International Journal of Applied Mathematics
Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

THE MEDIATING ROLE OF REGULATORY STRATEGIES IN ACHIEVING SUSTAINABLE ROAD SAFETY IN MALAYSIA: AN EMPIRICAL ANALYSIS USING PLS-SEM

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Abstract

Road accidents constitute a persistent global public health and global crisis, demanding comprehensive and systematic intervention, particularly within rapidly developing, middle-income nations like Malaysia. This investigation addresses the critical need for effective policy evaluation by examining the determinants of Sustainable Road Safety (SRS) through the lens of a mediated structural model. Specifically, the study explores the influence of the Human Factor and Environment Factor on sustainable road safety, concurrently analysing the mediating role of Regulatory Strategies within this relationship. The research employed a rigorous quantitative methodology, collecting data via a survey from a target sample of 363 respondents across the states of Selangor, Kuala Lumpur, and Johor Bahru regions significantly affected by high road accident incidence in Malaysia. The resultant data were subsequently analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The empirical analysis confirmed that all proposed path relationships were positive and statistically significant. The findings demonstrate that both the Human Factor ($ß = 0.187 < 0.001$) and the Environment Factor ($ß = 0.283 < 0.001$) significantly influence Regulatory Strategies. Crucially, the analysis confirms that Regulatory Strategies serve as a vital, positive, and significant mediator, actively channeling the effects of the antecedent factors toward Sustainable Road Safety. This indicates that the effectiveness of human- and environment-focused interventions is contingent upon the regulatory framework that formalizes and enforces them. Practically, the findings necessitate that policymaker prioritize the strategic design and robust enforcement of targeted regulations to institutionalize positive changes and effectively reduce road accident among Malaysia drivers.

Keywords: Regulatory Strategies, Sustainable Road Safety, Human Factor, Environment Factor, PLS-SEM.

1. INTRODUCTION

Road accidents constitute a persistent global public health and socio-economic tragedy, demanding comprehensive and sustainable intervention, particularly in developing and middle-income nations (WHO, 2023). The international community has responded by prioritizing the concept of Sustainable Road Safety (SRS), which calls for long-term, systematic, and integrated approaches aimed at the ambitious goal of eliminating fatal and serious road accidents (Khasawneh & Smith, 2022). This commitment is formally enshrined in the United Nations' Decade of Action for Road Safety 2021-2030, which sets forth a mandate to halve global road traffic deaths and injuries by 2030 (Nation, 2017; Tavakkoli et

Received: August 07, 2025

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

al., 2022). Despite significant global efforts, the challenge remains acute in regions undergoing rapid motorization and infrastructural development, leading to persistent fatality rates.

In the Malaysian context, this issue is alarming and highlighting the urgent necessity for effective policy evaluation. Road accident continue to be the predominant cause of accidental death nationwide (MOT, 2023). Empirical data from 2024 reveals a sobering picture, with the country recording an average of approximately 1,729 traffic accidents per day and tragically, 14 daily fatalities**,** resulting in one death every two hours (Startimes, 2025). Furthermore, the financial repercussions of this epidemic are immense; the total cost of fatalities and serious injuries amounted approximately to an estimated RM25 billion in 2023**,** which is equivalent to roughly 3% of Malaysia’s Gross Domestic Product (GDP) (Rahman et al., 2023). The substantial economic and human burden of road accidents necessitates the development of robust and effective strategies that move beyond mere mitigation to achieve sustainable road safety and significantly minimize contributing factors.

This research contributes to the literature by exploring a hypothetical framework to investigate the mediating role regulatory strategies on human and environment factors toward sustainable road safety among private vehicle users in Malaysia. Previous studies have explored the positive effects on road accidents factors often adopts a narrow focus by, examining human factors in isolation rather than considering their interplay. For instance, studies have primarily concentrated on human factor (Salmon et al., 2019), vehicle defects (Moodley & Allopi, 2008) road infrastructure (Pembuain et al., 2019); (Musa et al., 2020), or environmental conditions (Shahid & Minhans, 2016); (Marizwan et al., 2018) in isolation. Furthermore, these studies often overlook the complex interplay between these factors and their broader impact on sustainable road safety. (Bucsuházy et al., 2020) limited their analysis to driver-related variables, while (Marizwan et al., 2018)focused solely on motorcycle crashes. This fragmented approach hinders a comprehensive understanding of accident causation. While existing research on road accidents in Malaysia has focused on specific aspects of the problem. For instance, (Khairul et al., 2018) examined road safety in Selangor and Perlis, but their study lacked a comprehensive analysis of driver behaviour, safety education, and technological interventions. Similarly, (Amalia et al., 2022) concentrated on driver behaviour and road environment, neglecting to explore driver attitudes, fatigue, and the full impact of weather conditions. Most of the prior studies conduct on road accident with contributing factors only.

In addition, existing literature rarely organically combines the theory of planed behavior (TPB) and system theory reveal the mediating mechanism by which core capabilities improve sustainable road safety development through regulatory strategy. To address these gaps, this research aims to comprehensively investigate the complex interaction of human, and environment factor contributing to road accident among Malaysian private vehicle users. By examining the mediating role of regulatory strategies, this research seeks to understand how these factors mediate by regulatory strategy to enhance the sustainable road safety. This study Focusing on private vehicle user’s mainly residence in highly effected states in road accident issues, which is Selangor, Kuala Lumpur, and Johor (Azan et al., 2023; Mohd Azami et al., 2024). This study addresses a critical gap in the literature by exploring the understudied relationship between regulatory strategies, sustainable road safety and road accident factors, thereby contributing novel insights to the field. This research focuses on Selangor, Kuala Lumpur, and Johor for reasons:

(1) Selangor, Johor, and Kuala Lumpur are three of Malaysia's most urbanized states, each

experiencing rapid growth and development in recent decades (Mohd Azami et al., 2024).

