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Analysis of traffic rule violations among bike riders. A structural equation model

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Abstract

Bikes are becoming an increasingly popular and reliable mode of transportation in developing countries because of their efficiency and ability to navigate through rough terrain and narrow roadways. Bikes are more vulnerable to road accidents and their riders' safety is the main concern at present days. Hence, it is essential to reduce the possibility of accidents caused by bike riders. The main reason for bike accidents is bike rider behaviours in the form of traffic rules violations. The paper's main aim is to categorize the importance of seven attributes on traffic rules violations, including bike rider behaviours, road features, ambient conditions, driving skills, type of license, bike age/tenure and riding without a safety device (helmet). Bike riders' violations that can lead to an accident and the impact of attributes have been analyzed using the structural equation modelling (SEM) technique. To analyze these attributes, 450 bike riders have been interviewed in Bhubaneswar, India. It has been concluded that bike rider behaviours are the most significant attribute of violations. Since most bike riders are young, with low income and education, paying more attention to their training and education before issuing a driving license is necessary. In addition, those who do not use safety devices (helmets) are more susceptible to committing violations. This relates to the lack of enough control and enforcement in developing cities. Also, it shows that the current traffic fines for not using safety devices (helmets) are not enforced enough. Finally, considering this research's outcomes can help minimize traffic rules violations among bike riders, which is a step towards safer roads.

Keywords: *traffic rules violations, SEM, bike rider safety, attributes*

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1. Introduction

Road traffic safety refers to the measures everyone must adopt while using roads. These safety methods are meant to reduce the risk of road accidents and injuries or causalities. Traffic safety is one of the most challenging issues worldwide. Based on the latest report of the World Health Organization (WHO) on road safety, about 1.35 million people have been killed by traffic accidents [59]. According to this report, bikes were involved in 28% of all road traffic accidents. The bike's problems include moving on two wheels can make the balance difficult, lacking protection for the riders and it is lighter than other vehicles [36, 62]. Indeed, bikes have inherent vulnerability and risk exposure. Thus, the probability and severity of bike accidents can be higher than in other vehicles. [11, 19, 23].

Traditionally, traffic accidents have been associated with human, road, environmental and vehicle factors [9, 29]. Human behaviour has been reported as the main contributing factor in 95% of bike accidents by Petridou and Moustaki [44], and Sheykhfard et al. [48]. Three types of wrong human behaviours are errors, lapses and violations, which can lead to bike crashes [52]. Errors and lapses are unintentional actions [1], and they are less likely to influence driving safety [52]. Traffic rules violations are considered deviations from governmental regulations that disobedience of them can harm the safety of drivers [45, 52]. Therefore, they must be considered in traffic safety studies.

Concerned about the increasing number of road accidents in Bhubaneswar, which shot up to about 4790 in 2017 from 4463 in 2016, the Commissionerate police launched on April 28 a year-long campaign to sensitise people about the five golden rules of road safety. The campaign, launched as part of the 29th Road Safety Week celebrations, aims to make people aware that it is the worst thing to die needlessly in a road accident – just because of overspeeding, driving under the influence of intoxicants, and not wearing helmets and seat belts. Understanding that the modification and improvement of road users' behaviour take time, the traffic department has designed this campaign for a year to bring in a culture of compliance with road safety rules to make the roads safer. As Bhubaneswar is a smart city and bikes are the predominant vehicles, it motivates authors to reduce and find the root cause of accidents.

The current study analyses bike riders' violations that can lead to an accident using the structural equation modelling (SEM) technique. This analysis leads to a better assessment of the model compared to traditional approaches such as regression analysis. One of the advantages of SEM is that it combines factor analysis and regression analysis, leading to a concise analysis that controls the relationship between two variables (i.e., observed and latent) [48].

The goal of this research is to examine seven attributes of traffic rules violations, including bike rider behaviours, road features, ambient conditions, driving skills, type of license, riding without a safety device (helmet), and bike age/tenure. Furthermore, the variety of violations along with their frequency of repetition was investigated, and the impact of different types of aforementioned factors on traffic rules violation was assessed as well.

2. Literature review

Traffic rules violations can contribute to both probability and severity of bike accidents [31, 39]. Cheng et al. [12] introduced violation behaviours as predictors of involvement in bike accidents. They found that bike riders with aggressive and violent behaviours are expected to be involved in crashes more than others. To highlight these behaviours, it is necessary to identify the factors that significantly impact violation occurrence to improve bike riders' safety.

