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Original Article

Analysis of Human Error Factors in Traffic Accident (Case Study: Tangerang-Merak Toll Road)

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Abstract

Traffic accidents carry significant social, economic, and public safety consequences. In Indonesia, human error accounts for over 60% of accident cases, based on data from the Indonesian National Police Traffic Corps. The Tangerang-Merak Toll Road, a vital corridor connecting industrial areas and major ports in western Java, has seen a notable increase in accidents in recent years, underscoring the need for a deeper understanding of human error contributions. This study aims to analyze the influence of human error-related factors, including driving behavior, risk perception, environmental factors, and individual characteristics, on traffic accidents on the Tangerang-Merak Toll Road. A quantitative approach using Structural Equation Modeling Partial Least Squares (SEM-PLS) was employed to examine these relationships. Data were collected through observation, literature review, and questionnaires. The model demonstrates strong explanatory power, with an R-square value of 0.606, indicating that 60.6% of the variation in traffic accidents is explained by the included variables. Driving behavior is the most dominant factor, with a path coefficient of 0.669, followed by risk perception (0.248). Environmental factors show a negative relationship (-0.478), suggesting that certain environmental conditions may reduce accident risk. Individual characteristics exhibit smaller and mixed effects, including driving experience (0.134), frequency of toll road usage (-0.149), vehicle type (-0.073), and gender (-0.144).

Keywords: Driver Behaviour, Human Error, Structural Equation Modelling Partial Least Square (SEM-PLS), Traffic Accidents.

1. Introduction

Traffic safety remains a strategic issue that continues to receive attention from both the government and society, particularly amid increasing population mobility and the growth of vehicle volumes in Indonesia. Over the past decade, the demand for land transportation, especially through toll road networks, has significantly increased in line with economic growth and urbanization. This phenomenon has introduced new challenges in road safety management, particularly in reducing traffic accidents that frequently result in fatalities and substantial material losses.

According to data from the Indonesian National Police Traffic Corps (Korlantas Polri), approximately 61% of total traffic accidents in Indonesia are caused by human factors or human error. Driving errors generally occur due to fatigue, lack of concentration, violations of speed limits, and the use of communication devices while driving. This indicates that despite advancements in vehicle technology and improvements in infrastructure quality, driver behavior remains a critical element in determining road safety levels.

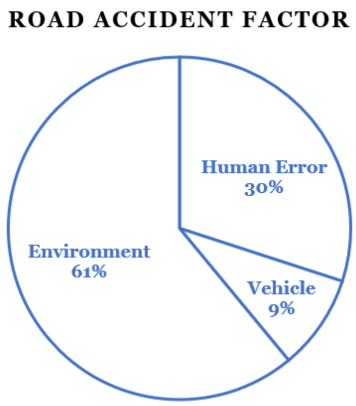

Figure 1. Road Accident Factor in Indonesia
Source: Indonesian National Police Traffic Corps, 2021

Based on Figure 1, environmental factors are the largest cause of traffic accidents in Indonesia, accounting for 61%. This indicates that road conditions, weather, lighting, and traffic infrastructure facilities remain the main problems affecting the high number of accidents. Meanwhile, human error factors contribute 30%, indicating that driver negligence such as lack of concentration, rule violations, and fatigue also plays a significant role in the occurrence of accidents. Vehicle factors account for only 9%, so it can be concluded that the technical condition of vehicles is not a dominant cause compared to environmental factors and human behavior.

The Tangerang-Merak Toll Road is one of the primary toll road corridors that serves as a vital link between economic centers in the Greater Jakarta (Jabodetabek) area and Merak Port (Figure 2). This toll road plays an important role in supporting logistics distribution and public mobility, particularly in the western part of Java Island. With its considerable length and high daily traffic volume, this corridor is associated with a significant potential risk of traffic accidents.

Figure 2. Tangerang-Merak Toll Road

Accident data from 2022 to 2024 show a fluctuating trend but consistently indicate that human error remains the primary cause of accidents on this corridor (Table 1). For instance, in 2022, there were 44 accident cases, resulting in 25 fatalities and 81 minor injuries. Meanwhile, in 2024, although the number of fatalities decreased to 21, the number of minor injuries increased significantly to 108 cases. These data suggest that the intensity of accidents remains high, and overall safety performance has not shown consistent improvement.

Table 1. Number of Traffic Accidents Tangerang-Merak Toll Road

Year	Fatalities	Serious Injuries	Minor Injuries	Total Accidents
2022	25	15	81	44
2023	23	19	67	45
2024	21	3	108	43

Source: Indonesian National Police Traffic Corps, 2021

This condition reinforces the urgency to conduct a more in-depth analysis of the factors contributing to traffic accidents, particularly those related to human error. By identifying specific elements that contribute to accident occurrences such as fatigue, impaired decision-making, and driving distraction, this study provides a scientific basis for developing more effective and context-specific traffic safety policies on the Tangerang-Merak Toll Road.