(2) This study focuses on the leading three states with the highest incidence of road accidents in Malaysia which is Selangor, Johor, and Kuala Lumpur (Azan et al., 2023; Mohd Azami et al., 2024; Shaadan & Suhaimi, 2021).

(3) These states were selected due to their varying levels of urbanization, economic activities, and traffic conditions, offering a comprehensive overview of factors influencing road accidents (Mohd Azami et al., 2024).

RQ1: Does the road accident factors directly impact on sustainable road safety

RQ2: Does the mediator regulatory strategy impact on road accident factors and sustainable road safety

The significance of this research focus on the contributing factor on road accident which is human factor and environment factor, directly impact on sustainable road safety mediate by regulatory strategies among Malaysia private vehicle users. The results of this research have significant contributions to both theory and practice. Analysis from a theoretical perspective, based on the Theory of Planned Behaviour (TPB) was developed by Ajzen, (2019). In relation to road accidents, drivers' attitude towards safety precautions, regulations and other risky behaviors influences their intentions and actual behavior (Ledesma et al., 2018). This theory is significantly applicable in this field of sustainable road safety. The existing literature on road safety revealed that most accidents are caused by human (Ajzen, 1991; Lee et al., 2008; Papantoniou et al., 2018). Consistently, TPB is a predictor of behavior, it positively applicable for this study. This research combines with system theory Bertalanffy, (1972). systems theory can also be used to develop and evaluate effective environmental policies and interventions by considering the interconnectedness of different environmental factors (Leydesdorff, 1996). This view correlates with this study which examines the road safety environment. This includes safety strategies, mediating human, and environment factor.

Following the collection of data from highly affected states, the research employs the Partial Least Squares Structural Equation Modeling (PLS-SEM) method for empirical testing, enhancing the study's external validity. From a practical standpoint, the resulting empirical evidence provides key insights for the Ministry of Transport and policymakers. This evidence directly supports the formulation of advanced, sustainable road safety strategies aimed at significantly minimizing road accident percentages and addressing the critical accident issue, ultimately leading to improved cost efficiency and heightened driver safety for Malaysian.

The overall objective of this research is to determine the direct impact of Road Accident Factors (Independent Variable) on Sustainable Road Safety (Dependent Variable). Additionally, to investigate the mediating effect of Regulatory Strategy on the relationship between Road Accident Factors and Sustainable Road Safety. This study aims to comprehensively investigate the complex interaction of human, and environment factor contributing to road accident among Malaysian private vehicle users. By examining the mediating role of regulatory strategies, this research seeks to understand how these factors mediate by regulatory strategy to enhance the sustainable road safety. This study Focusing on private vehicle user's mainly residence in highly effected states in road accident issues, which is Selangor, Kuala Lumpur, and Johor (Mohd Azami et al., 2024).This study addresses a critical gap in the literature by exploring the understudied relationship between regulatory strategies, sustainable road safety and road accident factors, thereby contributing novel insights to the field. This research intends to use SPSS and Smart PLS software, integration of reliability and validity tests, measurement model, structural equation model analysis and

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

Bootstrap mediation effect test to ensure the rigor of the research method and the credibility of the results.

2. LITERATURE REVIEW

This study predominantly examines two theories that significantly contribute to this research: the Theory of Planned Behaviour (TPB) (Ajzen, 2019) and System Theory (Bertalanffy, 1972). The TPB is utilized to analyse human factor, regulatory strategies, and sustainable road safety within the study, while System Theory concentrates on environmental factors of this study.

2.1 Theoretical Foundation

This study uses theory of planned behaviour (TPB), as primary theory to examine the road accidents factors to enhance sustainable road safety. TPB is the model work and analyse predicting human behaviours on road issues, which relatively comprehensive framework with multiple human's influence by attitude (Ajzen, 1991). This theory also widely implements in the domain of health behaviours, human behaviour, which significantly influence by behavioural intention (Cristea & Gheorghiu, 2016). More discussion of TPB will presented in following section. Additionally, Systems theory also have been utilized to analyse environment factor in this study to get clear understandings of all the variables in this study.

2.1.1 Theory of Planned Behaviour (TPB)

This study adopted the Theory of Planned behaviour as its underpinning theory. The Theory of Planned Behaviour (TPB) was developed by Ajzen, (2019). It was an extension of Ajzen's earlier work on the Theory of Reasoned Action (Ajzen & Fishbein, 1975). Over the decades, the TPB has been widely used and validated in various fields, including psychology, health, marketing, and Transportation to understand and predict human behaviour. It has been proven empirically by many researchers that TPB can predict the behavioural intentions of human beings (Ajzen, 2019). Intentions are translated into actual behaviour. They are three main components of this theory namely; attitude, subjective norm, and behavioural control (Ajzen, 1991). These three together predict the intention to act which subsequently materializes into actual behaviour.

