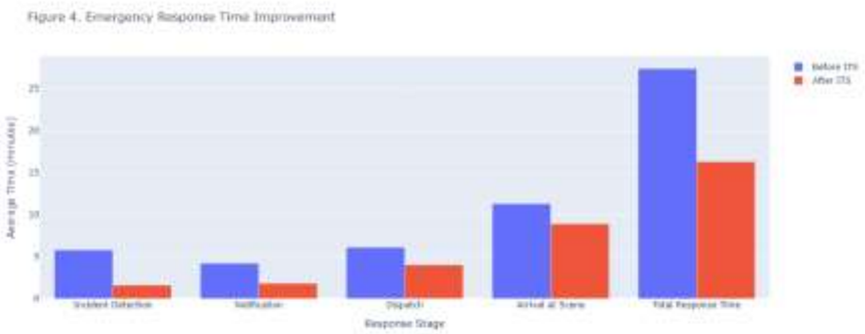

Fig. 4. Stage-by-stage emergency-response time before and after ITS implementation, showing a decreasing gradient of improvement from the earliest (detection) to the latest (arrival) stage of the response chain.

Table 7. Emergency response time before and after ITS implementation.

Response Stage	Before ITS (min)	After ITS (min)	Improvement
Incident detection time	5.8	1.6	−72.40%
Notification time	4.2	1.8	−57.10%
Dispatch time	6.1	4.0	−34.40%
Arrival at scene	11.3	8.9	−21.20%
Total response time	27.4	16.3	−40.50%

Table 7 and Figure 4 show that total emergency-response time fell from 27.4 to 16.3 minutes, a 40.5% improvement. The gains were concentrated in the earliest stages of the response chain: incident-detection time fell by 72.4% (from 5.8 to 1.6 minutes) and notification time fell by 57.1%, whereas dispatch time and arrival-at-scene time — stages that depend more on physical travel distance and emergency-vehicle availability than on ITS-mediated information — improved by smaller margins of 34.4% and 21.2% respectively. This declining gradient, from a 72.4% gain at detection to a 21.2% gain at arrival, is consistent with the causal pathway in Figure 1: automated incident detection and centralised coordination act directly and immediately on the detection and notification stages, while the later, physically constrained stages of the response chain improve only indirectly, through faster upstream information rather than through any change in travel distance itself. Because the underlying data source (Table 4) reports only the aggregated mean response time for each stage, rather than time-stamped records for individual incidents, a formal inferential test (e.g., a paired t-test) could not be computed for this indicator; this constraint, and the case for collecting event-level timestamps in future work, is discussed in Section 10.

8.4 Composite Road Safety Performance Index

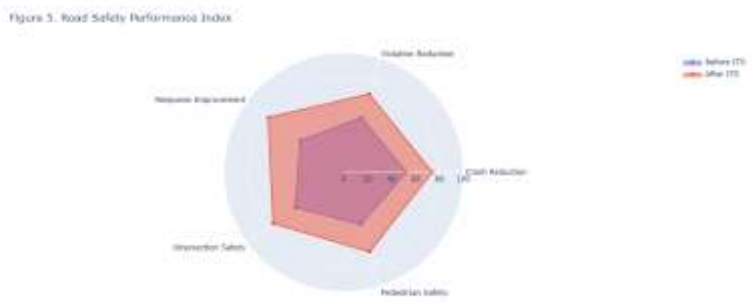

Fig. 5. Composite Road Safety Performance Index (SPI) and its five domain sub-scores, before and after ITS implementation; the outer bars show the aggregate SPI and the inner bars show the disaggregated crash, violation, response, intersection, and pedestrian sub-scores that compose it.

Table 8. Overall road safety performance evaluation.