Araujo et al. [6] concluded that it is necessary to pay more attention to the laws and to strengthen regulations for penalties at the time of violations to promote safety. Dandona et al. [14] also emphasized the impact of law enforcement on reducing bike riders' violations and safety promotion. In a study by

Skalkidou et al. [51], other reasons pertinent to not wearing a helmet have been listed as nighttime, weekend days, men, warm weather and moving at low speed. Suteja et al. [54] studied the factors that can affect traffic violations among student bike riders. The results indicated that the behaviour of bike riders consists of discipline in riding, driving skill, emotion level, knowledge of riding and fatigue during riding has a significant impact on traffic rule violations among students. Cheng et al. [12] indicated that there is a relationship between risk perception and bike violations. Those bike riders with aggressive and driving violation behaviours also have a lower risk perception. Wang et al. [58] evaluated the bike violation behaviour at intersections in China. They found that the frequency and severity of conflicts at the intersections for bike riders with more violation behaviours were greater. In addition, environmental conditions have more influence on bike violations than vehicle or bike rider behaviours. Joewono et al. [24] investigated the effective factors on violation behaviour among young bike riders in Indonesia. They found that bike riders' attitudes and the road environment were the main factors for traffic rules violations. Maghsoudi et al. [32] concentrated on the reasons for not wearing a helmet among bike riders in Iran. They found that socio-cultural factors, bike riders' standpoints toward fatalism and helmet-related problems are the main reasons that prevented them from wearing a helmet.

Bikes are a popular mode of transportation for intracity trips in developing societies [24, 33]. Statistics indicate that about 93% of road traffic deaths are related to low-income and middle-income countries, even though they have 60% of the total vehicles. Moreover, developing countries have distinct differences from developed countries in bike riders' behaviour and specification of the infrastructures [24, 25, 43]. To address the differences between these countries, it is vital to conduct specific studies concerning bike safety.

In India, there are about 37 million registered bikes which is the largest in the world. About 54% of road traffic fatalities were related to bike riders and are the most vulnerable category in line with global trends, according to the ministry report. It is essential to understand the contributing factors for bike riders' violations to provide interventions. Understanding these violations and their reasons is expected to promote bike riders' safety.(Ministry of Statistics and Programme Implementation-2021 http://mospi.nic.in/)

This data article examines the association between age, knowledge of traffic rules, risk perception, risky and positive behaviours on the road and traffic safety outcomes of cyclists. Data were collected using a structured self-administrable and online-based questionnaire, applied to a full sample of 1064 cyclists. The data contains 4 parts: descriptive statistics; graphical trends for each study variable according to age; Post-Hoc (Tukey-HSD) comparisons between cyclists classified in the different age groups; and, finally, the dataset for further explorations in this regard [57].

This study aimed at analyzing the cycling safety-related factors and the mental health indicators of elderly cyclists in comparison with other age groups. For this cross-sectional study, we analyzed the data of 911 bicyclists from two Latin American countries that have been experiencing substantial growth in urban cycling during the last few years: Colombia and Argentina. Participants responded to an e-questionnaire on bicycling behaviours, mental health and cycling safety. Results on aging adults reported lower rates of risky behaviours and traffic crashes (around 0.38 in five years), and, on the other hand, more cycling protective behaviours, higher risk perception and a better knowledge of traffic norms than both other adults (26–50 years old) and young cyclists. Cycling behaviours and crashes were found to be significantly related to mental health indicators, the latter being higher in ageing cyclists. However, this population remains more prone to distractions experienced while cycling than other age groups [57].

3. Methodology

Structural equation modelling (SEM) is a multivariate statistical analysis technique that is used to analyze structural relationships. This technique is a combination of factor analysis and multiple regression analysis, and it is used to analyze the structural relationship between measured variables and indirectly observed(latent) variables. SEM is composed of two models (1) the measurement model and (2) the structural model. The measurement model is defined as the relationship between latent and observed models. The structural model is focused on the relation of latent variables or between latent and observed indicators [30, 60, 50].

Latent variables and observed indicators are fundamental concepts in statistical analysis, especially the discussion of factor analysis and SEM. Latent variables are variables that are not directly measurable and need to be studied. In this regard, researchers use observed measures or items that form the questions of the questionnaire to measure latent variables.

In this study, SEM was applied to evaluate the impact of the variables on the frequency and variety of dangerous violations committed by bike riders. Models in the SEM approach can be tested against the data as a conceptual or theoretical model and can be assessed for a fit of the sample data [10, 30]. These attributes have made SEM popular in different fields, such as psychology, economics and engineering [4, 16]. Besides, a variety of scopes in transportation, including autonomous vehicles, public transport, mobility sharing, safety sciences and road user attitude have already used the SEM technique [15, 21, 24].

Multiple endogenous and exogenous variables can participate in the model simultaneously [44, 42]. Endogenous variables could be determined by the model, whereas exogenous variables are known before solving SEM. Endogenous variables would be determined based on their relationships with exogenous variables and interactions between endogenous variables.

3.1. SEM model and attributes

Seven attributes relating to bike rider behaviour, road features, ambient conditions, driving skills, type of license, riding without a safety device (helmet), and bike age/tenure were considered in the model. The latent and observed exogenous and endogenous indicators are in Table 1.