According to Ajzen, (1991), attitude indicates "the degree to which a person has a favourable or unfavourable evaluation or appraisal of the behaviour in question (Ajzen, 1991). Ledesma et al., (2018) define attitudes as positive and negative evaluations an individual has about objects, concepts, or living things". Other scholars justify, attitude as a phenomenon that induces individuals to act in certain ways. In relation to road accidents, drivers' attitude towards safety precautions, regulations and other risky behaviours influences their intentions and actual behaviour (Ledesma et al., 2018). A positive attitude towards road safety will promote sustainable road safety on the roads. However, a negative attitude puts drivers and other road users at risk that can lead to accidents. Ajzen, (1991) also defined subjective norms as the global social pressure from the individuals close to the person (family and friends), who could affect the ethical decisions of the person. The third component of the theory is behavioural control. This refers to the ability to actualize a particular behaviour intention. The actual performance of intentions depends on nonmotivational factors such as the availability of requisite opportunities and resources. These include time, money, skills, access, cooperation of others (Ajzen, 1991).

This theory is significantly applicable in this field of sustainable road safety. The existing literature on road safety revealed that most accidents are caused by human (Ajzen, 1991; Lee

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

et al., 2008; Papantoniou et al., 2018). Consistently, TPB is a predictor of behaviour, it positively applicable for this study. Evidence of this theory been applied in road safety research included (Javid & Al-Hashimi, 2020; Ranaei et al., 2021, 2022). With this evidence, the theory implication to predictability and reliability. This study intends to employ it, to examine the relationship between the dependent and the independent variables of the study.

2.1.2 System Theory

Bertalanffy, (1972), a German scientist, introduced systems theory in the 1930s at a philosophy seminar at the University of Chicago. Initially developed in the context of life sciences, systems theory has evolved into the modern field of ecology. He defined a system as a coherent entity with discernible boundaries, distinguishing internal and external elements and identifying input and output relationships (Bertalanffy, 1972). Systems theory is a theoretical perspective that analyses phenomena as an interconnected wholes rather than as isolated components. Lai, (2017) believed that understanding a system required examining its interconnected components rather than isolating individual parts. In his work "General Systems Theory: Essays on Its Foundation and Development," by Bertalanffy outlines the objectives of systems theory as: (1) integration of various sciences, (2) development of a general theory of systems, (3) advancement of exact theory in non-physical fields, (4) establishment of unifying principles across different sciences, and (5) integration of scientific education (Bertalanffy, 1972). While systems theory was not originally intended for applications in communication, family studies, or applied science, it has proven valuable in understanding the systems of the world around us. Through systems theory, we can gain a deeper understanding of the world and explore problems and their underlying causes (Bertalanffy, 1972; Khuzwayo, 2020).

Systems can be found in nature, science, society, economics, and information systems (Larsson et al., 2010). A distinctive characteristic of systems theories is their simultaneous development across various disciplines. Scholars working from a systems theory perspective often build upon knowledge and concepts developed within other fields. Examples included natural and ecological sciences, with concepts such as organic aspects, homeostasis, and equifinality.

Additionally, systems theory can also be used to develop and evaluate effective environmental policies and interventions by considering the interconnectedness of different environmental factors (Leydesdorff, 1996). This view correlates with this study which examines the road safety environment. This includes safety strategies, mediating human, environmental, vehicle, and road infrastructure factors in a coherent manner to ensure the utmost safety of the road.

2.2 Factor Impact Sustainable Road Safety

Human factor impact on sustainable road safety

There are multiple complex causes collectively compromise sustainable road safety, with human factors consistently identified as the primary determinant (Bucsuházy et al., 2020). Road accidents are predominantly influenced by human behaviours (McCarty & Kim, 2024). Supporting this, the National Highway Traffic Safety Administration (NHTSA) consistently reports that human error is the leading cause of road crashes. The World Health Organization (WHO, 2018) further emphasizes the necessity of addressing human behaviour through targeted education, enforcement, and engineering interventions.

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

Academic research has extensively explored the psychological, social, and behavioural factors that amplify accident risk. For instance, Wang et al., (2019) determined that human factors encompassing driver behaviour, cognitive abilities, and physical conditions are the main determinants of road traffic accidents, accounting for an estimated 93% of incidents in Belgium. A comprehensive examination of human factors Alecu, (2019), Elslande & Naing, (2019), unequivocally identifies inappropriate driver behaviour as a primary factor. This detrimental behaviour spans a broad spectrum, including fatigue, lack of attention, aggressive driving, running red lights, speeding, driving under the influence, and breaking traffic regulation, all of which collectively contribute to a substantial proportion of accidents and critically undermine road safety by human factor.

2.2.1 Environment factor impact on sustainable road safety

Environmental factors in road safety refer to the specific conditions within the operational road setting that directly affect driver and consequently, heighten the probability of collision occurrence. These factors such as road conditions, weather, climate change, night time and lighting are substantial contributors to accident causation (Hammad et al., 2019). Specific weather conditions such as fog, rain, snow, and sun glare directly compromise road environment quality, while night-time and cloud cover affect ambient lighting of the road environment. Both weather and light conditions subsequently impair drivers' visibility and overall driving ability, leading to increased accident risk among road users (Mohtar et al., 2023). Previous research highlights the rainy season as a critical environmental factor. Sangkharat et al., (2021) found that the percentage of fatalities due to road accidents rapidly increases in areas with high rainfall. Rain compromises driving performance in multiple ways, including diminishing headlight effectiveness, reducing the clarity and contrast of objects and road markings, and distorting vehicle distance perception, thereby reduce road safety outcome.