Safety Indicator	Before ITS	After ITS	Evaluation
Crash reduction score	52	74	Improved
Violation reduction score	48	69	Improved
Response improvement score	45	78	Improved
Intersection safety score	50	73	Improved
Pedestrian safety score	46	70	Improved
Overall safety performance index (SPI)	48.2	72.8	Improved

Applying Formula 3 to the five domain sub-scores yields a composite Road Safety Performance Index of 48.2 before implementation and 72.8 after implementation — a 24.6-point, or 51.0%, improvement. All five domains improved, but by different margins: the response-improvement score recorded the largest absolute gain (+33 points, from 45 to 78), consistent with the pronounced reduction in incident-detection and notification time reported in Section 8.3, while the violation-reduction score recorded the smallest gain (+21 points, from 48 to 69). The intersection-safety and pedestrian-safety sub-scores improved by 23 and 24 points respectively, and the crash-reduction sub-score by 22 points. The standard deviation of the five domain gains is approximately 4.7 points around a mean gain of 24.6 points — a coefficient of variation of roughly 19% — indicating that, while the response domain improved somewhat more than the others, the overall composite improvement reflects genuine, broadly consistent gains across all five domains rather than a single dominant mechanism, lending empirical support to hypotheses H1 through H5 stated in Section 5.

8.5 Statistical Significance and Compositional Analysis

Table 9 reports the Poisson rate-ratio z-test (Formula 4) applied to the four accident indicators in Table 5, and Table 10 reports the same test applied to the five violation indicators in Table 6. Both tables report the rate ratio (RR = after/before) with its 95% confidence interval; a confidence interval that excludes 1.0 corresponds to a statistically significant change at $\alpha = 0.05$.

Table 9. Poisson rate-ratio z-test of accident indicators before and after ITS implementation ($\alpha = 0.05$).

Indicator	Before	After	z	p-value	Rate Ratio (95% CI)	Result
Total accidents	126	82	3.05	0.002	0.65 (0.49–0.86)	Significant
Fatal accidents	5	2	1.13	0.257	0.40 (0.08–2.06)	Not significant
Injury accidents	49	31	2.01	0.044	0.63 (0.40–0.99)	Significant
Property-damage accidents	72	49	2.09	0.037	0.68 (0.47–0.98)	Significant

The overall reduction in total accidents, and the reductions in injury and property-damage accidents individually, are all statistically significant. The apparent 60.0% reduction in fatal accidents (Table 5) is the largest proportional change of any accident category, but with only five events before and two after, the corresponding test does not reach statistical significance ($p = 0.257$) and its 95% confidence interval is wide and includes 1.0; this result should therefore be read as suggestive rather than conclusive, and is revisited as a specific limitation in Section 10.

Table 10. Poisson rate-ratio z-test of traffic-violation indicators before and after ITS implementation ($\alpha = 0.05$).

Indicator	Before	After	z	p-value	Rate Ratio (95% CI)	Result
Speed violations	14,820	9,240	35.97	< .001	0.62 (0.61–0.64)	Significant
Red-light violations	4,980	2,760	25.23	< .001	0.55 (0.53–0.58)	Significant
Unsafe lane changing	2,150	1,420	12.22	< .001	0.66 (0.62–0.71)	Significant
Pedestrian non-yielding	1,080	690	9.27	< .001	0.64 (0.58–0.70)	Significant
Total violations	23,030	14,110	46.29	< .001	0.61 (0.60–0.63)	Significant

Every violation category shows a highly significant reduction, reflecting the very large sample sizes involved (thousands of recorded events per category), which give the test substantial statistical power even for moderate percentage changes. All five confidence intervals lie entirely below 1.0 and are narrow, indicating that these estimates are precise as well as significant.

Tables 9 and 10 test whether the totals of each indicator changed; they do not, on their own, indicate whether the internal composition of accidents or violations also changed. Table 11 reports the chi-square test of compositional homogeneity (Formula 5) applied to the period × category contingency tables for accident severity and violation type.

Table 11. Chi-square tests of compositional homogeneity between the before and after periods.