It is intended to evaluate the impact of bike rider behaviour, road features, ambient conditions, driving skills, type of license, riding without a safety device (helmet), and bike age/tenure on violations of bike riders. For traffic violations, the frequency and variety of them were vital. Indeed, those bike riders who commit various violations, have more potential for being involved in a crash. In addition, those with a high frequency of dangerous violations again have the potential for crash occurrence. It should be mentioned that it was tried to consider just those violations that are dangerous. For bike rider behaviour, different papers in the field of traffic safety have introduced similar parameters such as age, income, gender, education level, driving license, and bike ownership for drivers or bike riders [14, 24, 30]. There are papers, which highlight the role of drivers' and bike riders' experience and previous training on violations and crashes [14, 38, 47] and such that deal with road features and their impact on traffic violations and crashes [24, 30, 34]. Joewono et al. [25], Lee et al. [30], Pai et al. [37] researched the role of weather conditions and pillion passengers in violations of bike riders and traffic crashes. For bike riders as another variable in the model, we wanted to know if those who have new bike riders commit more violations than others or not. Overall, the authors have studied many research papers in the field of traffic safety, and traffic violations and the emphasis was laid on bike riders.

Here, we have tried to use confirmatory factor analysis (CFA). CFA is used when we do have a priori hypotheses about which items or variables are grouped as manifestations of an underlying construct and wish to test how well our data match or fit this model. CFA is used to test whether measures of a construct are consistent with a researcher's understanding of the nature of that construct (or factor). As such, the objective of CFA is to test whether the data fit a hypothesized structural model. The main contribution of the article is proposing the conceptual SEM model as presented in Figure 1.

The attributes have been categorized below for modelling. This process is called data transformation by discretization in data mining. For this purpose, a continuous attribute like age would be divided into intervals. Labels then can be used to replace actual data values.

Table 1. Indicator attributes for the measurement model and latent attributes in the structure model

Attribute	Symbol	Type	Attribute	Type	Symbol
Male	BRB 1	observed exogenous	bike rider's behaviour	latent exogenous	BRB
Female	BRB 2				
Income	BRB 3				
Having driving license	BRB 4				
Life satisfaction	BRB 5				
Age	BRB 6				
Education	BRB 7				
Amount of previous training	DS 1		driving skill		DS
Amount of riding experience	DS 2				
Frequency of received fines in the recent year	WH 1		riding without helmet		WH
Number of accidents in the recent three years	WH 2				
Valid driving license	TL 1		type of license		TL
Without a valid driving license	TL 2				
Weather condition	AC 1		ambient condition		AC
Lighting condition	AC 2				
Traffic violation control	RF 1		road features		RF
Traffic congestion	RF 2				
Bike age	BA 1		bike age		BA
Number of violations in each scenario	VF 1		violation factor		VF
Variety of violations in each scenario	VF 2				

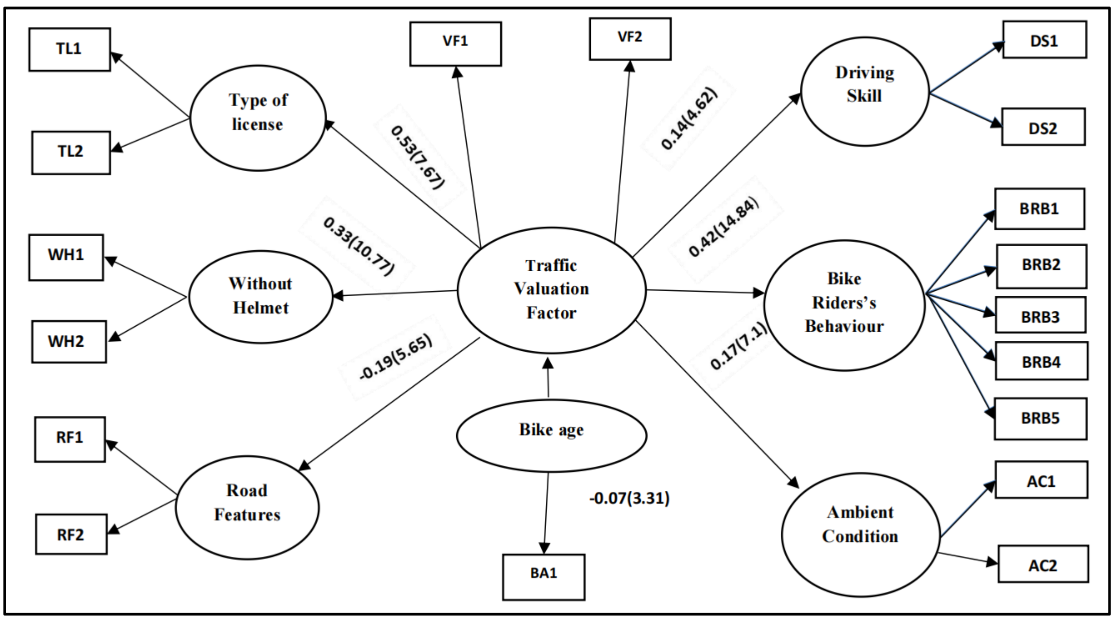

Figure 1. SEM violation factor

For ordinal variables such as education also we can use numbers as labels to insert them into a mathematical model [20, 61, 53].

- Gender is categorized as male/female.
- Income is an ordinal variable with categories of less than 1 lakh,1–1.5 lakh,1.6–2.0 lakh, 2.1–2.5 lakh, 2.6–3.0 lakh, and more than 3.0 lakh rupees.