Additionally, night driving represents another critical environmental factor impacting on sustainable road safety (Fleyeh & Mohammed, 2012). Reduced visibility during night-time makes it challenging for drivers to detect oncoming vehicles, pedestrians, or road elements, leading to delayed or erratic performance that compromises sustainable road safety. As Åkerstedt et al., (2001) established, darkness and inadequate or excessive lighting directly impair a driver's vision, consistently affecting safety outcomes. Moreover, recent literature demonstrates the escalating threat of climate change to road safety. Nazif-Munoz et al., (2021) showed that climate changes, including extreme temperatures and heavy rainy seasons, contribute to high fatalities in the USA. Supporting this, Akorli et al., (2024) found that climate changes significantly impact road crashes in Ghana, noting that rainfall trends negatively affect crash severity, with accidents increasing by approximately 3.59% during the wet season alone. Consistently, Islam et al., (2019) examined the effects of rainfall and sandstorms in Saudi Arabia, demonstrating a positive correlation between road accidents and the wet season, resulting in significant fatalities and high levels of injuries among motor vehicle users. Collectively, all these environmental and climate-related factors directly and substantially degrade the quality of sustainable road safety.

2.2.2 Mediating factor regulatory strategy impact on sustainable road safety

Regulatory strategies are fundamentally defined as the comprehensive framework of traffic rules, regulation, laws, and policies established to control the safe road environment to all road users, including vehicles, motorcycles, pedestrians, and general road transport (Zelikov et al., 2019). The aims of such regulation are broad, encompassing the achievement of efficient transportation, predictability, environmental protection, accessibility, safe driving practices, and overall transport sustainability (Zelikov et al., 2019). Multiple traffic rules and regulations must collaborate effectively to enhance sustainable road safety outcomes.

Current research identifies that major accident causes, including vehicle defects, infrastructure flaws, human errors, and adverse road environments, often arise from or are exacerbated by the failure to comply with existing governmental regulations (Lee et al., 2025). Consequently, implementing effective regulatory strategies is crucial for ensuring safer transportation and a sustainable environment for all road users (Lee et al., 2025). This sentiment is supported by Azmi et al., (2024), whose analysis of regulatory strategies clearly demonstrates that human errors and road negligence frequently manifesting as rules violations significantly increase accident rates. Furthermore Prakash Giri et al., (2024), found that a major contributing factor to accidents stemming from human behaviour is a lack of clear understanding and knowledge of traffic rules. A driver's negative attitude toward, and subsequent violation of, road safety rules critically compromise overall safety issues.

Beyond that, A study by Ahmed & Ghasemzadeh, (2018)analysed the effectiveness of driving speed regulation during adverse weather conditions, particularly the rainy season, finding a significant positive correlation with sustainable road safety . Their findings demonstrated that the implementation of flexible speed limits that adapt to adverse weather and changing climate conditions effectively mitigates accident risk. This principle of adaptive regulation is crucial as it acknowledges the reduced driver visibility and compromised vehicle performance inherent in severe weather, thereby allowing jurisdictions to proactively adjust operational parameters to sustain higher levels of road safety and prevent severity escalation Wang et al., (2021).

To address the human and environment factor, various rules and regulations are authorized by transport departments (Shukurov, 2023; WHO, 2018). Previous study by Landowski, (2018) demonstrates that specific traffic rules significantly improve sustainable road safety performance. The findings justify those regulations concerning speed limits, safety belt use, helmet use, child restraint systems, and the prohibition of impaired driving (drunk driving and intoxicating substances) all negatively influence hazardous driving behaviour. Additionally, research by Ahmed & Ghasemzadeh, (2018) highlights the impact of analysing and implementing driving speed regulation during adverse weather, particularly rainy seasons, on sustainable road safety. Their findings demonstrated that implementing revised speed limits during inclement weather and climate changes effectively reduces accident risk. These studies conclude that such rules and regulations resulted in a 23% reduction in accident severity occurrence which significantly improve sustainable road safety among drivers.

2.3 Research Gap and Innovation of This Research

Previous road safety research is often criticized for its fragmented and narrow focus, tending to examine individual accident causation factors such as driver behaviour or environmental conditions in isolation, which fails to capture the complex interplay needed for comprehensive policy (Salmon et al., 2019; Shahid & Minhans, 2016). Specific analyses, including those conducted in Malaysia, have either limited their scope to specific variables or geographic areas (Bucsuházy et al., 2020; Khairul et al., 2018) resulting in an incomplete picture regarding the full impact of human behaviour, safety education, and technological elements. This fragmented approach constitutes the core research gap, hindering a holistic understanding of accident causation and its impact on sustainable road safety. To address this, this research offers a major innovation by proposing and testing an integrated theoretical

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

model where sustainable road safety serves as the dependent variable, and crucially, by introducing regulatory strategy as a mediator variable. This novel, comprehensive structural analysis will allow for a more actionable framework, providing evidence that directly encourages policymakers and authorities to implement more integrated and effective road safety measures.

