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Quantifying the Effect of Smart Traffic Cameras on Speeding Patterns through Structural Equation Modeling

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ABSTRACT: Exceeding speed limits is a significant factor contributing to accident risks, which, in turn, stands as a major cause for the 1.3 million global road deaths per annum, which translates to 3700 dead people every single day. The percentage of fatalities is increasing every year as a one percent increase in speed results in a 3.5-4% increase in deaths. Therefore, a critical issue was evaluated by investigating the effectiveness of speed enforcement smart cameras as a part of advanced information and communication technologies (ICTs) installed by the relevant government authorities in the metropolitan area for efficient traffic management. To understand speeding behavior, a questionnaire was designed and piloted to collect data from 616 road users. The collected data were analyzed using a statistical package for the social sciences (SPSS) and analysis of moment structure (AMOS). The results indicated a 10% decrease in vehicle speed in the vicinity of the camera enforcement area, compared to other areas where the ICTs' enforcement was not present. This reduction in speed variations across vehicles was also noticeable, signifying that the risk of traffic crashes should be lower with increased safety. The output of the structural equation model showed that the perception variables have a positive correlation with speed behavior. In conclusion, the presence of smart camera enforcement led to a significant reduction in vehicle speed in the area of enforcement. As a result, an increase in the number of cameras correlates with a reduction in instances of traffic violations. The research findings are helpful for multiple institutions, particularly those dealing with traffic management, control, safety, and urban planning.

KEYWORDS: Driver's Attitude; Road Crashes; Smart Speed Enforcement Cameras; Speeding Behavior; Traffic Safety

1. INTRODUCTION

Traffic accidents cause millions of deaths and injuries globally, causing significant economic losses, and it is the 8th leading cause of death across all age groups (Atombo et al., 2016). A study claims that by 2030, traffic crashes will be the fifth leading cause of death (Sameen & Pradhan, 2017). One of the main reasons for these fatal accidents is drivers' disregard for traffic laws and safety standards, mainly speeding (Høye, 2020). Drivers' behavior toward speeding remains underexplored due to the involvement of multiple factors and variables (Cai et al., 2021). Not only limited to motorized traffic, but speeding is also the top contributing factor for pedestrian and bicyclist fatalities, most of which occur on suburban arterials (Goel, 2021). According to the Emergency Service Department of the government of Punjab, Pakistan, in the metropolitan city of Lahore, a total of 1018434 road accidents were reported from 2004 to 2024, with speeding among the leading factors. Therefore, this study focuses on the evaluation of speeding behaviors of urban areas' road users in the presence of speed enforcement smart cameras on high-speed traffic roads.

Speeding is the main cause of traffic accidents worldwide, largely due to inappropriate driving behaviors. International organizations are conducting studies to reduce road fatalities due to speeding, focusing on understanding the relationship between driving habits and speeding behavior (Kong et al., 2020). Preventing road traffic accidents is possible, and each country can develop a specific traffic safety framework through targeted interventions. Key factors for implementing safe driving practices in developing countries include age, driving experience, personality traits, and a supportive attitude toward traffic safety (Martínez-Ruíz et al., 2019).

Smart traffic cameras have emerged as a promising tool for speed enforcement, designed to alter driver behavior by increasing the perceived risk of being caught. While existing research highlights their effectiveness in monitoring and enforcing speed limits, much of it has focused on enforcement techniques rather than understanding driver behavior across various socioeconomic and situational contexts. There is limited research on how drivers perceive and respond to speed enforcement measures and how these perceptions influence their driving habits.

This study aims to bridge that gap by evaluating drivers' speeding behavior under different scenarios and examining their perceptions of smart camera enforcement. By analyzing behavioral changes in response to these interventions, the research will contribute to a deeper understanding of the factors influencing speeding. Ultimately, the findings will help develop targeted strategies to mitigate speeding behavior and enhance road safety, particularly on high-speed urban roads.

2. LITERATURE REVIEW

Low-income countries have a 2.6 times higher death rate than high-income countries, with 9.2 deaths per 100,000 people, often due to speeding (de la Santé, 2020). Studies in Europe and North America indicate that speeding behavior is influenced by situational constraints, social and environmental factors, and individual norms. Speeding behavior is also shaped by socioeconomic conditions such as income, education, employment status, and travel frequency. However, understanding the complex relationship between these factors and speeding requires further research (Sheykhfard et al., 2024; Javid et al., 2021). To improve road safety, several

countries implemented traffic violation detection cameras. For example, in Colombia, fixed cameras were installed at various roadways and intersections to detect multiple traffic violations such as speeding, running a red light or stop sign, violating traffic schedules, and blocking pedestrian crosswalks. Initially, experimentation was done that included 38 intervention areas and 50 comparison areas (within a 250m radius), observed 42 months before and 34 months after camera installation. The effects were analyzed by using mixed negative binomial regression models, and results showed reductions of 19.2% in crashes and 24.7% in injury and fatal crashes over 12 months. It was concluded that the camera-equipped sites performed better than the non-surveillance sites with a yearly reduction of 5.3% ($p = 0.045$) for all crashes. This implies that the use of traffic violation detection cameras has a positive impact on road safety and a decrease in crashes and injuries (Castillo-Manzano et al., 2019).

Speed management is also a critical challenge in South Asian countries, where financial and mobility restrictions shape public transportation use. Enhancing service quality alongside mobility regulations can help shift travel behavior. However, enforcing speed limits remains difficult in developing nations with weaker economic conditions, where cost-effective strategies are necessary for sustainable road safety improvements (Berhanu et al., 2023; Kanitpong et al., 2013). People's preferences to utilize public transportation in third-world countries are highly desirable but dependent on mobility restrictions, financial constraints, and car entry restrictions. The integration of service qualities with mobility restriction is an effective solution to changing travel behavior (He et al., 2013). Various factors influence drivers' speed behavior, with socioeconomic factors being one of the essential determinants and impacts of socioeconomic factors, including income, education, employment status, economic development, traveling frequency, and compliance with traffic regulations on speeding behavior. The existing research findings still require an understanding of the complex relationship between socioeconomic factors and speeding behavior (Pervez et al., 2021).

The National Traffic Safety Administration (NTSA) estimated that speeding-related accidents resulted in a $40.4 billion economic loss. The number of speeding-related fatalities in the U.S. rose from 32,077 in 2014 to 35,029 in 2015, highlighting a growing concern. In developing countries, cost-effective enforcement strategies are vital, as economic constraints limit the extensive implementation of advanced speed control measures (Kanitpong et al., 2013; Perez et al., 2021; Rezapour et al., 2018). Drivers' preferences and attitudes significantly influence policy effectiveness. Road safety education and awareness programs play a crucial role in shaping driver behavior, particularly in lower-income areas. Research suggests that experienced drivers, particularly those with over 10 years of driving; often oppose strict speed control measures, favoring warning signs and rumble strips instead. Long-distance drivers, however, support more comprehensive measures, including radar guns and automatic speed cameras (Durrani et al., 2012). Enforcement of legally declared speed limits is crucial to ensure driver compliance with rules and regulations to prevent potential risks to lives (Wali et al., 2017). Therefore, the enhancement of road safety education and awareness programs, particularly in lower-income areas, helps in reducing speeding incidents.