- Life satisfaction is an ordinal variable with categories of very low, low, medium, high and very high.
- Age is an ordinal variable with categories of 18–25, 26–33, 34–41, 42–49, and more than 50-year old.
- Qualification level is an ordinal variable with categories of matriculation, intermediate, graduation and post-graduation.
- The amount of previous training is an ordinal variable with categories of very little, little, medium, much, and very much.
- The amount of driving experience is an ordinal variable with categories of less than 20, 20–30, 30–40 and more than 40 min per day.
- The frequency of accidents in the recent five years and fines due to the non-use of safety devices in recent years are ordinal variables. The bike riders were asked to announce the frequency of previous considerable crashes when riding bikes. We have explained to them that the prominent crashes are those, which have led to injury and property damage of more than 10 000 rupees.
- Type of driving license was categorized as-valid driving license and without a valid license. The type of license was asked generally to determine the violation type and frequency.
- The weather condition was categorized into three levels such as hot, warm and cold.
- The lighting condition was categorized into three levels such as low, medium and high.
- Traffic violation control was categorized into three levels such as little, moderate and much.
- Traffic congestion was categorized into three levels such as jam, heavy and light.

For our modelling, the latent endogenous variable is the violation factor. Observed endogenous indicators are the number of violations and the variety of violations.

There are two main approaches to solving SEM models: Covariance-based SEM (CB-SEM) and Partial Least Squares (PLS-SEM) by analyzing the variance.CB-SEMand PLS-SEM uses different approaches when assessing the quality of a structural model. For example, CB-SEM fit is based on accurately estimating the observed covariance matrix, while PLS-SEM fit is based upon accounting for explained variance in the endogenous constructs [18, 53. For CB-SEM, software packages such as AMOS, EQS, LISREL and MPlus can be used. For the PLS approach, packages like ADANCO, PLS-Graph, ViualPLS, SmartPLS and WarpPLS are available. PLS has several advantages, including no need for assumption for data distribution, no limitations about the number of observed indicators per latent variables, no need for observations to be independent, and its ability to solve large and complex models using a small sample size [60, 25]. In the present article, we utilized SmartPLs for the SEM model. SmartPLS can deal with binary and ordinal variables [17]). However, it is necessary to change the categories from qualitative to quantitative formats. Namely, an ordinal scale is needed to be assigned to the responses to the questions. For this purpose, for each ordinal variable based on the categories presented above, numbers starting from 1 are considered. For the binary variable, also 1 is considered for having no license and 2 for having a bike driving license [4, 24, 28].

3.2. Questionnaire process

In the current study, 450 bike riders have been interviewed in Bhubaneswar. Samples were selected randomly in different areas of the city and from different groups of people. The total sample size to be surveyed is determined by [26]

$$n >= N\left[1+\frac{N-1}{pq}\left(\frac{d}{Z_{\alpha/2}}\right)^2\right]^{-1} \qquad (1)$$

where *n* is the sample size, number of bike riders for data collection, *N* population size, number of bike riders in Bhubaneswar, 17 942, *Z* is 1.96 for 95% confidence level, *p*, *q* the quality characteristics which are to be measured. When no previous experience exists, *p* is taken as 0.5 and $q = 1 - p = 0.5$, *d* is the desired level of precision and is considered 5%.

Table 2 presents some socio-economic details about Bhubaneswar. However, it should be mentioned that bike riders are a specific group of people. Typically, young people use a bike for recreational purposes.

Table 2. Socio-economic data for Bhubaneswar
(Ministry of Statistics and Programme Implementation, 2021, http://mospi.nic.in/)

	Category	Relative frequency
Variable age (years)	18–25	35.2
	26–33	16.4
	34–41	20.1
	42–49	18.1
	>50	10.2
Qualification	matriculation	26.4
	intermediate	55.3
	graduation	13.2
	post graduation	5.1
Employment rate	employed	88.2
	unemployed	11.8
Annual income (Rupees in lakhs)	<1	
	1–1.5	
	1.6–2.0	
	2.1–2.5	
	2.6–3.0	
	>3	

For income, no valid statistics were found. The average income is about 1.3 lakhs.

A comparison between the socio-economic data of Bhubaneswar in Table 2 and surveyed bike riders in this city can be made. There is a relatively high similarity between the distribution of ages in the city and surveyed people. Nevertheless, for qualification, there is a great difference between the citizen distribution and surveyed people. Most bike riders now use this vehicle for the delivery of food or other products and services. Those citizens with high incomes and qualification levels use this vehicle rarely, especially because of social attitudes. Thus, overall it is hard to say that there must be a proportion between the socio-demographics of the city and our samples.

To have samples, which are representative of each part of the city, Bhubaneswar is first divided into 67 wards. In each ward, the socioeconomic condition of citizens, specification of streets and buildings and land use are relatively similar throughout the ward. Then for each ward, by multiplying the per cent of bike riders by 450, the number of samples is determined. Official statistics regarding the number of bike riders in each ward are not available; thus, in three workdays for 5 h, the number of bike riders is determined in different streets of each ward. In this way, an estimation of the number of bike riders in each ward could be extracted.