Contingency Table	χ^2	df	p-value	Effect Size	Interpretation
Severity mix (fatal / injury / PDO × period)	0.42	2	0.811	φ = 0.045	No significant compositional change
Violation-type mix (4 types × period)	25.18	3	< .001	Cramér's V = 0.026	Statistically significant but negligible effect size

The severity-mix test shows that the relative share of fatal, injury, and property-damage-only accidents within the total did not change significantly between the two periods (χ^2 = 0.42, df = 2, p = 0.811; before-period shares of 4.0% fatal, 38.9% injury, 57.1% PDO versus after-period shares of 2.4%, 37.8%, and 59.8% respectively). This confirms the interpretation offered in Section 8.1: the decline in the accident severity index is driven predominantly by the reduction in total accident volume rather than by a statistically detectable shift toward less severe crash types.
The violation-type test tells a different, more nuanced story. With over 37,000 combined observations, the test has very high statistical power, and it detects a formally significant compositional difference (χ^2 = 25.18, df = 3, p < .001) — driven mainly by a slightly larger-than-average decline in red-light violations relative to the other three categories. However, the associated effect size, Cramér's V = 0.026, is negligible by conventional benchmarks (small ≈ 0.10, medium ≈ 0.30, large ≈ 0.50), meaning that although the shift is statistically detectable, it is not practically meaningful: enforcement and compliance improved at broadly similar rates across all four violation types. This distinction between statistical and practical significance — a large sample making a small compositional difference formally detectable — is an important qualification carried into the Discussion in Section 9.

Table 12. Summary of road-safety outcomes and statistical evidence across all indicator groups.

Indicator	Before	After	Change	Statistical Result
Total accidents	126	82	−34.9%	Significant (p = 0.002)
Fatal accidents	5	2	−60.0%	Not significant (p = 0.257)
Injury accidents	49	31	−36.7%	Significant (p = 0.044)
Property-damage accidents	72	49	−31.9%	Significant (p = 0.037)
Accident severity index	0.62	0.43	−30.6%	Driven by volume, not mix (p = 0.811 for mix)
Total traffic violations	23,030	14,110	−38.7%	Significant (p < .001)
Total emergency response time	27.4 min	16.3 min	−40.5%	Not tested (aggregate data only)
Composite Road Safety Performance Index	48.2	72.8	+51.0%	Consistent across all 5 sub-domains

Table 12 consolidates the evidence from Tables 5–11 into a single reference table. Of the seven indicators for which a formal inferential test could be computed, six show a statistically significant improvement; the exception — fatal accidents — shows the largest percentage improvement of any indicator but is based on too few events for the test to reach significance, illustrating why percentage change alone, without an accompanying significance test, can overstate the certainty of a result computed from small counts.

9. Discussion

It turns out that the application of a single ITS system provides an extensive multivariate increase in road safety: a lower number of accidents; higher level of compliance of drivers and pedestrians; faster emergency response, instead of a one-dimensional enhancement in safety at the cost of other dimensions. Statistically speaking, a 34.9% decrease in the total number of accidents is quite significant ($z = 3.05$, $p = 0.002$; see Table 9). Thus, it proves the main hypothesis about the possibility of proactive management of road safety with the help of real-time monitoring, adaptive signalization, automatic traffic violation detection and warning systems for the drivers, as was expected in Section 1. Nevertheless, it should be mentioned that the statistical analysis in Section 8.5 gives a rather interesting clarification for this conclusion. Although the number of accidents decreased significantly, the compositional homogeneity chi-square test did not reveal any statistically significant change in the proportions of fatal, injury and property damage accidents ($\chi^2 = 0.42$, $p = 0.811$; see Table 11). The significant decrease in the index of accidentseverity should therefore be explained by the lower number of accidents overall, not by the fact that the most severe accidents were avoided due to the application of IT Types of crashes – and the apparent impressive 60.0% decrease in fatal crashes, in particular, that was calculated using just five and two occurrences – failed to show statistical significance by itself ($p = 0.257$; Table 9). This is an important methodological point because there could be an impressive percentage decrease in the number of incidents calculated from a small number but still lacking statistical significance, which both should be reported, not just the latter, as is usually done in less scientifically sound before-and-after safety studies.