Higher education is strongly correlated with safer driving behaviors, as educated individuals are more likely to adhere to traffic laws and avoid speeding (Floreskul et al., 2016). Employment status also plays a role; unemployment and job instability increase stress levels, leading to riskier driving behavior. Financial insecurity can thus contribute indirectly to speeding and road accidents (Kim & Kwan, 2019; Wanberg et al., 2010). Gender differences in speeding behavior are well-documented, with male drivers exhibiting higher tendencies for aggressive and reckless driving compared to females. Studies exploring speeding through the theory of planned behavior indicate that attitudes, social norms, perceived control, and cultural influences shape speeding tendencies. Young male drivers, in particular, are more prone to speeding due to personality traits, driving culture, and situational constraints (Javid et al., 2020; Javid et al., 2019).

Research on road design and its impact on speeding behavior has utilized visual models and field investigations. Studies using Random Forests and logistic regression indicate that improved road environments can significantly reduce motorway accidents. Data collection through driver surveys, risk perception analysis, and behavior tracking provides deeper insights into over-speeding patterns, aiding policymakers in designing more effective interventions (Lucidi et al., 2019). Driver speed preferences have been analyzed through preference surveys, with studies showing that imposing higher driver's license demerit point penalties is more effective than monetary fines. The penal mixed logit model suggests that stricter enforcement strategies, alongside driver education and improved road design, can significantly reduce speeding and enhance road safety (Hung et al., 2018).

Speed enforcement cameras are widely used to deter speeding and enhance road safety, but their long-term effectiveness declines due to user familiarity, insufficient enforcement, and delayed maintenance. Research recommends installing cameras optimally within 200 meters and using multiple cameras, which have been shown to reduce personal injuries by 21.4% and 13.2%. Combining cameras with monetary penalties has also been effective in reducing speeding incidents among professional drivers, as seen in Hong Kong (Chen & Warburton, 2006). Driver preferences for speed were evaluated using a preference survey technique, and the effects of fines and enforcement strategies were examined using a penal mixed logit model. The findings demonstrated that imposing higher driver's license demerit penalties is more effective than imposing monetary fines (Yu et al., 2019).

The literature reviewed confirms that smart speed enforcement cameras play a crucial role in monitoring speeding and enhancing road safety by influencing driver behavior through an increased perceived risk of detection. However, previous research has primarily emphasized enforcement strategies while overlooking the impact of various socioeconomic conditions on driver behavior. This study addresses that gap by analyzing drivers' attitudes, awareness, and behavioral patterns under different circumstances, providing a more comprehensive understanding of the factors shaping speed compliance. The objective is to evaluate drivers' speeding behavior across various scenarios and their perceptions following smart camera enforcement. By analyzing behavioral changes, the research contributes to mitigating the causes of speeding and enhancing safety on high-speed roads.

3. METHODOLOGY

Following the defined objective of the study, the methodology consists of sorting out the study area using the appropriate sampling method and sample size, and designing a comprehensive questionnaire to delve into the subject matter. Data were collected by surveys at four locations near designated study areas and analyzed using different statistical software, such as SPSS and AMOS. A methodological flowchart of the study is provided in Figure 1 for reference.

3.1. Sample size

Random sampling was chosen to reduce the chances of bias and manipulation in the *sampling* process. Cochran's formula for the sample size calculation was chosen eq. (1).

(1) $n_0 = \frac{z^2 pq}{e^2}$

Where:
e is the desired level of precision (i.e., the margin of error)
p is the (estimated) proportion of the population that has the attribute in question
q is *1-p*
z is the desired confidence level

A sample size of 616 was gathered from the target population, surpassing the minimum requirement of 385 to attain a significant confidence level (Etikan & Bala, 2017).

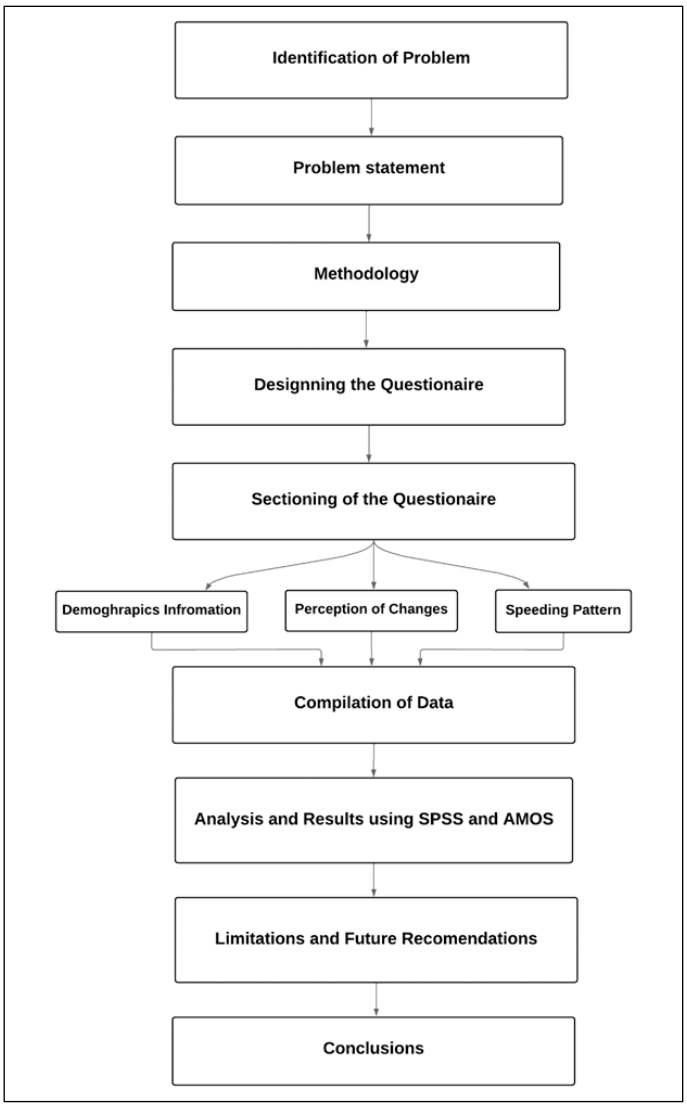


Figure 1. Flow chart of research activities

3.2. Questionnaire Design

The questionnaire has four sections with a total of 26 questions. The first part was related to road and vehicle-related information so that those who didn't drive or were unfamiliar with driving could be filtered out immediately (Boparai et al., 2018). The second section comprised 09 questions related to speed behavior, such as traveling speed near the speed cameras, and driving speed under the influence of driving during peak hours' time. The third section consisted of a total of 05 questions, focused on the perceptions of drivers about the changes observed after the speed camera installations (Roopa & Rani, 2012). The final section of the survey dealt with the demographics of the respondents to give insights related to the demographics and socio-economic characteristics of road users. On average, each respondent took 5 to 7 minutes to complete the questionnaire, which depends on the familiarity with the questions and level of understanding.