In addition, this study is expected to enrich the existing local literature on data-driven road safety analysis and driver behaviour factors, which remain relatively limited. The resulting recommendations are intended to serve as valuable inputs for toll road operators, law enforcement agencies, and policymakers in formulating intervention strategies based on education, technology, and more adaptive and precise traffic law enforcement.

Research on human error factors in traffic accidents has been widely conducted, however most studies still focus on the general identification of accident causes such as negligence, rule violations, fatigue, and lack of driver concentration (Mardikawati et al., 2025; Natama, 2023). Research by Tjahjono and Maulina (2018) shows that the dominant human error factor stems from the driver's failure to recognize situations and make decisions while driving. Meanwhile, Santoso and Maulina (2019) also Zhang et al. (2019) place greater emphasis on legal liability resulting from human error rather than in-depth analysis of driver behavior. Research by Bucsuházy et al. (2020) and Singh et al. (2016) also confirms that the human factor is the primary cause of accidents compared to vehicle or road factors.

However, most previous studies still use descriptive approaches and have not comprehensively integrated behavioral analysis, the psychological condition of drivers, and the interaction between human, environmental, and vehicle condition factors (Bucsuházy et al., 2020; Waskito et al., 2024). In addition, research related to human error in Indonesia is still limited to certain regions or cases, thus not yet providing a specific picture of accident characteristics at different research locations. On the other hand, the development of modern analytical methods such as the Human Factors Analysis and Classification System (HFACS) (Fajar et al., 2025; Kurniasih et al., 2024; Sari et al., 2020), Bayesian Network (Faishal et al., 2025; Hasugian et al., 2021), and artificial intelligence-based approaches are still rarely applied in traffic accident research in Indonesia.

The novelty of this study is emphasized through a more specific analytical focus on human error factors on a particular toll road segment, namely the Tangerang-Merak Toll Road, by considering traffic characteristics, driver behavior, and toll road operational conditions that differ from previous studies. Most previous studies only identified human error as a general cause of accidents without in-depth analysis of the relationships between driver fatigue, speeding violations, lack of concentration, decision-making, and traffic conditions on intercity toll roads with high volumes of heavy vehicles. Furthermore, previous studies in Indonesia generally still use descriptive approaches and have not extensively examined dominant human error patterns based on actual accident data on strategic toll road segments. Therefore, this study offers novelty through a more contextual and specific analysis of human error factors on the Tangerang-Merak Toll Road as a major logistics corridor on the island of Java.

Based on these conditions, this study aims to analyze the human error factors that contribute to the occurrence of traffic accidents on the Tangerang-Merak Toll Road. This study focuses on identifying the forms of driver error, the dominant factors causing accidents, and the relationship between driver behavior and the characteristics of accidents that occur. The findings are expected to contribute to the development of traffic safety strategies and serve as evaluation material for relevant parties in efforts to reduce the number of accidents on toll roads.

2. Literature Review

2.1. Human Factors in Traffic Accidents

Human factors are recognized as the dominant cause in most traffic accidents compared to vehicle-related or road condition factors. Various transportation safety studies indicate that human error significantly contributes to accident occurrences, either through limitations in perception, errors in decision-making, or delayed responses to dynamic traffic situations (WHO, 2019; Reason, 1990). Therefore, understanding the role of human factors is a critical aspect in comprehensive accident prevention efforts. Empirical findings in Indonesia also show that approximately 88% of traffic accidents are influenced by human factors, while road and environmental factors contribute around 8-9%, and vehicle-related factors account for about 3%. This further emphasizes the dominant role of driver behaviour in both accident occurrence and injury severity (Setiawan & Rustam, 2025).

In general, human factors in traffic accidents can be categorized into several key aspects, including driver fatigue and physical condition, distraction and reduced concentration, risky driving behaviour, as well as the level of knowledge and compliance with traffic regulations. Fatigue and drowsiness are known to reduce alertness and slow reaction time, thereby increasing the likelihood of accidents, particularly on high-speed roads (Williamson et al., 2011). Distraction, such as the use of mobile phones while driving, has also been proven to significantly increase accident risk because it diverts the driver's visual, cognitive, and manual attention from road conditions (WHO, 2018).

Furthermore, risky driving behaviours such as speeding, maintaining unsafe following distances, and making sudden lane changes are strongly associated with increased accident severity (International Transport Forum, 2017). The level of understanding of traffic signs, road markings, and safety regulations also plays an important role, as drivers with lower safety knowledge tend to be less capable of anticipating potential hazards on the road (Evans, 2004). This indicates that human factors are not only related to driving actions but also to cognitive capacity, experience, and attitudes toward road safety.