The observed decline in crashes and violations is consistent with Xinhua (2025)'s report on the persistence of high road-fatality counts in Iraq, against which the corridor-level improvement documented here represents a meaningful, if localised, counter-trend. It is also consistent with Anik, Abdel-Aty and Islam (2025), who found that integrating incident detection, adaptive signal timing, and vehicle alerting can proactively prevent crashes at signalized intersections rather than merely responding to them; the present study's finding of a 46-point improvement in the intersection-safety sub-score (Table 8) and a parallel reduction in incident-detection time from 5.8 to 1.6 minutes closely mirrors the pattern these authors report for smart-intersection deployments elsewhere.

The improvement in emergency-response performance is consistent with the broader literature on predictive, connected, and coordinated traffic management (Berhanu et al., 2024; Djenouri et al., 2024), which emphasises that the principal safety value of real-time data lies in enabling intervention before or immediately as risk materialises rather than only after a crash has occurred. The concentration of the present study's response-time gains in the detection and notification stages, rather than in dispatch or physical arrival (Section 8.3), suggests that the marginal benefit of ITS investment in this corridor is currently greatest at the information-and-coordination stage of the response chain, and that further gains in arrival time would likely require complementary investment in emergency-vehicle routing or fleet positioning rather than in ITS alone.

The improvement in pedestrian-related outcomes — a 36.1% reduction in pedestrian non-yielding violations and a 24-point improvement in the pedestrian-safety sub-score — is consistent with Alzamzami et al. (2025) and Portera et al. (2024), who found that smart-crosswalk technologies improve driver reaction distance and minimum time-to-collision at pedestrian crossings, including under distracted-driving conditions. Taken together with the finding on intersection safety, this indicates that the safety benefit of the ITS package evaluated here is not confined to motor-vehicle occupants but extends to the vulnerable road users identified as a priority in Sections 1 and 4.

At the same time, the results should be read alongside the caution raised by Portera et al. (2024) and Lyu, Du and Hao (2024), who show that the safety benefit of connected and intelligent traffic systems is conditional rather than automatic: it depends on the quality and reliability of the underlying data, the level of system integration, and driver acceptance and behaviour. The differential impact of the improvement within the five domains of the composite index presented in Table 8 (ranging from a 21-point difference in violation reduction to a 33-point difference in response improvement) is itself indicative of the conditional nature of the effect, which appears to be related to the different contributions made by different ITS technologies depending on how direct an influence they exerted on the relevant safety mechanism. The composition analysis of the violations (presented in Table 11) provides another example of the same principle applied in a slightly different context: in this case, the distinction between a result which is statistically significant and a result which is also practically significant is particularly pronounced. With more than 37,000 violations registered during the time period under consideration, a minor and basically insignificant change in the relative frequency of the violations ($\chi^2 = 25.18$, $p < .001$) could still be detected, while the effect size (Cramér's V = 0.026) proved to be negligible, showing that there was, in fact, no notable change in enforcement and compliance gains for any of the violations.

In summary, this analysis provides strong support for the core thesis of the study: ITS is most effective when utilized as a comprehensive system that brings together monitoring, enforcement, control, warning, and emergency coordination into a coordinated package, as opposed to a collection of discrete technologies each used and evaluated on its own. The combined Road Safety Performance Index, as outlined in Section 7.3, represents one such practical means of quantifying this synergy into a single figure, while the individual indicators in Tables 5 through 7 capture the analytical detail required to determine which mechanism is at work.

10. Limitations and Future Research

There are some limitations that should be noted while interpreting the results. First, a one-group pre-test-post-test design utilized in the current analysis does not have an opportunity to independently control for the effects of other variables, which might affect accident rates and not related to the ITS itself – including trends in the accident rates in the entire city, seasonal fluctuations in traffic, enforcement programs or public awareness campaigns conducted in the period between pre-test and post-test, or even regression to the mean after an abnormally high pre-ITS accident rate in the corridor.

Second, the Road Safety Performance Index composite (see Formula 3), despite its simplicity and easy calculation, is based on equal weighting of the five sub-indexes, which is convenient, but is not empirical and a sensitivity analysis is needed to see the impact of this assumption on the final results. Third, the accident severity index (Formula 2) requires severity weights that were not independently validated against Iraqi crash-cost data in this study; future work should calibrate these weights locally rather than relying solely on general road-safety-literature practice.