3.3 Discussions with Officials

Further information from experts was taken to support the information collected through the questionnaire. Though the questionnaire included a question regarding the number of E-challans received by road users, the exact number of fines was not directly asked from respondents, keeping in view that they might hesitate or feel uncomfortable discussing the number of fines that they have received. To address this aspect, therefore, the information was collected through face-to-face discussions with Punjab Safe City Authority Officials. The officials confirmed that the Government has issued an ordinance related to traffic violations. Under this ordinance, a 2000 PKR fine will be imposed on a bicycle driver for speeding, while a car driver will be fined 5000 PKR.

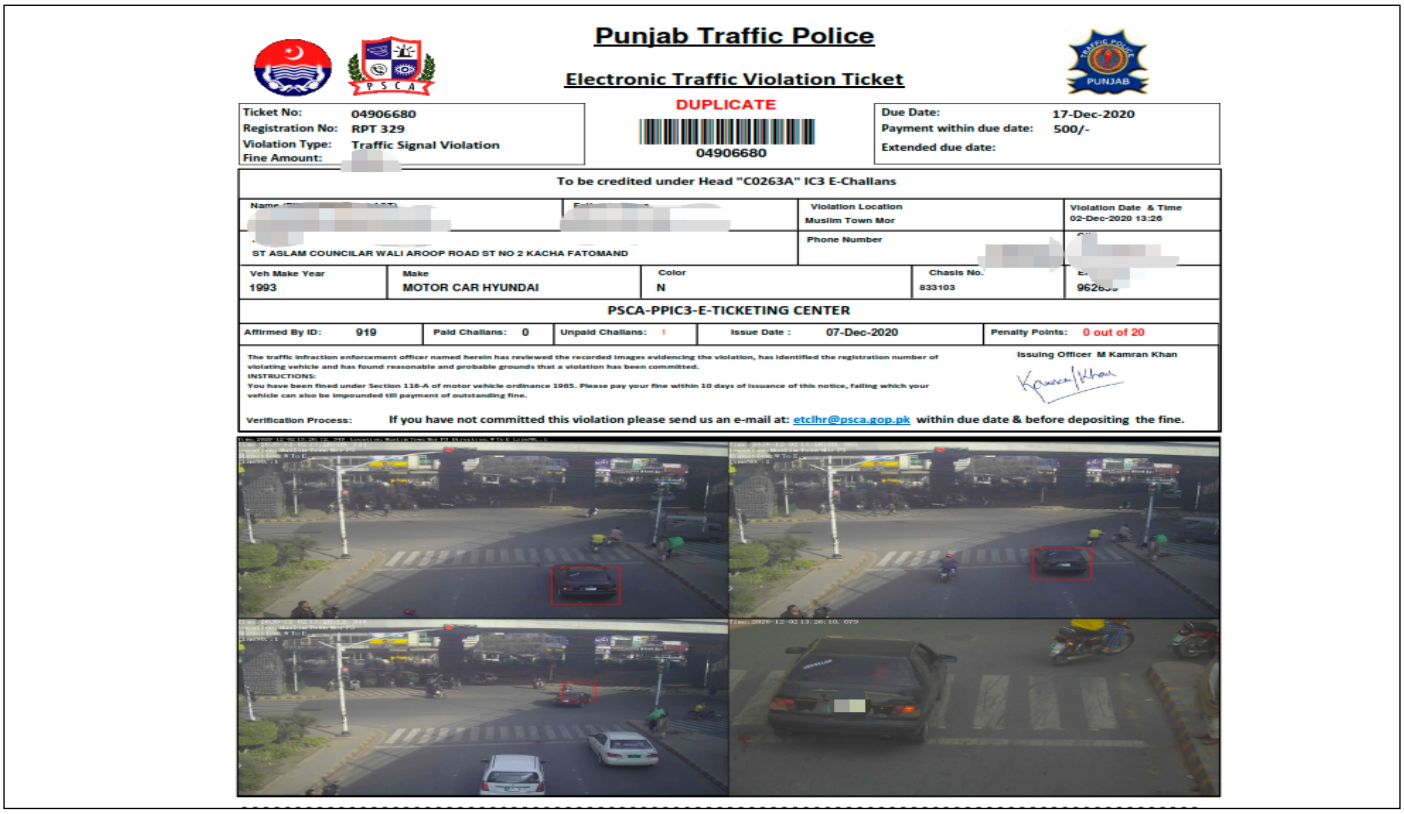
The officials also explained that four different types of cameras are being used for monitoring the traffic within the system. The first type is PTZ (Pan-Tilt-Zoom) cameras, which can rotate in all directions and offer both zoom-out and zoom-in options. Mainly, these cameras are used for continuous monitoring of dynamic traffic situations. The second type is Fixed-Cameras, which remain pointed in a single direction and are installed at predetermined locations for a particular section of the road. The third type is ANPR (Automatic Number Plate Recognition) Cameras, according to officials; these are mostly used in traffic-related operations. These cameras support systems such as the Journey Time Management System (JTMS) and Red-Light Monitoring System (RLMS). Whenever a vehicle passes by this camera, the camera captures a clear image of the number plate and sends it directly to the database management system. In case of a traffic violation occurrence, the system automatically records both "before "and "after" images of the number plate. These images are verified by the database, and once verified, the E-Challan is issued to the violator/user, i.e., registered owner of the car, as shown in Figure 2. The fourth type is FR (Face Recognition) Cameras. These cameras record facial features of individuals passing through monitored areas and send their information to the central base data management, where it helps monitor violations and has helped in crimes and criminal detections. For example, it helps in locating stolen cars following recovery and returning them to the original owner.

To obtain the information regarding traffic accidents, a holistic discussion was also conducted with the Government Rescue Department 1122. The officials confirmed that the implementation of smart traffic cameras had a significant impact in reducing traffic accidents, particularly related to speeding, and it has also helped to control vehicle-related crimes. According to their records, traffic accidents related to speeding decreased by approximately 10 % since the installation of smart traffic cameras.

The Traffic Monitoring Pole Shown in Figures 3 and 4, corresponding to the Punjab Safe City Authority, consists of a combination of cameras, including a 360-degree rotatable PTZ camera, a fixed camera, and FR Cameras. This Setup is generally used for traffic surveillance and violation detection, automatic number plate recognition, and is mostly used in traffic-related operations such as JTMS and RLMS.

3.4 Selection of study area

This study was carried out in the second most populous metropolitan city of Pakistan, i.e., Lahore. The arterial Canal Road, commonly referred to as Canal Bank Road, is a wide eight-lane roadway in Lahore, Punjab, Pakistan, as shown in Figure 5.