The data for the assessment of the proposed model was provided by a detailed survey form and interviews with bike riders in Bhubaneswar. We have done interviews conducted by several experts in the field of transportation safety from October to November 2020 by taking protocols for COVID-19.

They explained the necessary details for bike riders before and during the interview process. It was tried to clarify the meaning of each question for the respondents as much as possible. The respondents were asked to feel free to ask any question if they think that there are ambiguities about our questions. A friendly and trustful atmosphere during the interview was made. We have emphasized that the results are secret without any names and just they would be used for research and development purposes, and at the same time, their responses are precious to us. We gave them a code and told them several prizes would be given to several respondents by draw to increase their motivation to devote enough time. During the interview, also several questions were repeated in different formats to see how much they were honest in answering previous questions.

In the survey form, the first questions were about the bike riders' behaviour, bike age/tenure, safety device (helmet) and skills of bike riders, as mentioned in Table 1. Afterwards, different scenarios were constructed based on the changes in ambient conditions, road features and type of license. In each scenario, the types and frequencies of the violations that the bike riders have committed in a recent year were asked in the questionnaire.

In this research, just those violations that had been identified by the police officer as contributors to severe accidents were considered. These violations consist of speeding and street racing, no helmet, wrong-way riding, sidewalk riding, disobeying traffic signs and signals, driving against traffic flow, pushing bike riders between vehicle lanes, sudden turning movement without signalling, smoking, eating, drinking or using mobile while riding. The 5-point scale was used for the frequency of engagement in each violation (1 – never, 2 – rarely, 3 – occasionally, 4 – frequently, 5 –nearly all the times). The average of committed violations has been inserted for each record. Thus, the range of the variety of committed violations is between 0 and 9, and frequencies are between 1 and 5.

Respondents belong to different age groups ranging from 18 to 50 and more, and they have been divided into five age groups. About 56% of respondents had a qualification of intermediate. More than 40% of respondents indicated that they spend more than an hour a day riding a bike.

In this article, as stated data collection was done by interviewing bike riders, and it was tried to have an answer for most of the questions. However, there were some questions for a few respondents, without any answers because of privacy concerns or other reasons. For these cases, the answer was found based on the responses to see other questions and by checking the answers for this question for other respondents with similar characteristics. For example, we did not have the answer for the income of a bike rider. Then, we checked his/her age, education and satisfaction in life. Then for those respondents with the same age, qualification and satisfaction, the average income is determined and reported as the income for the missing data [20].

4. Results and discussion

Considering the guidelines of Hair et al. [18], all latent variables were studied for the reliability and validity of constructs, convergent validity and discriminant validity. Reliability deals with the consistency or stability of measurements and validity relate to the suitability or meaningfulness of the measurements. To evaluate the reliability of the measurement model, its internal consistency of it must be determined. Internal consistency is a general term used for estimating the reliability of a measure by evaluating the within-scale consistency of the responses to the items of the measure. Cronbach Alpha and composite reliability coefficient are applied for this purpose. The closer this coefficient is to 1, the higher reliability is reported by Bacon et al. [7] and Peterson and Kim [20]. Typically, values greater than 0.7 are considered acceptable for Cronbach Alpha and composite reliability coefficient.

The validity of the measurement model is determined with convergent validity. The average variance extracted (AVE) would be applied as the convergent validity index. AVE measures the extent of the latent variable's explanation by its observed indicators. AVE should be greater than 0.5 to be acceptable [8, 13]).

Another form of validity, which must be controlled in SEM, is discriminant validity. To establish discriminant validity, it is necessary to show the measures that should not be related, and, in reality, are not related. In this research, discriminate validity by cross-loading is applied, which means that the correlation between measures of each construct must be checked with that construct and with other constructs. Furthermore, the correlations between measures of each construct and that construction must be close to 1. Correspondingly, the correlations between measures of different constructs should be close to 0.

4.1. Structural equation model of bike rider's violation

To test the research hypotheses, an SEM model is constructed, as presented in Figure 1. The model is run by Smart PLS, and the input data are those, which have been collected by field interviews in Bhubaneswar. In this article, it is hypothesized that all seven attributes modelled in the SEM technique have a significant impact on the frequency and diversity of violations among bike riders. In Figure 1, two numbers can be seen on each arrow. The ones in the parentheses are *t*-values, and the others are standard coefficients for each variable.

4.2. Model assessment

As shown in Figure 1, all *t*-values (values in parentheses) are greater than 1.96, indicating that all latent exogenous variables have a significant impact on the violation factor (significant at 0.5 level). The factor loadings and significance of each observed indicator have also been checked for reliability. High factor loadings on a construct are signs of observed indicators having much in common with latent variables, which is captured by the construct.