Figure 3 shows that human factors are the primary cause of traffic accidents, particularly unruly behaviour at 45.66% and careless driving at 32.2%. In addition, speeding also contributes considerably at 14.53%. Meanwhile, other factors such as fatigue, drowsiness, alcohol, drugs, and psychological conditions have relatively small percentages. These findings indicate that undisciplined and careless driver behavior is the dominant factor in the occurrence of traffic accidents (Santosa et al., 2017).

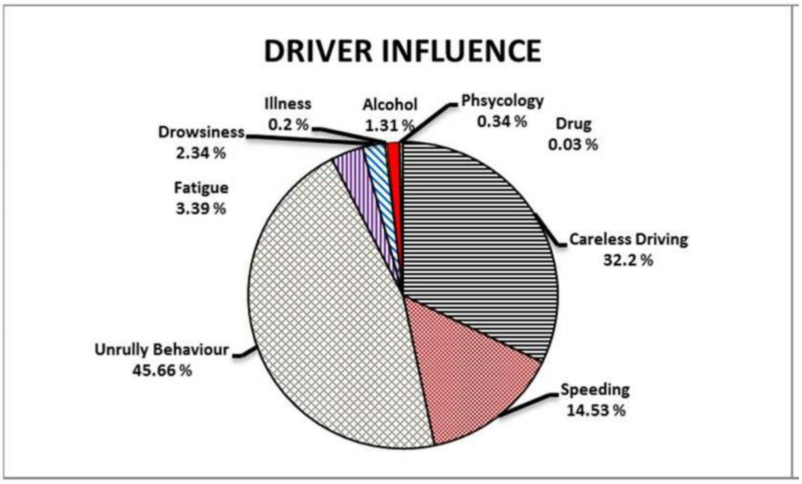

Figure 3. Distribution of Human Factors in Traffic Accidents
Source: Santosa et al. (2017)

The visualization of accident causation distribution presented above indicates that driver-related factors are significantly more dominant compared to vehicle and road condition factors. This suggests that safety interventions cannot rely solely on infrastructure improvements but must also emphasize enhancing driver behaviour and safety awareness (Setiawan & Rustam, 2025).

In the context of toll roads, the influence of human factors becomes even more significant due to high operational speeds, which reduce the time available to respond to potential hazards. Minor errors such as brief loss of concentration or delayed braking can lead to accidents with high fatality rates. Therefore, the analysis of human factors is essential to identify the most dominant types of errors, understand their relationship with toll road operating conditions, and formulate appropriate preventive strategies through safety education, law enforcement, and integrated road safety system improvements (WHO, 2019; International Transport Forum, 2017). Accident analysis in Indonesia also indicates that injury severity is influenced by factors such as the type of collision, the age group of road users, and the time of occurrence, where younger age groups and periods of high traffic activity are more vulnerable to severe accidents (Setiawan & Rustam, 2025).

Thus, the analysis of human factors in traffic accidents serves as a fundamental basis in transportation safety research, as it enables the development of more effective behaviour-based interventions aimed at reducing accident rates and their associated fatality levels (Reason, 1990; WHO, 2019).

2.2. Structural Equation Modelling-Partial Least Square (SEM-PLS)

The Structural Equation Modeling method based on Partial Least Squares (SEM-PLS) is a multivariate analysis approach used to test causal relationships between latent variables simultaneously, including both direct and indirect relationships as well as mediation effects. This method is widely used in social research and transportation safety because it can handle complex models, large numbers of indicators, and does not require strict data normality assumptions (Hair et al., 2014; Henseler et al., 2009).

SEM-PLS consists of an outer model to test the validity and reliability of indicators through outer loading, AVE, and CR, as well as an inner model to test the relationships between latent variables using path coefficients and R-square values (Hair et al., 2014; Chin, 1998). The analysis was conducted using the PLS algorithm and bootstrapping technique to obtain T-statistics and p-values for hypothesis testing (Efron & Tibshirani, 1993; Hair et al., 2014). In this study, SEM-PLS was used to analyze the influence of driving behavior, risk perception, environmental factors, and individual characteristics on accident occurrence. This method was selected for its flexibility, good predictive capability, and ability to provide a comprehensive analysis of the relationships between variables in transportation safety research (Hair et al., 2014; Wong, 2013).

3. Methods

Figure 4 illustrates the overall research flow applied in this study, covering the stages from problem identification to the interpretation of results.