Punjab Traffic Police

Electronic Traffic Violation Ticket

DUPLICATE

Ticket No:	04906680
Registration No:	RPT 329
Violation Type:	Traffic Signal Violation
Fine Amount:	
Due Date:	17-Dec-2020
Payment within due date:	500/-
Extended due date:	

04906680

To be credited under Head "C0263A" IC3 E-Challans

		Violation Location: Muslim Town Mor	Violation Date & Time: 02-Dec-2020 13:26
ST ASLAM COUNCILAR WALI AROOP ROAD ST NO 2 KACHA FATOMAND		Phone Number	
Veh Make Year: 1993	Make: MOTOR CAR HYUNDAI	Color: N	Chasis No.: 833103

PSCA-PPIC3-E-TICKETING CENTER

Affirmed By ID: 919	Paid Challans: 0	Unpaid Challans: 1	Issue Date : 07-Dec-2020	Penalty Points: 0 out of 20	

The traffic infraction enforcement officer named herein has reviewed the recorded images evidencing the violation, has identified the registration number of violating vehicle and has found reasonable and probable grounds that a violation has been committed.

INSTRUCTIONS:

You have been fined under Section 116-A of motor vehicle ordinance 1965. Please pay your fine within 10 days of issuance of this notice, failing which your vehicle can also be impounded till payment of outstanding fine.

Issuing Officer M Kamran Khan

Verification Process: If you have not committed this violation please send us an e-mail at: etclhr@psca.gop.pk within due date & before depositing the fine.

Figure 2. Sample of an Electronic Traffic Violation Ticket and Automatic Number Plate Recognition Camera-A footage illustrating a violation Incident



Figure 3. Traffic Monitoring Pole equipped with PTZ, FR and Fix Cameras under the Punjab Safe City Authority

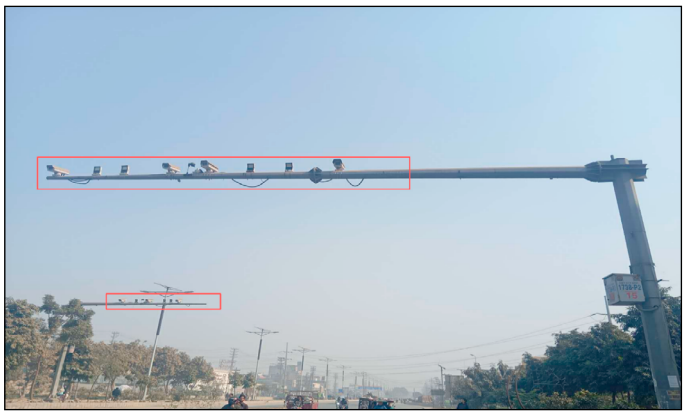


Figure 4. Traffic Monitoring Pole equipped with Automatic Number Plate Recognition Cameras



Figure 5. Google Map Aerial View of the Canal Road from Thokar Naiz Baig to Jallo Mor



Figure 6. Google Earth Pictorial Ariel View of the Thokar Naiz Baig area near Canal Road



Figure 7. Google Earth Pictorial Aerial View of the Scheme Mor Stop and its linkage road connecting to Canal Road

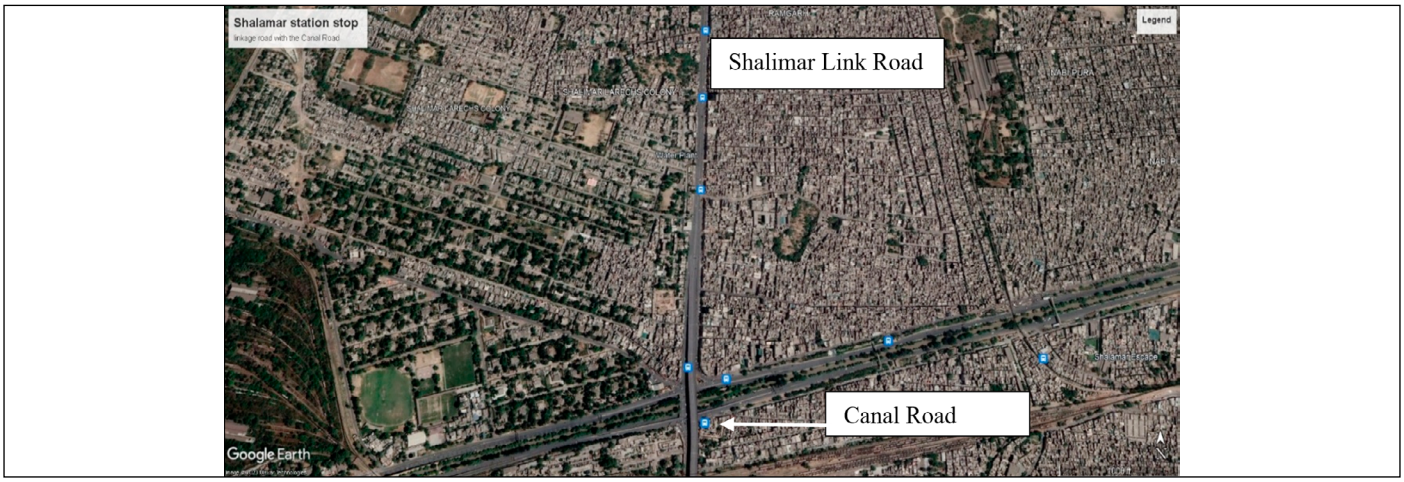


Figure 8. Google Earth Pictorial Aerial View of the Shalimar Link Road near Canal Road

The purpose of choosing this road was that it holds complicated traffic with many connecting roads, mixed traffic, complicated lane discipline, and high-speed traffic. It was a challenge to collect data directly from fast-moving traffic streams; therefore, due to safety concerns of drivers, the data was collected from the spots with less speedy streams, such as Scheme or stop and Thokar Niaz Baig, that have a direct link with the canal road, as shown in Figures 6 and 7. The Shalimar Link Road was also chosen to collect data because of its high ridership and direct connections to the Canal Road, Figure 8.

The questionnaire was administered through face-to-face interactions conducted by the expert team of surveyors to get insights into the prevailing driving behavior and level of awareness of traffic laws among road users. All the responses were recorded on a paper-based printed questionnaire during onsite data collection visits. After completing the fieldwork, all questionnaires were compiled, reviewed, and manually transferred into digital files for proper data management and further analysis. This process ensured the consistency, validity, accuracy, secured the storage of collected data, and made it ready for further analysis (Han et al., 2023).