Table 3. Loading factors and t-values for observed indicators

Latent variable	Observed indicators	Factor loading	*t*-value
Bike rider's behaviour	Male (BRB1)	0.49	4.20
	Female (BRB2)	0.95	212.46
	Income (BRB3)	0.48	7.59
	Having a driving license (BRB 4)	0.55	7.99
	Life satisfaction (BRB 5)	0.51	7.10
	Age (BRB 6)	0.76	22.95
	Qualification (BRB 7)	0.51	5.82
Driving skill	Amount of previous training (DS1)	0.94	30.12
	Driving time (DS2)	0.56	4.25
Without helmet	Frequency of received fines in the recent year (WE1)	0.98	214.45
	Number of accidents (WE2)	0.96	214.51
Type of license	Valid driving license (TL1)	0.92	46.34
	Without a driving license (TL2)	0.93	47.48
Ambient condition	Weather condition (AC1)	0.85	35.98
	Light condition (AC2)	0.77	25.12
Road features	Traffic violation control (RF1)	0.98	8.12
	Traffic congestion (RF2)	0.98	9.02
Bike age/tenure	Bike age (BA1)	1.00	0.00
Violation factor	Number of violations in each scenario (VF1)	0.95	156.34
	Variety of violations in each scenario (VF2)	0.95	189.21

As a rule of thumb, the latent variable can explain a considerable part of each indicator's variance, normally at least 50%, meaning that an indicator's factor loading should be above 0.708 because that number squared (0.7082) equals 0.50. Factor loadings between 0.4 and 0.7 are also acceptable that are significant at the 0.1 level [18]. Considering Table 3, factor loading and *t*-values of observed indicators are shown.

According to Table 3, factor loadings of most of the observed indicators are above the threshold level of 0.7 and have a significant impact on the violation factor (significant at .05 level), and the rest are above the threshold level of 0.4, showing a significant impact at 0.1 level. Moreover, *t*-values are all above the threshold of 1.96, reflecting that all indicators of latent variables have significant and positive outer weight values.

4.3. Measurement model evaluation

An alternative for assessing the proposed model is to check the latent variables, specifically by Cronbach's alpha. By this method, an estimation of the reliability based on the inter-correlations of the observed indicator variables can result. A specific limitation regarding Cronbach's alpha is its sensitivity to the number of items in the scale, and normally it tends to underestimate the internal consistency reliability. Consequently, it might be used as a more conservative measure of internal consistency reliability. Due to Cronbach's alpha's limitations, applying another measure of internal consistency reliability seems more appropriate. This measure is referred to as composite reliability by Hair et al. [18]. The composite reliability ranges between 0 and 1, with higher values showing higher levels of reliability. Its interpretation is commonly similar to Cronbach's alpha. Reliability values above 0.60 are acceptable and can be regarded as satisfactory, while composite reliability values below 0.60 imply a lack of internal consistency reliability [18].

As previously mentioned, Cronbach's alpha brings about relatively low-reliability values; however, composite reliability overestimates the internal consistency reliability. Thus, the results are higher compared to Cronbach's alpha. Therefore, taking into account both criteria to assess the measures' internal consistency reliability is more sensible. Furthermore, true reliability generally is between Cronbach's alpha and composite reliability [18].

To establish convergent validity on the construct level, AVE is suggested. This criterion is defined as 'the sum of the squared loadings divided by the number of indicators. Values above 0.50 indicate the fact that the construct explains more than half of the variance of its indicators [18]. Cronbach's alpha, composite reliability and AVE of latent variables are presented in Table 4.

Table 4. Validity and reliability of latent variables

Latent variable	Cronbach's alpha	Composite reliability	AVE
Bike rider's behaviour	0.609	0.742	0.612
Driving skill	0.625	0.751	0.623
Without helmet	0.932	0.982	0.951
Type of license	0.775	0.912	0.832
Ambient condition	0.648	0.775	0.652
Road features	0.982	0.992	0.991
Bike age	1	1	1
Violation factor	0.853	0.926	0.876

Based on Table 4, the results of the validity and reliability of latent variables satisfy the mentioned threshold criteria. Furthermore, to evaluate the discriminant validity, the Fornell–Larcker criterion was recommended. Discriminant validity is used to investigate whether a construct is truly distinct from other constructs or not. In the Fornell–Larcker criterion, the square root of the AVE values is compared to the latent variable correlations, and the square root of each construct's AVE must be greater than its highest correlation with any other construct by Hair et al. [18]. Table 5 presents discriminant validity) Fornell –Larcker criterion (of latent variables).

Table 5. Discriminant validity (Fornell–Larcker criterion)

Latent variable	WH	RF	AC	BA	TL	BRB	DS	VF
Without helmet (WH)	**0.975**							
Road features (RF)	–0.038	**0.988**						
Ambient condition (AC)	0.315	–0.144	**0.808**					
Bike age (BA)	–0.048	–0.001	–0.016	**1.000**				
Type of license (TL)	0.255	0.667	0.192	–0.005	**0.908**			
Bike rider's behaviour (BRB)	0.405	–0.023	0.385	0.067	0.291	**0.545**		
Driving skill (DS)	–0.207	0.038	–0.022	–0.125	–0.013	0.035	**0.788**	
Violation factor (VF)	0.654	–0.076	0.524	–0.045	0.355	0.693	–0.185	**0.937**