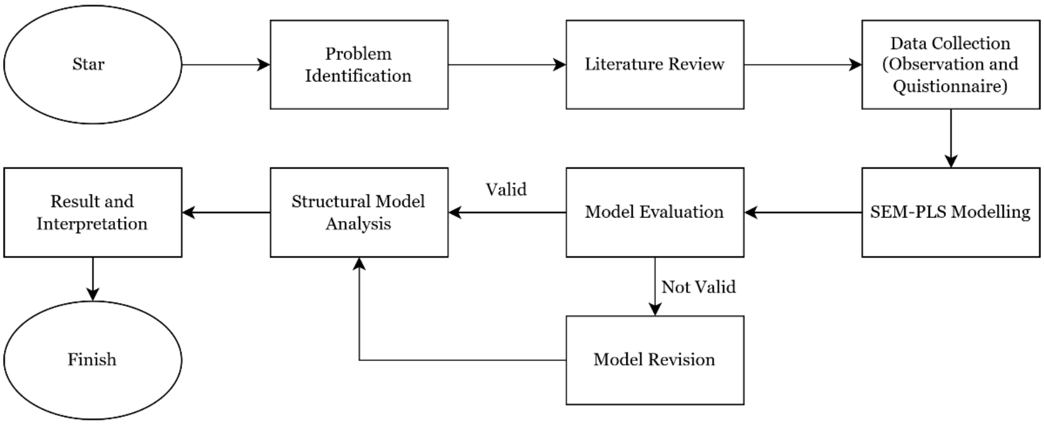

Figure 4. Research Flowchart
Source: Researcher processed data, 2026

The research process begins with problem identification, focusing on the issue of traffic accidents influenced by human error (Figure 4). This stage is followed by a literature review to establish the theoretical foundation and define the research framework. Subsequently, data are collected through field observations and structured questionnaires to capture relevant variables related to driver behaviour, perception, and accident characteristics.

The collected data are analysed using Structural Equation Modelling Partial Least Squares (SEM-PLS). The analysis starts with SEM-PLS modelling, followed by model evaluation to assess the validity and reliability of the constructs. If the model does not meet the required criteria, an iterative model revision process is conducted until the model achieves acceptable validity and reliability standards.

Once the model is validated, structural model analysis is performed to examine the relationships among variables and identify dominant factors influencing accident occurrence. The results are then interpreted to provide meaningful insights, which serve as the basis for drawing conclusions and supporting the development of effective traffic safety strategies.

3.1. Data Collection Method

Data were collected using a combination of historical traffic accident records and primary survey data. The first stage involved reviewing historical accident data obtained from official accident reports on the Tangerang-Merak Toll Road. These records were used to identify accident cases, extract relevant accident characteristics, and trace the individuals involved in the incidents. The historical data also provided contextual information such as accident year, time of occurrence, weather conditions, road conditions, severity level, and number of vehicles involved.

In the second stage, respondents were selected from the identified accident records using a purposive sampling approach. The inclusion criterion was drivers who had been involved in traffic accidents on the Tangerang-Merak Toll Road and were willing to participate in the study. Based on the information available in the accident reports, the researcher contacted eligible respondents and invited them to participate in structured interviews and questionnaire surveys. This approach was chosen to ensure that the collected data reflected the direct experiences of drivers involved in actual accidents.

Figure 5. Interviews with Accident-Involved Respondents
Source: Researcher processed data, 2026

The primary data collection instrument consisted of a structured questionnaire designed to capture respondent characteristics, driving behaviour, and risk perception related to human error factors. In addition, interviews were conducted to support the interpretation of the responses and to provide contextual understanding of accident-related behaviour. By combining historical accident data with purposively selected respondent data, the study was able to integrate accident records and driver perspectives in a single analytical framework.

Table 2. Driver Questionnaire Structure

Section	Variable/Statement	Response Options
Identity	Name (optional)	Respondent identity
	Gender	Male / Female
	Age	In years
	Occupation	Main occupation
	Travel Frequency	Daily / Weekly / Monthly / Rarely
	Vehicle Type	Car / Truck
Accident Characteristics	Accident Year	Year of accident
	Location (KM)	Accident location
	Time of Accident	Morning / Afternoon / Evening / Night
	Weather	Clear / Rainy / Foggy / Dark
	Road Condition	Straight / Curved / Uphill / Downhill
	Severity Level	No injury / Minor injury / Serious injury / Fatality
	Number of Vehicles Involved	Number of vehicles involved