4. DATA ANALYSIS

The findings from the data that were collected through surveys were analyzed, and results were drawn. The speed behavior of vehicle users on Canal Road was evaluated after the implementation of speed camera enforcement measures by the Punjab Safe City Authority (PSCA). The data analysis process involved examining participants' demographic characteristics, descriptive statistics, survey responsiveness, data trends, and correlations. To handle and analyze the data, a few software programs were used, including Microsoft Excel, the premium edition of SPSS, and Analysis of Moment Structure (AMOS). The goal of this analysis was to identify any pattern or trend in the responses and gain insights into the driving behavior and attitude toward traffic laws among the participants.

Data analysis was done through various statistical tests, such as factor analysis, correlation, and regression analysis, to ensure the validity and robustness of the results. Correlations were determined using the Pearson correlation method, and a multiple linear regression analysis was performed through structural model equations. The details are discussed in the sections below. A well-fitted model is accepted if the value of CMIN/df is ≤ 5, which indicates a reasonable fit; the goodness-of-fit indices (GFI) and the comparative fit index (CFI) are greater than > 0.9. In addition, the root mean square error of approximation (RMSEA) values ranging from 0.05 to 0.08 are considered acceptable (Schermelleh-Engel et al., 2003).

4.1. Demographic characteristics of the sample

The measurable characteristics of the participants were determined by various factors such as gender, age, occupation, education, monthly income, and marital status. A comprehensive overview of the participants' demographic information is presented in Table 1. Males involved in response were 79% compared to females with 21%, which shows that males were usually the drivers and were more responsive compared to females. The major percentages of respondents involved the age group of 18-35 with 84.7%, undergraduated degree holders at 61.7%, 48.2% were students, 36.4% belonged to the middle-class socio-economic group, and 71% were unmarried. With the installed cameras, it was frequently observed that speeds between 71-90 km/h occurred 70.6% of the time.

4.2. Relationship of speed ranges with gender, age, education, occupation, monthly income, marital status, and travelling frequency

The relationship between various speed ranges and other variables was developed by using the Pearson correlation, as shown in Table 2. The relationship between speed in the case of no cameras on the road and the frequency of participants' traveling was significant ($p = 0.000$), which showed a positive relationship of 15.2%. The correlation between speed behavior when there were no cameras or poles installed nearby, and gender was significant ($p = 0.01$). The correlation between speed behavior when there was a camera or poles installed nearby, with age was significant ($p = 0.01$).

4.3 Sampling adequacy, reliability, and validation tests for data

KMO and Bartlett tests were used to validate the sample size. A KMO value over 0.5 and a significance level for Bartlett's test's p-value ≤ 0.05 suggested that there was a substantial correlation in the data. Values above 0.5 are considered good for data reliability (Thao et al., 2024). In this study, the value of sampling adequacy was 0.723, which is considered an excellent value. The Cronbach's alpha value was calculated for all variables to assess the internal consistency across all variables. The consistency and stability of the collected data were checked through a reliability test. A value of 0.622, through the reliability test, is deemed satisfactory (Brown, 2002). This indicates a good level of reliability within the data, suggesting a consistent and dependable outcome for the study's purposes.

4.4 Development of Measurement Models or Equations

Measurement models were developed using observed variables, and standardized estimates were obtained using AMOS software. These generated models identified the relationships between the type of vehicle, speed behavior, and perception of people regarding the changes after law enforcement. The results of measurement models or equations are shown in Table 3. All the measurement equations were significant ($p < 0.001$). The measurement equation of SB_Q3 (No of E-challan Received) and SB_Q8 (Speed behavior during the night after 10 o'clock) with the speeding pattern was not significant.

4.5 Development of the SEM Model

A structural model was developed, as shown in Figure 9, to test the following hypotheses.

Hypothesis 1: The perceptions about the CCTV cameras affect the speeding behavior of drivers.
Hypothesis 2: The awareness of drivers about the speed limit and e-challan on speeding behavior.
Hypothesis 3: The driver's driving patterns and personal characteristics are related to their speeding behavior.

The latent variable of awareness has a negative structural estimate with the speeding behavior. This means a driver with high speeding behavior has a lower perception and awareness of traffic rules (Hypothesis 1 is accepted). In other words, drivers with low awareness about the speed limit and the e-challan system may speed more than others. The structural estimate of perceptions about CCTV cameras and speeding behavior was not significant (Hypothesis 2 is rejected). Hypothesis 3 is accepted as the variables of driving frequency, driver's age, type of car, and type of motorcycle used have significant estimates on speeding behavior. The positive estimate of the frequency of speeding behavior indicates that those who drive frequently are more likely to speed. The type of car is positively related to the speeding behavior, whereas the type of motorcycle is negatively related. It shows that the drivers of different types of cars have different tendencies to speed. The gender (male) is negatively related to speeding behavior. The RMR = 0.041, and GFI = 0.835 values of this model show that the model is fit for the observed data. This model incorporated all the latent variables and their relationships with the observed variable.

5. DISCUSSION

The study provides a meaningful insight into how smart traffic cameras influence driver behavior on urban corridors, particularly in mixed traffic environments such as Lahore's Canal Road. While the previous studies primarily focused on whether automated speed enforcement can reduce vehicle speed and increase the road safety outcomes, most of the existing studies emphasized the aggregate measures, such as average speed reduction and crash frequency, often within a relatively homogeneous traffic environment. In addition, driver's awareness towards the enforcement system, individual driving characteristics, and socioeconomic factors on speeding behavior under enforced and non-enforced conditions remain insufficiently examined. This study seeks to

Variable	Categories	Type	Frequency	Distribution
Types of vehicles used by participants	Motorcycle	Categorical	236	38.3%
	Auto Rickshaw		108	17.5%
	Car (Hatchback Saloon)		217	35.2%
	Pickups		28	4.5%
	Minibus		27	4.4%
Frequency of participants' traveling	Rarely	Categorical	250	40.6%
	Daily		227	36.9%
	Frequently		139	22.6%
Gender	Male	Binary	487	79.0%
	Female		129	21.0%
Age	<18	Categorical	9	1.5%
	18-35		522	84.7%
	36-60		77	12.5%
	>60		8	1.3%
Education	Primary	Categorical	31	5.0%
	Matric		40	6.5%
	Intermediate		72	11.7%
	Under-Graduate		380	61.7%
	Post-Graduate		93	15.1%
Occupation	Student	Categorical	297	48.2%
	Private Employee		196	31.8%
	Govt Employee		48	7.8%
	Un-employed		41	6.7%
	Retired		12	1.9%
	Missing		22	3.6%
Monthly income	< 25k	Categorical	169	27.4%
	25k-50K		224	36.4%
	50K-100K		74	12.0%
	>100k		10	1.6%
	Missing		139	22.6%
Marital status	Unmarried	Categorical	437	70.9%
	Married		154	25.0%
	Widow		2	0.3%
	Missing		23	3.7%
Travelling speed if cameras and Poles are installed on Canal Road	<50km/h	Categorical	129	20.9%
	51-70 km/h		435	70.6%
	71-90 km/h		42	6.8%
	>90km/h		5	0.8%
	Missing		5	0.8%