Table 6. Results of discriminate validity by cross-loading

	DS	BRB	BA	WH	AC	TL	RF	VF
DS1	0.976	0.026	–0.118	–0.199	–0.016	–0.001	0.036	–0.186
DS2	0.532	0.057	–0.088	–0.135	–0.012	–0.047	0.014	–0.045
BRB1	0.034	–0.034	0.000	–0.036	–0.141	0.454	0.995	–0.081
BRB2	0.036	–0.006	–0.006	–0.041	–0.139	0.368	0.984	–0.072
BRB3	–0.085	0.458	0.132	0.192	0.123	0.085	–0.013	0.215
BRB4	0.206	0.447	–0.026	0.064	0.132	0.135	–0.005	0.322
BRB5	0.172	0.382	–0.057	0.105	0.108	0.104	–0.006	0.184
BRB6	–0.185	0.715	0.226	0.407	0.255	0.224	–0.022	0.354
BRB7	0.287	0.326	–0.043	–0.007	0.065	0.025	–0.001	0.097
BA1	–0.125	0.067	1.000	–0.045	–0.014	–0.006	–0.001	–0.046
WH1	–0.214	0.206	–0.055	0.976	0.328	0.255	–0.039	0.664
WH2	–0.156	0.275	0.024	0.581	0.365	0.267	–0.112	0.435
AC1	–0.023	0.324	–0.004	0.297	0.838	0.249	–0.056	0.342
AC2	–0.005	0.305	–0.021	0.204	0.775	0.052	–0.183	0.390
TL1	0.017	0.245	–0.037	0.198	0.165	0.896	0.536	0.304
TL2	–0.031	0.287	0.028	0.263	0.177	0.917	0.574	0.338
RF1	0.035	–0.034	0.000	–0.035	–0.144	0.456	0.996	–0.083
RF2	0.036	–0.006	–0.004	–0.041	–0.136	0.368	0.985	–0.072
VF1	–0.195	0.378	–0.025	0.366	0.279	0.236	–0.034	0.603
VF2	–0.182	0.624	–0.102	0.344	0.214	0.396	–0.036	0.944

According to Table 5, values in bold are greater than other values in each column, indicating the discriminant validity of the variables involved in the proposed measurement models. By Hussain et al. [22], the coefficient of determination or R^2 measures the overall effect size and variance explained in the endogenous construct for the structural model and is thus a measure of the model's predictive accuracy. In this article, R^2 is 0.681. Results above the cutoffs of 0.67, 0.33 and 0.19 can be considered substantial, moderate and weak [13]. Thus, $R^2 = 0.681$ indicates that the model goodness of fit is satisfactory. This means that 7 latent exogenous variables (WH, RF, AC, BA, TL, BRB and DS) substantially explain 68.1% of the variance in VF.

A question might be posed whether BRB can affect WH as well as VF. Similarly, it can be established that DS is affected by the experience, which is affected by age. This might indicate that BRB can also explain DS. To answer this challenge, first, it should be mentioned that by considering DS as a mediator, it is hard to identify the impact of BRB and DS separately on VF. However, there are other statistical reasons, which can persuade us to consider DS and BRB as separate latent exogenous variables in the model. As can be observed in Table 6, the correlation between DS1 and DS2 with BRB is low. This indicates that we could not consider these measures in BRB. For more investigations to check the relationship between the measures considered in BRB with measures of DS, we have done a correlation analysis.

The results indicated that there are low relationships between these variables. It is because a bike is not the same as a passenger car and it is hard to find a relationship between the rider's age and bike experience. For example, there are very young riders with high experience in riding. Recently, due to the increase in fuel prices and economic limitations some people have shifted to the bike. Conversely, although many bike riders in Iran also own a passenger car and usually use the car for daily trips, they sometimes use their bike riders for recreational purposes or during peak hours. The results of discriminate validity by cross-loading are presented in Table 6 to check the correlation between measures of each construct and other constructs. For most of the constructs and measures, the outputs are acceptable.

5. Discussion

The results of SEM indicated that most of the studied factors have a significant impact on the frequency and variety of violations by bike riders. Among all these factors, the most important one was the behaviour of bike riders. Joewono and Susilo[24] stated that younger bike riders have more potential for traffic violations, and they need a behavioural change policy. The second most important factor affecting the frequency and variety of violations of bike riders is riding without a safety device (helmet). This indicates that people riding without safety devices (helmets) in their driving history commit more violations. Other studies also confirm this relationship between bike riders' accident experiences and committing traffic violations [12, 31]. The present results confirm this observation. Moreover, the majority of our respondents have not been fined since 2020 and it can be concluded that the main reason is the lack of powerful traffic enforcement in India. As a result, bike riders keep committing violations and no law enforcement is observed. Previous literature also emphasized the role of traffic enforcement in shaping the driver behaviour of bike riders [24, 25].

Lack of safety devices (helmets), unfortunately, has become an effect of traffic violations, especially among young riders with low qualification levels. This has two main reasons; first of all, the fines are not discouraging for young riders and those with low qualification levels in India. There are a group of people with no or low frequency of traffic violations; conversely, there are riders who violate traffic laws frequently. Because of some social and economic reasons, the amount of traffic fines in India is not as high as in other countries. In addition, less control is existing over bikes and strict enforcement is not established for bike riders who violate the traffic rules in India. The second reason relates to a sense of experiencing dangerous situations and a reduction of anxiety about the same situations in the future. A group of young riders who have had the experience of riding without safety devices show more audacity. This case is more evident, especially among those who have experienced fewer severe accidents. Sagberg and Ingebrigtsen [46] evaluated two hypotheses about the impact of previous penalty points of drivers on the probability of receiving new penalty points. Their analyses indicated that the relationship between the number of penalty points in a year and the number of received penalty points in the subsequent year is in the form of an inverse U.