Section	Variable/Statement	Response Options
Driving Behaviour	Driving while fatigued or drowsy	Likert 1-5
	Using a mobile phone while driving	Likert 1-5
	Exceeding the speed limit	Likert 1-5
	Paying insufficient attention to signs or markings	Likert 1-5
	Feeling rushed or under time pressure	Likert 1-5
	Losing focus on surrounding vehicles	Likert 1-5
	Overtaking in inappropriate areas	Likert 1-5
	Failing to maintain a safe distance	Likert 1-5
	Not wearing a seat belt	Likert 1-5
	Losing vehicle control	Likert 1-5
Risk Perception	Fatigue and drowsiness	Likert 1-5
	Distraction (mobile phone, conversation, radio)	Likert 1-5
	Speeding	Likert 1-5
	Lack of attention to signs	Likert 1-5
	Aggressive behaviour	Likert 1-5
	Lack of driving alertness	Likert 1-5

Source: Researcher processed data, 2026

3.2. SEM-PLS Data Input

The dataset used in this study was prepared prior to SEM-PLS analysis and consists of 37 respondents who had been involved in traffic accidents on the Tangerang-Merak Toll Road. All variables were transformed into numerical formats to ensure compatibility with the SEM-PLS modeling approach.

The data in this study are represented using ordinal and binary scales. Driving behavior and risk perception variables were measured using a five-point Likert scale, reflecting ordinal data. Meanwhile, several variables such as gender and vehicle type were coded as binary variables to represent categorical distinctions in a simplified numerical form.

The model includes several latent constructs, namely driving behavior, risk perception, environmental factors, and individual characteristics, which are hypothesized to influence accident occurrence. Driving behavior is represented by ten indicators, while risk perception consists of six indicators.

Prior to analysis, the dataset was checked for completeness and consistency to ensure data quality. The final dataset was then imported into SEM-PLS software for model estimation and evaluation.

Table 3. Variable Coding Scheme

Variable	Code	Description
Gender	1	Male
	2	Female
Age	-	Original data (years)
Driving Experience	-	Original data (years)
Toll Usage Frequency	1	Rarely
	2	Monthly
	3	Weekly
	4	Daily
Vehicle Type	1	Passenger car
	2	Truck
Accident Year	1	2020

Variable	Code	Description
	2	2021
	3	2022
	4	2023
	5	2024
Time of Accident	1	Morning
	2	Afternoon
	3	Evening
	4	Night
Weather Condition	1	Clear
	2	Rainy
	3	Foggy
	4	Dark
Road Condition	1	Straight
	2	Curved
	3	Uphill
	4	Downhill
Accident Severity	1	No injury
	2	Minor injury
	3	Serious injury
	4	Fatality
Number of Vehicles Involved	1	1 vehicle
	2	2 vehicles
	3	≥ 3 vehicles
Driving Behavior (B1-B10)	1-5	Likert scale (1 = Never, 5 = Very often)
Risk Perception (P1-P6)	1-5	Likert scale (1 = Not influential, 5 = Very influential)

Source: Researcher processed data, 2026

Table 3 presents the coding scheme used in this study. Continuous variables such as age and driving experience were retained in their original form (years), while categorical variables were transformed into ordinal or binary numerical codes. Driving behavior (B1-B10) and risk perception (P1-P6) were measured using five-point Likert scales. This coding approach ensures consistency and compatibility with SEM-PLS analysis, which accommodates ordinal and binary data without requiring strict distributional assumptions.

4. Results and Discussion

4.1. Result Analysis

4.1.1. Respondent Characteristics

A total of 37 respondents were included in this study, representing drivers who had experienced traffic accidents on the Tangerang-Merak Toll Road. These data were used to describe respondent characteristics and to support further statistical analysis. The respondent characteristics presented in Table 4 indicate that the majority of respondents were female (59%), while male respondents accounted for 41%. In terms of age distribution, most respondents were within the 35-44 age group (30%), followed by 25-34 (27%). This suggests that respondents were predominantly within the productive age group with relatively high mobility levels.

In terms of driving experience, the majority of respondents had more than 10 years of experience, indicating that most participants were experienced drivers. However, despite this level of experience, accidents still occurred, suggesting that experience alone does not guarantee safe driving behavior.

Table 4. Respondent Characteristics

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	15	41
	Female	22	59
Age	<25	8	21
	25-34	10	27
	35-44	11	30
	≥45	8	22
Driving Experience	≤5 years	5	13
	6-10 years	10	27
	11-15 years	11	30
	≥16 years	11	30
Travel Frequency (Toll Road)	Daily	9	24
	Weekly	5	14
	Monthly	12	32
	Rarely	11	30
Vehicle Type	Passenger Car	35	95
	Truck	2	5
Accident Year	2020	3	8
	2021	6	16
	2022	9	25
	2023	9	24
	2024	10	27
Time of Accident	Morning	10	27
	Afternoon	10	27
	Evening	5	14
	Night	12	32
Weather Condition	Clear	7	19
	Rainy	14	38
	Foggy	8	22
	Dark	8	21
Road Condition	Straight	14	38
	Curved	14	38
	Uphill	3	8
	Downhill	6	16
Number of Vehicles Involved	1	10	27
	2	12	32
	≥3	15	41
Accident Severity	No Injury	7	19
	Minor Injury	15	41
	Serious Injury	13	35
	Fatality	2	5