Table 1. Different variables, categories, types of data, and distribution

Variables		Gender	Age	Education level	Occupation	Monthly income range	Marital status	Frequency of participants' travel
Travelling speed if cameras and Poles are installed on the road	Pearson Correlation	.110**	.058	.027	-.007	.089	.057	.057
	Sig. (2-tailed)	**.007**	.150	.510	.867	**.054**	.168	.160
	N	609	611	611	589	472	588	611
Travelling speed if cameras and Poles are not installed on the road	Pearson Correlation	.106**	.025	.021	.058	.078	.050	.152**
	Sig. (2-tailed)	**.009**	.536	.596	.159	**.088**	.228	**.000**
	N	614	616	616	594	477	593	616

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2. Pearson's correlation of traveling speed with gender, age, education, occupation, monthly income, and marital status, with installed and not installed cameras

Parameters		Estimate	S.E.	C.R.	p-value
PV1(Compliance to Speed Limit)	Perception	1.582	.169	9.347	***
PV2 (Severity Reduction)	Perception	1.118	.078	14.329	***
PV3(Increased Safety)	Perception	.892	.063	14.089	***
PV4 (Advanced System)	Perception	.930	.107	8.654	***
PV5(Accident's reduction)	Perception	.633	.066	9.517	***
SB_Q1(Speed behavior near camera pole)	Speed behavior patterns	1.000			
SB_Q2(speed behavior in case of no camera)	Speed behavior patterns	.993	.053	18.647	***
SB_Q3 (No of E-challan Received)	Speed behavior patterns	.011	.59	.183	.855
SB_Q4 (speed behavior on weekend)	Speed behavior patterns	1.182	.069	17.069	***
SB_Q5(Speed behavior on weekdays)	Speed behavior patterns	.716	.077	9.245	***
SB_Q6 (Speed behavior during peak Hours)	Speed behavior patterns	.925	.085	10.900	***
SB_Q7(Speed behavior during off-peak hours)	Speed behavior patterns	.796	.094	8.450	***
SB_Q8(Speed behavior during the night after 10 o'clock)	Speed behavior patterns	.182	.100	1.828	.068
SB_Q9(Speed behavior during Stress environment)	Speed behavior patterns	.703	.078	9.053	***

Note: ***. Correlation is significant at the 0.01 level (2-tailed).

Table 3. Model results for driver's behavior and perception (DBP), assessment of driver awareness for traffic rules (DATR), and variable relationship (VR) Model)

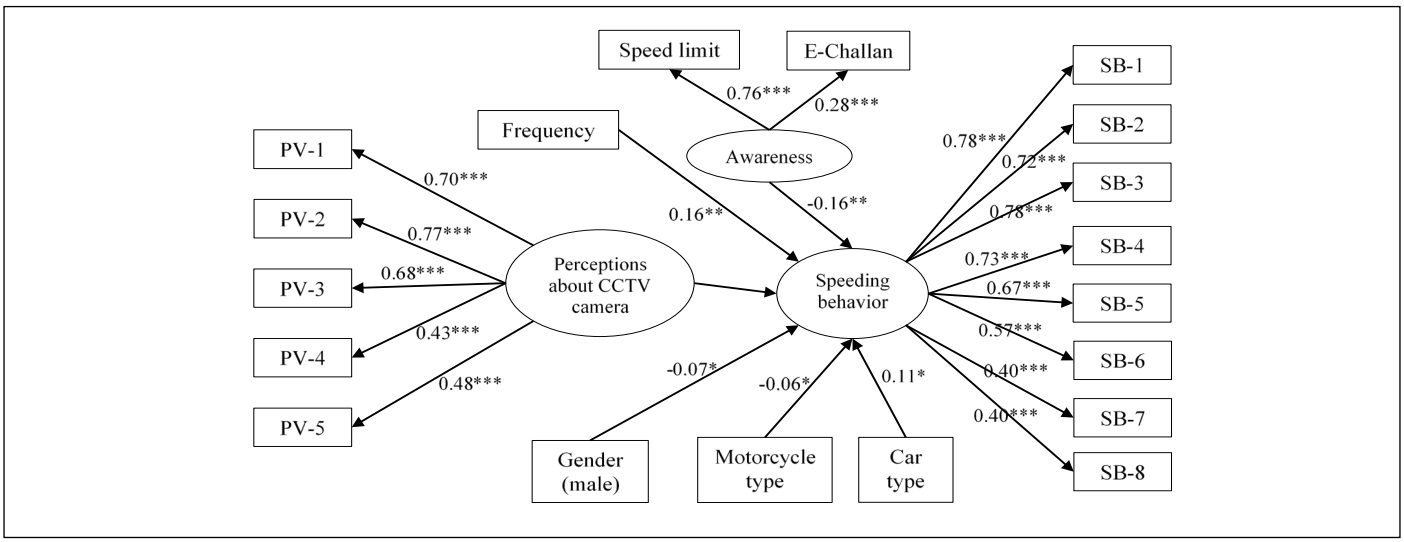


Figure 9. Structural model flow chart describing the relationship between all the dependent and independent variables

address this gap by investigating speeding behavior through a behavioral modeling approach within a complex urban mixed traffic condition. Three hypotheses were formulated to critically assess the effectiveness of smart cameras in promoting road safety by analyzing driver behavior, using the SEM technique on data collected through a stated preference survey of road users. It is concluded that for H1, drivers with low awareness about the speed limit and the e-challan system speed more than others. 17% of participants preferred to travel faster than the posted speed where cameras were not installed. 7% of participants preferred to travel faster than the posted speed where cameras were installed. The speed enforcement cameras play a significant role in reducing speed violations and subsequent accidents.

For H2, the structural estimate of perceptions about CCTV cameras variable with speeding behavior was not significant; therefore, Hypothesis 2 is rejected. For H3, accepted as variables of driving frequency, driver's age, type of car, and type of motorcycle used have significant estimates with speeding behavior. The positive estimate of the frequency of speeding behavior indicates that those who drive frequently are more likely to speed. 7% of participants preferred to travel faster than the posted speed where cameras were installed. Speed behavior has a positive and significant impact on vehicle type. This means that the behavior of vehicle drivers can vary from vehicle to vehicle. The type of car is positively related to the speeding behavior, whereas the type of motorcycle is negatively related. It shows that drivers of different types of cars have different tendencies to speed. As compared to other types of vehicles, pickup drivers drive at higher speeds. The gender (male) is negatively related to speeding behavior. This result is closely aligned with another previous study conducted in Thailand (Kanitpong et al., 2013) in which attitudes of different groups of drivers towards various speed enforcement strategies are examined, and results found that most of the male respondents exhibited negative attitudes towards all forms of speed enforcement techniques. The analysis of traffic data of this study before and after the implementation of speed cameras has demonstrated a statistically significant decrease of 10% in vehicle speed in the vicinity of the camera enforcement and a corresponding decline in the number of traffic accidents. The SEM model confirms that speed enforcement cameras significantly mitigate speeding behavior and related traffic crashes, while individual socio-demographic and vehicular attributes critically modulate drivers' speed choices. The findings of this study are also consistent with previous research on speed enforcement. Similar reduction in the total injury crashes following speed cameras deployment was reported by