This means that those who have committed traffic violations previously have the potential to do new violations. However, when they are at risk of losing their driving license or a severe danger, they would commit fewer violations than the previous year [46].

Valid driving licenses had a significant impact on the frequency and variety of violations of bike riders. Most bike riders do not wear helmets in India [32]. Besides, a significant part of bike riders in India has turned to bike courier services due to the country's economic problems. Bike couriers try to deliver the service (e.g., usual food) as quickly as possible to the consumer so that they can get to the next service right away. This situation leads to committing various violations and repeating them regularly due to a lack of traffic violation control. Road features and ambient conditions have shown less impact on the frequency and variety of bike riders' violations than other factors. This shows that bike riders' violations are less dependent on road features and weather conditions. They are related to a lack of traffic violation control as well as their habits and behaviours. Traditional and modern strategies can help to diminish these shortcomings.

A traditional method of controlling these violations is traffic enforcement. Moreover, to minimize these traffic violations and accidents, parallel to the preventive regulations that are more common in developing countries, qualification can play an essential role to change bike riders' habits, behaviours and perceived risk of accidents. Previously, Maghsoudi et al. [32] emphasized providing programs for young bike riders to reduce their risky behaviours and especially not using helmets during riding bikes. Truong et al. [55] stated that perceiving the consequences of accidents can reduce the probability of risky behaviours among bike riders. Informing bike riders about the consequences of accidents with heavy vehicles has been introduced as an effective approach to reducing (2021) bike accident severity [28]. Education and training programs can be an appropriate opportunity to present such items to bike riders. Innovative methods that can be used to train bike riders and study their behaviours include developing virtual learning environments using virtual reality and 360 videos [27], and predicting bike rider behaviours using driving simulators [3]. Last but not least, banners and billboards are recommended to be installed in locations with potential hazards for bike riders, especially in the downtown area, to inform the bike riders about the consequences of destructive traffic violations.

Enforcement may be a more effective factor than a qualification in controlling violations in the long term. Qualification tends to have a less sustained effect. Actions for improving enforcement can be suggested, such as tight enforcement during the day for bike riders the same as other vehicles [25, 37]. The attitude of police officers must be changed toward the violations of bike riders, and fixing of traffic fines must be stopped as is prevalent in developing countries [2]. The number of traffic fines for bike riders must be high. Other countermeasures such as penalty points can also be an effective deterrent countermeasure to reduce traffic violations bySagberg&Ingebrigtsen [46].

The training and enforcement strategies can be a subject of other research and need careful consideration to ensure that desired outcomes of safety are achieved in a sustained manner.

6. Limitations and future research

The limitations of the study are as follow. First, data were collected from a particular city Bhubaneswar. Future studies need to be performed to collect data from other developing countries with diverse groups of people. Second, the trip purpose and bike riders' job as nominal variables have not been considered as the SEM model variables. Despite these limitations, the study still provides a significant contribution to understanding bike riders' traffic violations in developing countries by helping decision-makers to define safety strategies to minimize bike riders' injuries and death. In further stages of this research, a survey could be conducted to validate its findings. Using mixed-methods analysis is also recommended for comparing various results and providing valuable lessons on developing a more sophisticated framework.

7. Conclusion

Bike riding is one of the most unsafe modes of transportation, and special attention is needed to reduce the possibility of getting involved in accidents. Various factors can affect bike rider safety, but behavioural issues are believed to have the most contribution to bike rider safety. Human errors in the form of traffic violations are among the most effective factors when studying bike crashes. In this article, the role of seven attributes, including bike rider behaviour, road features, ambient conditions, driving skills, type of license, bike age/tenure and riding without a safety device (helmet) on frequency and variety of bike riders' traffic violations were studied.

The proposed model data was based on a detailed survey form and interviews with bike riders in Bhubaneswar, India. After interviewing 450 bike riders, an SEM method was utilized to identify the role of seven attributes on traffic violations among bike riders. The results indicated that riding without helmets has the highest impact on the frequency and variety of violations, respectively.

On the one hand, evaluation of the bike riders' behaviour indicated that most of them are young, with low income and qualifications. These groups need more training and education before getting permission for driving. On the other hand, we do not have strict and continuous traffic enforcement in Bhubaneswar. As bike riders announced, they have not received traffic fines for a long time, although committing different violations continuously. The model outputs indicated that those riding without safety helmets are more often susceptible to committing new violations, and strict traffic enforcement can be helpful to reduce such behaviours. The impact of road features and ambient conditions was low.

This output shows that when a bike rider has the related background and motivation for the violation, then, the type of road features and ambient conditions cannot be essential. In conclusion, applying the results of this study can help to improve road safety, especially for bike riders.

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