2.4 Research framework

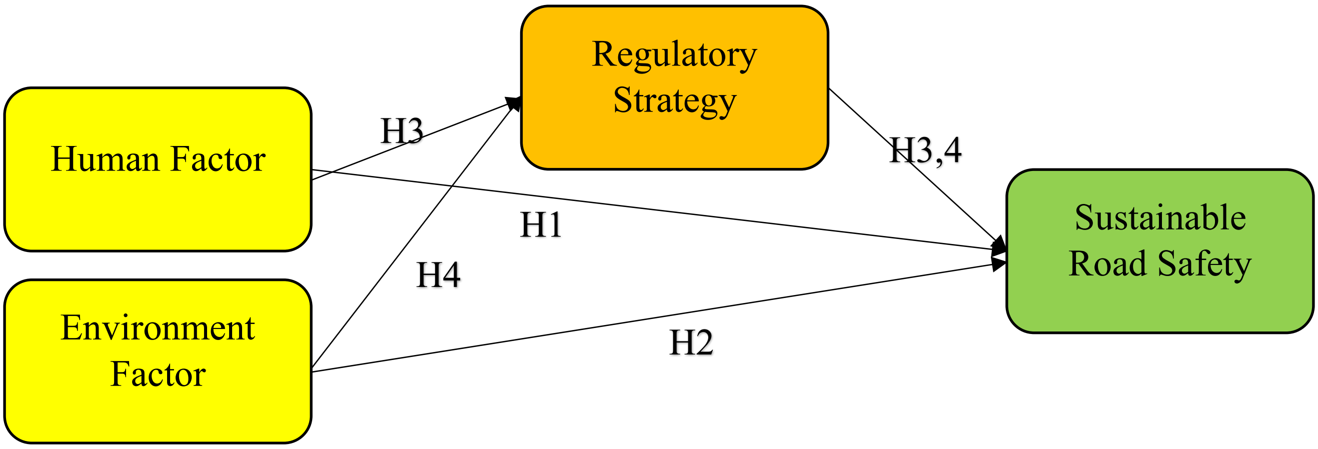

Figure 1: The Conceptual Model of The Research

2.5 Hypothesis development

This study investigates the relationship between road accident factors and sustainable road safety. While road accident factors are hypothesized to directly impact sustainable road safety, a mediator variable is expected to exert an indirect impact on this relationship. Furthermore, this research explores how regulatory strategies influence (mediator) the relationship between these variables. The following hypotheses were developed based on the literature review and theoretical frameworks.

THE DIRECT EFFECT ON SUSTAINABLE ROAD SAFETY

2.5.1 Human factor and Sustainable Road Safety

The Theory of Planned Behaviour (TPB) is frequently applied in the fields of road safety and human factors, specifically focusing on the attitude toward the human behaviour, which is instrumental in improving road safety knowledge and awareness of accident risk through a driver's disposition. Within human factors, this attitude encompasses a driver's self-assessment of their driving skills and their disposition toward violating traffic regulations, often leading to road accidents (Ledesma et al., 2018). Attitude toward behaviour, as defined by Ajzen, (1991), can be positive or negative, with this valence directly affecting an individual's intention to execute a behaviour; positive attitudes stem from beliefs in valued outcomes, while negative attitudes arise from beliefs in negatively valued outcomes (Canova & Manganelli, 2020). The high incidence of road accidents, which substantially reduces sustainable road safety primarily due to human factors (Payani et al., 2019) necessitates an examination of driver intentions. Research confirms the significant effect of the human factor

Received: August 07, 2025

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

on road safety (Irawati & Khair, 2021; Reseai, 1982; Shukurov, 2023).Although some studies indicate a positive association between attitude and the human factor, others, including topic Cristea & Gheorghiu, (2016); Ledesma et al., (2018) have concluded that negative attitudes toward human factors negatively impact sustainable road safety.

H_{1a}: Human Facto positively and significantly influence sustainable road safety outcomes in Malaysia

2.5.2 Environment factor and Sustainable Road Safety

The National Incident Database (NID) reports that environmental factors are significant contributors to road accidents (Goode et al., 2015). System theory, specifically the element of "nature," helps identify these environmental factors that compromise sustainable road safety. Goode et al., (2015) justify these factors as adverse weather conditions such as rainy, foggy, snowy, or stormy weather and poor visibility which are among the most impactful elements affecting road safety. Earliest study data support the system theory argument by Yu & Dawson, (2014) that reduced visibility and other environmental factors can impair driving ability, increasing accident risk and minimizing sustainable road safety. Specifically, their findings demonstrate a significant positive correlation between poor visibility and road accidents. In a similar vein, Tregear et al., (2010) found that driving performance and road safety depend on environmental factors such as wind speed, poor visibility, and general adverse conditions, all of which can elevate the risk of road accidents among road users.

H_{1b}: Environmental conditions are positively and significantly influence sustainable road safety outcomes in Malaysia

THE MEDIATING EFFECT ON SUSTAINABLE ROAD SAFETY

2.5.3 Regulatory Strategies and Human Factor on Sustainable Road Safety

Ajzen, (1991), posits that sustainable road safety can be effectively integrated and understood through the attitude that stems from human factors. Empirical evidence supports this, as study findings indicate that including attitude toward human factors within the TPB significantly increases the explanatory power of the model and strengthens its relevance to road safety (Setyowati et al., 2024).

Furthermore, the research justifies that human behaviour can be managed and directed through regulation strategy, which is essential for establishing and maintaining sustainable road safety. This emphasis on governance is echoed by more recent work, such as Lajunen, (2009), which suggests that implementing proper regulatory strategies concerning human factors positively enhances sustainable road safety and is effective in mitigating accident issues.

$H_{2a:}$ Regulatory strategies mediate the relationship between human behaviour factors and sstainable road safety.