Source: Researcher processed data, 2026

Regarding accident characteristics, most incidents occurred at night (32%) and under rainy conditions (38%), which may indicate reduced visibility and increased risk factors during these conditions. Additionally, most accidents involved more than one vehicle (41%) and resulted in minor injuries (41%), although serious injuries were also significant (35%). These findings highlight that both environmental conditions and driving behavior contribute to accident occurrence.

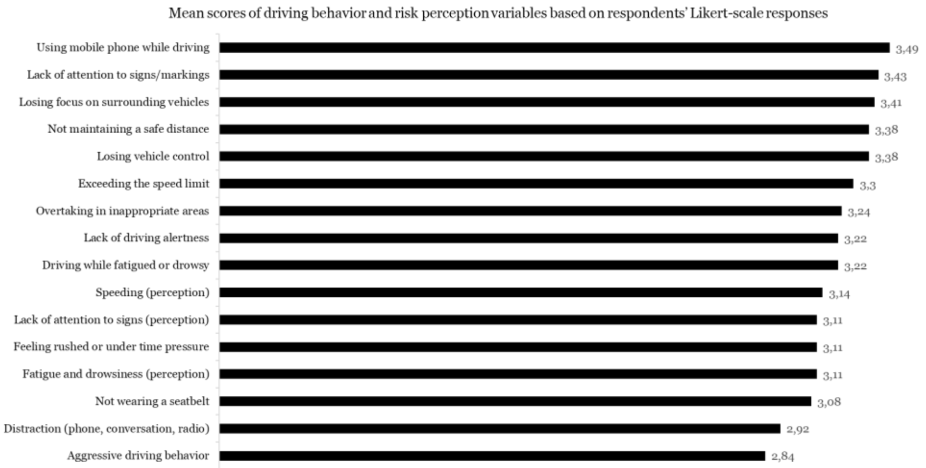

Figure 6. Mean Scores of Driving Behavior and Risk Perception Variables
Source: Researcher processed data, 2026

The results indicate that mobile phone use while driving has the highest mean score, suggesting that distraction is the most dominant risky behavior among respondents. This is followed by lack of attention to road signs and loss of focus on surrounding vehicles, which further highlights the importance of cognitive factors in accident occurrence. Additionally, behaviors such as unsafe distance and loss of vehicle control also show relatively high mean values, indicating their significant contribution to accident risk.

4.1.2. Model Construct

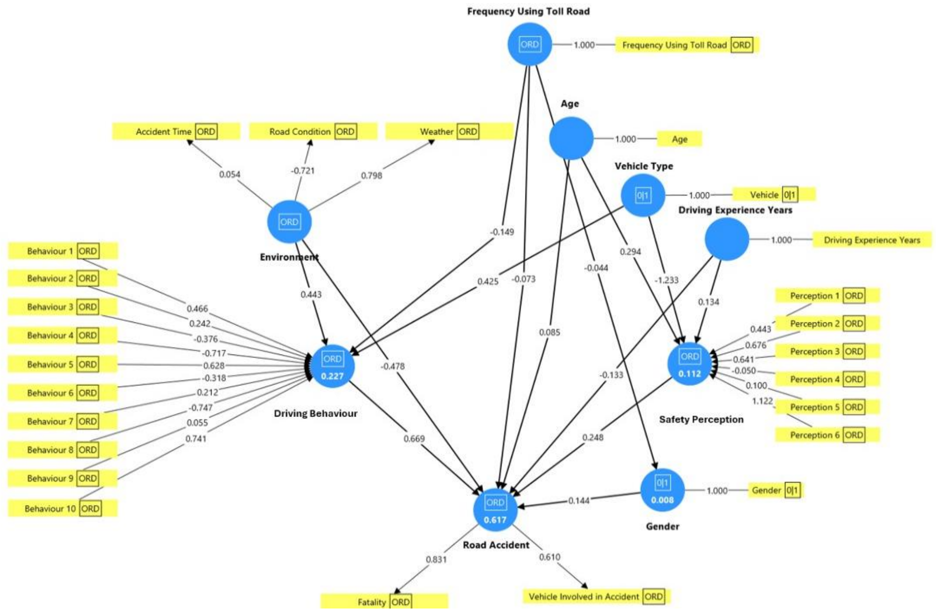

Figure 7. Research Model Construct
Source: Researcher processed data, 2026

The research model is constructed to examine the relationships among variables influencing traffic accident occurrence (Figure 8). The Driving Behaviour construct is measured using indicators B1 to B10, representing various forms of risky driving behaviour such as fatigue, distraction, speeding, and non-compliance with traffic rules. This construct is hypothesized to have a direct effect on accident occurrence, indicating that higher levels of risky behaviour increase the likelihood of accidents.