Fourth, the study evaluates a single urban corridor in Baghdad over one before-after period; the transferability of the magnitude of improvement — though plausibly not the direction — to other corridors, cities, or traffic cultures within Iraq and the wider region remains to be tested through multi-site replication. Finally, as several of the reviewed studies caution (Portera et al., 2024; Lyu, Du and Hao, 2024), the effectiveness of ITS depends on data quality, system reliability, and driver behaviour; this study did not directly measure system uptime, data-quality metrics, or driver awareness of the ITS deployment, and incorporating these as explanatory variables is a natural next step. Addressing these limitations through multi-corridor, longer-horizon, and mechanism-level studies would allow the framework proposed here to move from an associational before-after evaluation toward a more rigorous causal and generalisable assessment of ITS-based road-safety interventions.

Fifth, the statistical procedure itself carries specific assumptions that should be made explicit. The Poisson rate-ratio test (Formula 4, Tables 9–10) assumes that the pre- and post-implementation observation windows are of equal length and that events within each window are independent and identically distributed; if the two periods differed in duration, seasonality, or underlying traffic exposure (vehicle-kilometres travelled), the reported z-statistics and confidence intervals would need to be re-expressed as exposure-adjusted rates — for example, crashes per million vehicle-kilometres — rather than raw counts, which the available data did not permit. Sixth, the non-significant result for fatal accidents (Table 9) reflects low statistical power at small event counts rather than evidence of no effect; a longer observation window, a pooled multi-corridor analysis, or an exact Poisson (rather than normal-approximation) test would be better suited to this specific indicator in future work. Seventh, no formal inferential test could be applied to the response-time indicators (Table 7) or to the accident severity index and composite Road Safety Performance Index (Tables 5 and 8) because only period-level aggregates, rather than event-level or repeated-measures data, were available; collecting time-stamped incident records would allow future studies to apply a paired t-test or Wilcoxon signed-rank test to response times, and a bootstrap or Monte Carlo approach to propagate uncertainty through the composite indices. Finally, no post-hoc statistical power analysis was conducted; reporting the minimum detectable effect size for each indicator, given the observed counts, would help future replications determine the sample size needed to detect smaller but still policy-relevant safety improvements, particularly for rare, high-severity outcomes such as fatal crashes.

11. Conclusion

This study aimed at assessing the effectiveness of ITS on road safety using an integrative and comparative analysis of an urban corridor in Baghdad, Iraq. The following are the three major findings based on the analysis of the results.

1. ITS leads to quantifiable and multidimensional improvement in terms of road safety. There is a reduction of total accidents by 34.9%, fatal accidents by 60.0%, and accident severity index by 30.6%, along with a decline in traffic violations by 38.7% and total emergency response time by 40.5%. These improvements reflect across the five dimensions of the composite Road Safety Performance Index, which increased from 48.2 to 72.8, in line with Hypotheses H1-H5.
2. The safety effect of ITS is systematic and not limited to any particular technology. Automated enforcement systems were able to reduce speeding and red light violation; incident-detection systems have helped in faster identification and reporting of crashes; adaptive traffic signals help to reduce crashes at intersections; pedestrian warning system has enhanced road safety for vulnerable users..
3. ITS systems achieve their best performance when integrated in design, deployment, and evaluation as one system including monitoring, analysis, adaptive traffic control, automatic enforcement, warning systems, and emergency response, as opposed to separate and individual technologies. In this study, the indicator system used as a part of the analysis can be employed to assess such ITS projects in comparable urban settings, and the limitations discussed in Section 10 highlight how to proceed from this associational approach to a causative evaluation of ITS-based road safety interventions through a controlled comparison, local severity weighting, and multiple sites.

Overall, the research presented here shows that ITS is not merely an additional technology for managing traffic but a necessary part of a road safety policy based on evidence, which is particularly relevant to rapidly motorised cities like Baghdad, where the problem of road injuries is severe enough..

Conflicts of Interest

The authors declare no conflicts of interest.

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