(Wali et al., 2017), who observed that the speed enforcement has a significant impact on safety improvement, particularly in the direct influence area of enforcement. Previous Studies showed that injuries and severe crashes experience greater proportional reductions than minor crashes, highlighting the role of speed control in mitigating crash severity (Pilkington & Kinra, 2005). This study also confirms that the institutional policy-related factors, such as the presence of safety traffic strategies, effective legislation for traffic awareness, and socio-economic factors, play a critical role in enhancing road safety. In Australia, it is also reported that the existence of formal policies related to the enforcement Laws significantly increases the likelihood of higher enforcement compliance (Ebrahim & Nikraz, 2015). Overall, the results emphasize that the effectiveness of the technologies is directly linked with road user awareness, driving habits, and socio-demographic characteristics. The drivers who demonstrated a lower level of awareness are more likely to exceed the posted limits both in the presence and absence of the cameras. The negative relationship between speeding and awareness reaffirms this pattern of behavior, showing that awareness must remain an essential factor to achieve improvements in driving behaviors. Despite its contribution, this study is subject to limitations related to its reliance on stated preference survey data and its focus on a single urban corridor. Behavioral responses may vary across locations and over time as drivers adapt to enforcement with the passage of time. Overall findings suggest that smart traffic cameras contribute positively to speed reduction and safety improvements, but full potential can only be realized through the education of drivers, optimization of camera placements, and integration of broader traffic management strategies. Further studies may explore this area by incorporating real-time speed data, extending analysis to other corridors with mixed traffic conditions, and evaluating the combined impact of enforcement, engineering, and education interventions.

6. CONCLUSIONS

Traffic safety is a critical concern for urban planners, transportation engineers, and policymakers. The implementation of the intelligent transportation system (ITS) has become a common practice to enhance traffic safety through various technologies (Anwer et al., 2022). Usual practices involve the deployment of advanced technology such as speed cameras, sensors, and communication systems to monitor and manage the traffic flow effectively (Anwer et al., 2024). Technologies play a crucial role in creating a safer road environment and reducing the likelihood of accidents. The results of this research indicated a significant impact of the ITS, particularly the speed enforcement cameras, on drivers' behavior.

This study underscores the statistically significant role of speed enforcement cameras in reducing speeding behavior and enhancing road safety, contingent on public acceptance shaped by awareness and transparency. Future advancements require integrated data-sharing frameworks and cross-institutional collaboration to optimize enforcement efficacy and public trust. Although the findings are encouraging, the study is limited by the scope of the data analyzed and the potential influence of confounding variables. Future research should incorporate broader datasets and account for additional influencing factors to enhance the robustness of the results. For future research and recommendations, a comprehensive model integrating enforcement strategies, speeding behavior, public compliance, violation frequency, and socioeconomic variables should be developed. Additionally, a detailed cost-benefit analysis can be conducted to evaluate the economic viability and limitations of speed-reduction interventions in urban settings.

REFERENCES

Anwer, I., & Yousuf, M. I. (2022). Mapping Undermined Role of Information and Communication Technologies in Floods. *Transport and Telecommunication, 23*(2), 168-179. https://doi.org/10.2478/ttj-2022-0015

Anwer, I., Yousuf, M. I., & Grant-Muller, S. (2024). Evaluation of Barriers to Deployment of Information and Communication Technologies to Sustain Information and Communication Flow in Floods. *Applied Sciences, 14*(2), 592. https://doi.org/10.3390/app14020592

Atombo, C., Wu, C., Zhong, M., & Zhang, H. (2016). Investigating the motivational factors influencing drivers intentions to unsafe driving behaviours: Speeding and overtaking violations. *Transportation research part F: traffic psychology and behaviour, 43*, 104-121. 10.1016/j.trf.2016.09.029

Berhanu, Y., Alemayehu, E., & Schröder, D. (2023). Examining Car Accident Prediction Techniques and Road Traffic Congestion: A Comparative Analysis of Road Safety and Prevention of World Challenges in Low-Income and High-Income Countries. *Journal of Advanced Transportation, 2023*(1), 6643412. https://doi.org/10.1155/2023/6643412

Boparai, J. K., Singh, S., & Kathuria, P. (2018). How to design and validate a questionnaire: a guide. *Current clinical pharmacology*, 13(4), 210-215. DOI: 10.2174/1574884713666180807151328

Brown, J. D. (2002). The Cronbach alpha reliability estimate. *JALT Testing & Evaluation SIG Newsletter, 6*(1).

Cai, Q., Abdel-Aty, M., Mahmoud, N., Ugan, J., & Ma'en, M. (2021). Developing a grouped random parameter beta model to analyze drivers' speeding behavior on urban and suburban arterials with probe speed data. *Accident Analysis & Prevention, 161*, 106386. 10.1016/j.aap.2021.106386

Castillo-Manzano, J. I., Castro-Nuño, M., López-Valpuesta, L., & Pedregal, D. J. (2019). From legislation to compliance: The power of traffic law enforcement for the case study of Spain. *Transport Policy, 75*, 1-9. https://doi.org/10.1016/j.tranpol.2018.12.009

Chen, G., & Warburton, R. N. (2006). Do speed cameras produce net benefits? Evidence from British Columbia, Canada. *Journal of Policy Analysis and Management: The Journal of the Association for Public Policy Analysis and Management, 25*(3), 661-678. https://doi.org/10.1002/pam.20196

de la Santé, O. M. (2020). World health statistics 2020: monitoring health for the SDGs, sustainable development goals. *Geneva: World Health Organization. Licence: CC BY-NC-SA*.

Durrani, M., Waseem, H., Bhatti, J. A., Razzak, J. A., & Naseer, R. (2012). Associations of traffic safety attitudes and ticket fixing behaviours with the crash history of Pakistani drivers. *International journal of injury control and safety promotion, 19*(4), 351-356. DOI: 10.1080/17457300.2011.635207

Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal, 5*(6), 00149. DOI: 10.15406/bbij.2017.05.00149

Floreskul, V., Žardeckaitė-Matulaitienė, K., Endriulaitienė, A., & Šeibokaitė, L. (2016). Effectiveness of pre-driver education programme for high school students: Application of Theory of Planned Behaviour on road risk taking behaviour. *Journal of Behavior, Health & Social Issues, 8*(1), 8-16. DOI: 10.1016/j.jbhsi.2017.08.003

Goel, R. (2021). A new model to estimate pedestrian deaths from speed-related interventions. *Traffic Injury Prevention, 22*(4), 330-335. https://doi.org/10.1080/15389588.2021.1908544