The Risk Perception construct is measured using indicators P1 to P6, reflecting respondents' perceptions of accident-related risk factors. In this model, risk perception is assumed to influence accident occurrence both directly and indirectly through driving behaviour. Therefore, it is hypothesized that risk perception affects accident occurrence, although its effect may differ in magnitude compared to actual driving behaviour.

The Environmental construct is formed by variables such as weather conditions, road conditions, and time of occurrence, which represent external conditions during accidents. This construct is hypothesized to influence accident occurrence directly, as well as indirectly by affecting driving behaviour under certain conditions.

In addition, individual characteristics such as age and driving experience are included as numerical variables, while variables such as gender, vehicle type, and toll usage frequency are included as coded variables. These variables are assumed to influence both driving behaviour and risk perception, which in turn affect accident occurrence.

The Accident variable, as the main endogenous variable, is measured using indicators such as the number of vehicles involved and accident severity. Based on the proposed model, several key hypotheses are tested: (1) driving behaviour has a significant effect on accident occurrence, (2) risk perception influences accident occurrence, (3) environmental factors affect accident occurrence, and (4) individual characteristics influence driving behaviour and risk perception, which ultimately impact accident occurrence. This model allows the analysis of both direct and indirect relationships using the SEM-PLS approach.

4.1.3. Average Variance Extracted (AVE)

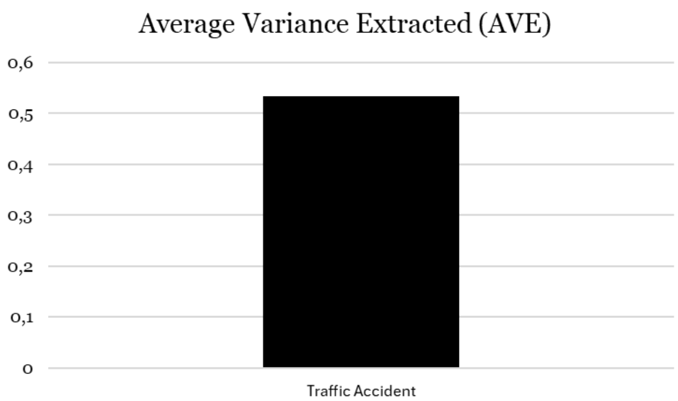

Figure 8. Average Variance Extracted (AVE)
Source: Researcher processed data, 2026

The measurement model was evaluated using the Average Variance Extracted (AVE) to assess convergent validity. As shown in figure 8 above, the AVE value of the construct exceeds the minimum threshold of 0.50, indicating that the latent variable is able to explain more than half of the variance of its indicators.

This result confirms that the indicators used in the model have adequate convergent validity and are capable of representing the underlying construct reliably. Therefore, the measurement model meets the required validity criteria and can be considered suitable for further structural model analysis.

4.1.4. Structural Model Evaluation

Table 5. Model R-square Overview

Variable	R-square	R-square Adjusted
Gender	0.008	-0.020
Age	0.606	0.511
Driving Behaviour	0.211	0.139
Risk Perception	0.113	0.033

Source: Researcher processed data, 2026

Based on the analysis results as in Table 5, the R-square value for the accident variable is 0.606, with an adjusted R-square of 0.511. This indicates that approximately 60.6% of the variance in accident occurrence can be explained by the variables included in the model, namely driving behaviour, risk perception, environmental factors, and individual characteristics. This value falls within the moderate to substantial category, suggesting that the model has a good explanatory power.

Meanwhile, the driving behaviour variable has an R-square value of 0.211, indicating that 21.1% of the variance in driving behaviour can be explained by the variables in the model. The risk perception variable has an R-square value of 0.113, which implies that only 11.3% of its variance is explained by the independent variables, indicating a relatively weaker explanatory power.

The gender variable shows a very low R-square value of 0.008, suggesting that it is not significantly explained by other variables in the model. Overall, these results indicate that behavioural factors play a more dominant role compared to individual characteristics in explaining accident occurrence.