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ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

2.5.4 Regulatory Strategies and Environment Factor on Sustainable Road Safety

Empirical evidence consistently demonstrates that environmental factors significantly impact on sustainable road safety , Zou et al., (2024) Pińskwar et al., (2024) . Within the system theory framework, the "nature" component encompasses adverse conditions such as rain, snow, fog, slick pavement, and mud. These weather conditions, as noted by Ahmed & Ghasemzadeh, (2018), directly compromise road safety by influencing pavement condition, degrading vehicle performance, and reducing driver visibility.

Given these variables, implementing an adaptive regulatory strategy is deemed essential Horn & Jannsson, (2000). Specifically, adjusting speed limits based on dynamic weather conditions is capable of mitigating accident issues. Research suggests that these flexible regulations varying speed limits according to weather can significantly improve sustainable road safety (Hasson et al., 2000; Helbing, 1998). This view is supported by earlier studies, such as researcher Zhang et al., (2014),, which argued that speed limit regulations effectively minimize accident risk during inclement weather. Therefore, regulatory strategy functions as a crucial mediating variable that positively enhances road safety by addressing the risks introduced by environmental volatility.

H_{2b}: Regulatory strategies mediate the relationship between environmental factors and

sustainable road safety.

3.Methodology

This research aims to systematically examine the direct effect of human factor and environment factor on sustainability road safety and mediate by regulatory strategy on this study. To ensure the rigor and repeatability of the research, this section elaborates on four aspects: research design, sample and data collection, measurement tool development and reliability and validity testing, and data pre-processing and analysis methods.

3.1 Research Design

This study employs a quantitative research approach utilizing a correlational design and a Structural Equation Model (SEM) to test the hypothesized relationships. This methodological selection precisely aligns with the study's objective to measure and quantify variables related to road accident trends, sustainable road safety factors, and the mediating influence of regulatory strategy. A questionnaire survey was chosen as the most appropriate data collection instrument due to its efficacy in systematically gathering standardized information from a large pool of respondents (Spanos, 2007). Consequently, the current research employed self-administered, structured questionnaires. The items within these questionnaires were primarily adopted from pertinent previous studies and meticulously refined to operationalize the specific constructs of the present investigation. Given that the research involves mediation effect analysis, the Partial Least Squares Structural Equation Modelling (PLS-SEM) method is utilized. PLS-SEM is particularly advantageous for this study as it has minimal requirements concerning sample distribution assumptions, can effectively manage complex model structures, and is robust when dealing with multidimensional constructs (Arifin, 2023; Hair, 2019; Hair & Alamer, 2022; Hair et al., 2019)

Received: August 07, 2025

Volume 38 No. 12s, 2025
ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

3.2 Sample and Data Collection

This study strategically focuses on the three Malaysian states reporting the highest incidence of road accidents: Selangor, Johor, and Kuala (Azan et al., 2023; Mohd Azami et al., 2024; Shaadan & Suhaimi, 2021). These states were specifically chosen for their diverse characteristics, including varying degrees of urbanization, robust economic activities, and complex traffic conditions, thus offering a comprehensive and representative basis for analysing factors influencing road safety (Mohd Azami et al., 2024).

To ensure robustness and proportional representation, a stratified sampling technique was employed. This method was selected to effectively address the inherent heterogeneity across the selected high-risk states, guarantee proportional data collection based on each state's accident statistics, enhance the precision of estimates by reducing variability within strata, and facilitate subsequent subgroup analysis (Iliyasu & Etikan, 2021). The procedure involved the following steps: first, the population was divided into three distinct state-based strata; second, a common sampling frame Malaysian residents possessing valid driving licenses and active driving experience was defined for each stratum; and finally, proportional allocation was used to determine the necessary sample size from each state. Within each established stratum, a simple random sampling method was subsequently used to select the participants. Based on a calculation using a 95.0% confidence level and a 0.05 margin of error, the total required sample size was determined to be 384 respondents drawn from these high-accident states.

Data collection was executed using a self-administered questionnaire deployed via Google Forms. This platform offers significant advantages, including its cost-free accessibility and intuitive design. Crucially, its seamless integration with Google Sheets facilitates real-time, error-free data collection, automatically generating a structured dataset ready for immediate analysis. Furthermore, the forms are mobile-friendly and support diverse question formats, ensuring efficient and convenient data gathering from a broad respondent base.

3.3 Measurement Tool Development and Reliability and Validity Test

The constructs in this study were operationalized using a multi-item scale approach adapted from established literature to ensure reliable and valid measurement of the latent variables. Specifically, the two Independent Variables, Human Factor and Environment Factor—were each measured using five (5) items, as was the Regulatory Strategy (Mediator Variable) and Sustainable Road Safety (Dependent Variable). This study employs a widely accepted five-point Likert scale for quantification, ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree") (Armstrong, 1987; Roselidyawaty & Mohd Rokeman, 2024). This established numerical scaling method provides a robust framework for systematically quantifying respondents' attitudes, opinions, and perceptions concerning the constructs within the proposed model.

Reliability test

SPSS version 23.0 was utilized to assess the internal consistency of each construct by calculating Cronbach's Alpha and Composite Reliability (CR). For the scales to demonstrate good internal consistency, both the Cronbach's Alpha and CR values were required to meet the threshold of ≥ 0.70.

Convergent Validity and Discriminant Validity

To begin with, it is convergent validity, which checks whether the standardized factor loading of each item is ≥ 0.70 and the Average Variance Extracted (AVE) is ≥ 0.50 (Courvoisier

International Journal of Applied Mathematics
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ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

et al., 2008; Fornell & Larcker, 1981). Following this, it is discriminant validity, which uses the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio (HTMT) method, requiring that the square root of AVE is greater than the correlation coefficient between latent variables and HTMT < 0.085 (Voorhees et al., 2015).