Han, J.-Y., Kwon, J.-H., Lee, S., Lee, K.-C., & Kim, H.-J. (2023). Experimental evaluation of tire tread wear detection using machine learning in real-road driving conditions. *IEEE Access,* 11, 32996-33004. doi: 10.1109/ACCESS.2023.3263727

He, J., King, M., Watson, B., Rakotonirainy, A., & Fleiter, J. (2013). Speed enforcement in China: National, provincial and city initiatives and their success. *Accident Analysis & Prevention, 50*, 282-288. DOI: 10.1016/j.aap.2012.04.017

Høye, A. (2020). Speeding and impaired driving in fatal crashes—Results from in-depth investigations. *Traffic Injury Prevention, 21*(7), 425-430. https://doi.org/10.1080/15389588.2020.1775822

Hung, Y. C., Bababekov, Y. J., Stapleton, S. M., Mukhopadhyay, S., Huang, S.-L., Briggs, S. M., & Chang, D. C. (2018). Reducing road traffic deaths: where should we focus global health initiatives? *Journal of surgical research, 229*, 337-344. https://doi.org/10.1016/j.jss.2018.04.036

Javid, M. A., & Al-Hashimi, A. R. (2020). Significance of attitudes, passion and cultural factors in driver's speeding behavior in Oman: Application of theory of planned behavior. *International journal of injury control and safety promotion*, *27*(2), 172-180. https://doi.org/10.1080/17457300.2019.1695632

Javid, M. A., & Al-Roushdi, A. F. A. (2019). Causal factors of driver's speeding behaviour, a case study in Oman: Role of norms, personality, and exposure aspects. *International Journal of Civil Engineering*, 17(9), 1409-1419. https://doi.org/10.1007/s40999-019-00403-8

Javid, M. A., Ali, N., Abdullah, M., & Shah, S. A. H. (2021). Integrating the Norm Activation Model (NAM) theory in explaining factors affecting drivers' speeding behaviour in Lahore. *KSCE Journal of Civil Engineering, 25*(7), 2701-2712. https://doi.org/10.1007/s12205-021-1289-x

Kanitpong, K., Jiwattanakulpaisarn, P., & Yaktawong, W. (2013). Speed management strategies and drivers' attitudes in Thailand. *IATSS Research*, *37*(1), 39-48. https://doi.org/10.1016/j.iatssr.2012.12.002

Kim, J., & Kwan, M. P. (2019). Beyond commuting: Ignoring individuals' activity-travel patterns may lead to inaccurate assessments of their exposure to traffic congestion. *International journal of environmental research and public health*, 16(1), 89. https://doi.org/10.3390/ijerph16010089

Kong, X., Das, S., Jha, K., & Zhang, Y. (2020). Understanding speeding behavior from naturalistic driving data: Applying classification based association rule mining. *Accident Analysis & Prevention*, *144*, 105620. DOI: 10.1016/j.aap.2020.105620

Lucidi, F., Girelli, L., Chirico, A., Alivernini, F., Cozzolino, M., Violani, C., & Mallia, L. (2019). Personality traits and attitudes toward traffic safety predict risky behavior across young, adult, and older drivers. *Frontiers in psychology*, 10, 536. DOI: 10.3389/fpsyg.2019.00536

Martínez-Ruíz, D. M., Fandiño-Losada, A., de Leon, A. P., Arango-Londoño, D., Mateus, J. C., Jaramillo-Molina, C., Bonilla-Escobar, F. J., Vivas, H., Vanlaar, W., & Gutiérrez-Martínez, M. I. (2019). Impact evaluation of camera enforcement for traffic violations in Cali, Colombia, 2008–2014. *Accident Analysis & Prevention*, 125, 267-274. DOI: 10.1016/j.aap.2019.02.002

Perez, M. A., Sears, E., Valente, J. T., Huang, W., & Sudweeks, J. (2021). Factors modifying the likelihood of speeding behaviors based on naturalistic driving data. *Accident Analysis & Prevention*, 159, 106267. DOI: 10.1016/j.aap.2021.106267

Pervez, A., Lee, J., & Huang, H. (2021). Identifying factors contributing to the motorcycle crash severity in Pakistan. *Journal of Advanced Transportation*, 2021(1), 6636130. https://doi.org/10.1155/2021/6636130

Rezapour, M., Wulff, S. S., & Ksaibati, K. (2018). Effectiveness of enforcement resources in the highway patrol in reducing fatality rates. *IATSS Research*, *42*(4), 259-264. https://doi.org/10.1016/j.iatssr.2018.04.001

Roopa, S., & Rani, M. S. (2012). Questionnaire designing for a survey. *Journal of Indian Orthodontic Society*, 46(4_suppl1), 273-277.

Sameen, M. I., & Pradhan, B. (2017). Severity prediction of traffic accidents with recurrent neural networks. *Applied Sciences,* 7(6), 476. https://doi.org/10.3390/app7060476

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of psychological research online, 8*(2), 23-74.

Sheykhfard, A., Haghighi, F., Saeidi, S., SafariTaherkhani, M., & Das, S. (2024). Understanding the influence of environmental factors on driver speed: A structural equation modeling analysis. *IATSS Research*, 48(3), 427-439. https://doi.org/10.1016/j.iatssr.2024.08.001

Thao, V. T. P., Giang, D. T., & Anh, L. V. (2024). Reliability assessment of land subsidence monitoring results using PSI technique in Ho Chi Minh City, Vietnam. *International Journal of Environmental Studies*, 81(2), 881-895. https://doi.org/10.1080/00207233.2024.2324623

Wali, B., Ahmed, A., Iqbal, S., & Hussain, A. (2017). Effectiveness of enforcement levels of speed limit and drink driving laws and associated factors–Exploratory empirical analysis using a bivariate ordered probit model. *Journal of traffic and transportation engineering (English edition)*, 4(3), 272-279. https://doi.org/10.1016/j.jtte.2017.04.001

Wanberg, K. W., Timken, D. S., & Milkman, H. B. (2010). Driving With Care: Education and Treatment of the Underage Impaired Driving Offender: An Adjunct Provider's Guide to Driving With Care: Education and Treatment of the Impaired Driving Offender--Strategies for Responsible Living and Change: Sage.

Yu, Y., Tang, X., Yao, H., Yi, X., & Li, Z. (2019). Citywide traffic volume inference with surveillance camera records. *IEEE Transactions on Big Data,* 7(6), 900-912. DOI: 10.1109/TBDATA.2019.2935057

Pilkington, P., & Kinra, S. (2005). Effectiveness of speed cameras in preventing road traffic collisions and related casualties: Systematic review. In Database of Abstracts of Reviews of Effects (DARE): Quality-assessed Reviews. Centre for Reviews and Dissemination (UK).

Ebrahim, Z., & Nikraz, H. (2012). Examining attitudes towards safe speed to protect pedestrians. *International Journal of Transportation Science and Technology, 1*(4), 319–333. https://doi.org/10.1260/2046-0430.1.4.319