4.1.5. Analysis of Relationship Between Variables

Table 6. Total Effects Matrix Between Variables

From / To	Driving Behaviour	Safety Perception	Road Accident
Environment	0.443	-	-0.478
Driving Behaviour	-	-	0.669
Safety Perception	-	-	0.248
Age	-0.149	-0.044	0.085
Driving Experience	0.425	0.134	-
Vehicle Type	-0.073	-1.233	-
Frequency Using Toll Road	-0.149	-	-
Gender	-	-	-0.144

Source: Researcher processed data, 2026

Based on the total effects analysis as in Table 6, the driving behavior variable has the strongest influence on accident occurrence, with a coefficient value of 0.669. This indicates that higher levels of risky driving behaviour significantly increase the likelihood of traffic accidents. The risk perception variable also shows a positive effect on accident occurrence, with a coefficient value of 0.248, suggesting that individuals' perception of risk is associated with accident occurrence, although the strength of this relationship is lower compared to driving behaviour. Meanwhile, the environmental factor exhibits a negative effect on accident occurrence, with a coefficient value of -0.478, indicating that certain environmental conditions may either increase or reduce accident risk depending on their characteristics.

Other variables, such as driving experience (0.134), frequency of using the toll road (-0.149), and vehicle type (-0.073), show relatively small effects on accident occurrence. Additionally, the gender variable also demonstrates a minor effect with a coefficient value of -0.144, indicating a limited contribution within the model. Overall, these findings confirm that driving behaviour is the most dominant factor influencing accident occurrence, compared to environmental and individual characteristics.

4.2. Discussion

Based on the results of the SEM-PLS analysis, the relationships among variables in the model exhibit a consistent pattern between driving behaviour, risk perception, environmental factors, and individual characteristics in explaining accident occurrence. Overall, the constructed model is able to adequately capture the interrelationships among variables, particularly in explaining the role of human error in traffic accidents on the Tangerang-Merak Toll Road.

Driving behaviour is found to be the most dominant factor influencing accident occurrence. This indicates that drivers' direct actions, such as speeding, distraction, and lack of alertness, are the primary contributors to increased accident risk. These findings reinforce the notion that traffic accidents are more strongly influenced by internal driver-related factors rather than external conditions.

Risk perception also shows an effect on accident occurrence, although with a lower magnitude compared to driving behaviour. This suggests that while respondents may be aware of accident risks, such awareness does not necessarily translate into safer driving behaviour. In other words, there is a gap between perceived risk and actual behaviour in real-world conditions. This condition can be explained through several psychological and behavioral factors. One of them is optimism bias, which is the tendency of drivers to feel that accidents are more likely to happen to others than to themselves, leading them to continue engaging in risky behavior despite understanding the dangers. In addition, overconfidence in driving ability, repetitive driving habits, time pressure, and mental fatigue can also reduce driver alertness and affect decision-making while driving. Previous research shows that drivers who are already accustomed to certain traffic conditions tend to regard risky behavior as normal and still manageable (Bucsuházy et al., 2020; Zhang et al., 2019). Therefore, increasing risk awareness alone is not sufficient to reduce the number of accidents without being supported by behavioral interventions, supervision, and consistent law enforcement.

Meanwhile, environmental factors demonstrate a relatively smaller and more indirect influence. Conditions such as weather, time of occurrence, and road characteristics still play a role in shaping accident situations; however, their influence is not as strong as that of driver behaviour. This indicates that environmental factors primarily act as supporting conditions that may either exacerbate or mitigate the effects of risky driving behaviour.

Individual characteristics, including age, driving experience, frequency of toll road usage, vehicle type, and gender, show relatively minor effects on accident occurrence. This implies that demographic factors do not directly determine accident occurrence, but rather influence driving behaviour and risk perception.

Overall, the results indicate that driving behaviour is the primary determinant of accident occurrence, followed by risk perception, while environmental and individual characteristics play more limited roles. These findings highlight the importance of interventions focused on improving driving behaviour as the main strategy to reduce traffic accident rates.

5. Conclusion

Based on the research findings, human error is the dominant factor in traffic accidents on the Tangerang-Merak Toll Road, heavily influenced by risk perception and driving behavior. External factors such as environmental conditions and individual characteristics also play an integrated role in determining accident risks. Addressing these challenges requires comprehensive and targeted intervention strategies.

To effectively reduce accident rates, multi-sectoral actions must be implemented, focusing on education, technology, and strict enforcement. Specifically, road operators and law enforcement should deploy advanced technology-based monitoring systems, such as automated speed monitoring systems (e.g., Electronic Traffic Law Enforcement/ETLE) and fatigue detection technology for long-distance drivers. Further, targeted driver awareness campaigns should be done regularly to improve risk perception. These efforts must be supported by stricter toll road supervision, including active patrol operations and more adaptive traffic law enforcement. Through these measures, toll road safety management can transition from a reactive approach to proactive prevention, ultimately minimizing the severity and occurrence of human error-related accidents on critical transport corridors.

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