Data processing and analysis methods

Data cleaning

The collected data underwent rigorous pre-processing within SPSS (Statistical Package for the Social Sciences) to ensure quality and suitability for subsequent analysis. The cleaning process began with missing value analysis, where items exhibiting a missing rate of less than 5% were processed using the mean interpolation method; conversely, any questionnaire with a missing rate exceeding 5% was systematically excluded. Next, a normality test was conducted, confirming a composite normal distribution if the absolute values of both skewness and kurtosis were found to be ≤2 (Kim, 2013). Finally, a multicollinearity test was performed using the Variance Inflation Factor (VIF) indicator, requiring a threshold of VIF < 5 to ensure independent variables were not overly redundant (Wangikar & Deshmukh, 2011).

SEM Modelling and Mediation Analysis

Following the completion of data cleaning, the purified dataset was imported into SmartPLS 4.0 software for the execution of the Partial Least Squares Structural Equation Modelling (PLS-SEM) analysis, which proceeded in a systematic, multi-step sequence (Cheah et al., 2024). The first step involved rigorously evaluating the measurement model to establish reliability and validity by testing item loadings, Composite Reliability (CR), Average Variance Extracted (AVE), and Discriminant Validity (Baharum et al., 2023). Subsequently, the structural model was estimated; the significance of the direct path coefficients (β) was calculated using the Bootstrapping procedure (5,000 samplings, unbiased correction) to derive the corresponding t-values and p-values (Kock, 2018). Following this, the mediation effect was tested, with the Bootstrapping method yielding the indirect effect and its 95% confidence interval; the mediation was deemed significant if this interval did not contain zero (Taylor et al., 2008). Finally, the overall model's explanatory power and predictive relevance were assessed and reported using key metrics such as the coefficient of determination (R^2) and the predictive relevance index (Schuberth et al., 2023; Voorhees et al., 2015).

4.Analysis and Result

Leveraging the established research methodology, the valid questionnaire data was subjected to a rigorous structural equation modelling (SEM) analysis. This process encompassed data screening, descriptive statistics, multicollinearity assessment, measurement model evaluation, structural model evaluation, hypothesis testing, and mediation effect analysis. All preliminary calculations were performed using SPSS 23.0, with the core SEM computations executed in Smart PLS 4.0, the comprehensive results of which follow.

4.1 Measurement Model Evaluation

The data were analysed using the variance-based Smart PLS software, primarily selected for its robust capability in handling complex relationships within Structural Equation Models (SEM). Specifically, Smart PLS is particularly suitable for studies involving small samples or non-normal data due to its sophisticated analytical options for estimating construct

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relationships (Hair et al., 2021). The research employed Smart PLS to empirically test the hypothesized constructs and relationships via a two-stage analytical procedure, beginning with the measurement model assessment in the initial stage.

The two-stage analytical procedure commenced with the assessment of the constructs' psychometric properties, where internal consistency was established using Cronbach's alpha and discriminant validity was tested via the Average Variance Extracted (AVE). Subsequently, the second stage involved evaluating the structural model by testing the path coefficients to ascertain the significance and direction of the hypothesized associations. A Bootstrap analysis was concurrently executed to determine the significance and confidence intervals for both the direct path coefficients and the indirect effects. This rigorous approach provided researchers with insightful interpretations of the complex relationships among road accident factors, sustainable road safety mediates by regulatory strategy by first confirming the reliability of the measures and then thoroughly investigating the hypothesis test and direct and indirect effects within the proposed model of this study.

Table 1 clearly justify the analysis of the constructs used in this research. The assessment of the measurement model confirms the high quality and psychometric soundness of all constructs by verifying both their internal consistency and convergent validity. All four constructs (Environment Factor, Human Factor, Regulatory Strategy, and Sustainable Road Safety) exhibited excellent internal reliability, demonstrated by Cronbach's Alpha values ranging from 0.893 to 0.945, and Composite Reliability (CR) values between 0.921 and 0.958, significantly exceeding the conventional benchmarks of 0.70 and 0.80, respectively. Furthermore, convergent validity is strongly supported, as all individual Factor Loadings are above the 0.70 threshold (minimum 0.803), and the Average Variance Extracted (AVE) values range from 0.699 to 0.820, comfortably surpassing the required 0.50. These results affirm that the measurement instruments are highly reliable and valid for subsequent structural model analysis.

Table 1: Reliability and Convergent Validity of Constructs

	Items	**Factor Loading**	**Cronbach's Alpha**	**CR**	**AVE**
Environment Factor	EF1	0.803	0.893	0.921	0.699
	EF2	0.848			
	EF3	0.854			
	EF4	0.827			
	EF5	0.847			
Human Factor	HF1	0.912	0.945	0.958	0.820
	HF2	0.893			
	HF3	0.908			
	HF4	0.917			
	HF5	0.896			
Regulatory Strategy	RD1	0.921	0.910	0.933	0.735

Received: August 07, 2025

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

	RD2	0.893			
	RD3	0.910			
	RD4	0.896			
	RD5	0.904			
Sustainable Road Safety	RDS1	0.872	0.945	0.958	0.819
	RDS2	0.846			
	RDS3	0.859			
	RDS4	0.854			
	RDS5	0.856			

4.2 Structure Model Evaluation

The final phase of the measurement model evaluation involved assessing discriminant validity using the Heterotrait-Monotrait Ratio (HTMT), which verifies that each construct is empirically distinct from the others in the model. Following the established criteria by (Henseler et al., 2015), the HTMT values should ideally be below the critical threshold of 0.90 (or < 0.85 for conceptually similar constructs). As evidenced in **Table 2**, the HTMT ratios across all constructs range from a minimum of 0.421 to a maximum of 0.621. Since all these values are well below the required 0.90 cut-off, the results provide strong evidence that discriminant validity is established, confirming that the latent variables are measuring unique concepts and are adequately differentiated from one another, thereby validating the integrity of the overall measurement model for proceeding with the structural model analysis.

Table 2: HTMT Discriminate Validity Analysis Results

	Environment Factor	Human Factor	Regulatory Strategy	Sustainable Road Safety
Environment Factor				
Human Factor	0.475			
Regulatory Strategy	0.421	0.621		
Sustainable Road Safety	0.546	0.543	0.589	

Discriminant validity was conclusively established using the Fornell-Larcker criterion, as detailed in **Table 3** below. This method requires that the square root of the Average Variance Extracted (AVE) for each latent construct (the diagonal values) must be greater than its correlations with all other constructs (the off-diagonal values). The results consistently satisfy this condition; for instance, the AVE values of 0.836 for the Environment Factor and 0.905 for the Human Factor are both significantly higher than any corresponding inter-construct correlations (e.g., 0.441 between them). This systematic finding confirms that the variance explained by each construct is greater than the variance shared between constructs, providing conclusive evidence that all latent variables in the model are empirically distinct, thereby validating the integrity of the measurement model.

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Table 3: Fornell-Larcker analysis result

	Environment Factor	Human Factor	Regulatory Strategy	Sustainable Road Safety
Environment Factor	**0.836**			
Human Factor	0.441	**0.905**		
Regulatory Strategy	0.396	0.590	**0.905**	
Sustainable Road Safety	0.495	0.505	0.551	**0.857**

Note: the values in the diagonals cells (bold) are the squared root of the AVE while the un-bolded values are the correlations

The Fornell-Larcker criterion provides strong empirical confirmation of discriminant validity, as the square root of the Average Variance Extracted (AVE) for each construct consistently surpasses its correlation with all other variables in the model. For instance, the Environment Factor's (0.836) is higher than its highest inter-construct correlation (0.441 with the Human Factor), and similarly, the Human Factor's (0.905) exceeds its maximum correlation (0.590 with Regulatory Strategy). The Regulatory Strategy's (0.905) also demonstrates clear distinctiveness by surpassing its correlation with Sustainable Road Safety (0.551). These systematic findings indicate that the variance internally explained by each construct significantly outweighs the shared variance between them, leading to the conclusion that all latent variables exhibit excellent discriminant validity according to the Fornell-Larcker standard.

Table 4 details the assessment of the structural model's predictive accuracy through the R^2 and Adjusted R^2 values for the endogenous variables. The results indicate that the antecedent constructs account for a substantial level of variance in the dependent variables: Regulatory Strategy exhibits an R^2 of 0.371 (37.1) and an Adjusted R^2 of 0.368 (36.8), while Sustainable Road Safety demonstrates an R^2 of 0.415 (41.5%) and an Adjusted R^2 0.410 (41.0%). Given that a variance explained of 20.0% is commonly considered robust in management, social science, and economics (Stoffel et al., 2021), both R^2 and Adjusted R^2 values, which significantly exceed this 0.20 threshold, confirm that the independent variables possess strong explanatory power for their respective dependent variables (Schober et al., 2018; Stoffel et al., 2021).

Table 4: R^2 Adjusted Analysis Results

Variable	**R-Square**	**R-Square Adjusted**
Regulatory Strategy	0.371	0.368
Sustainable Road Safety	0.415	0.410

Table 5: Demographics Information of Respondent

Variables	**Frequency**	**Percentage**	**Mean**	**Standard Deviation**

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Age Group			30.97	12.1
18-25	181	49.90%		
26-35	80	22%		
36-45	49	13.50%		
46-55	28	7.70%		
56 >	25	6.90%		
Gender				
Female	230	63.40%		
Male	133	36.60%		
State				
Selangor	205	56.50%		
Johor	100	27.50%		
Kuala Lumpur	58	16%		
Education Level				
High school	42	11.60%		
University studies (Under Graduate)	270	74.40%		
University studies (Post Graduate)	51	14%		
Driving experience				
1< year	67	18.5%		
1-3 year	102	28.1%		
4-7 year	67	18.5%		
8-10 year	25	6.9%		
10 > years	102	28.1%		
How often do you drive				
Daily	162	44.6%		
Weekly	91	25.1%		
Monthly	49	13.5%		

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Occasionally	61	16.8%		
Have you ever been involved in a road accident				
Yes	165	45.50%		
No	198	54.50%		

The findings from the demographic analysis of the sample (N=363) are detailed in **Table 5.** The sample exhibits a relatively young profile, with an overall mean age of 30.97 years (SD=12.1), and the largest single group being individuals aged 18-25 years, comprising nearly half of the sample (49.90%). Regarding Gender, the survey included a higher proportion of Female respondents (63.40%) compared to Male respondents (36.60%). Geographically, the sample is concentrated in major urban centres, primarily Selangor (56.50%), followed by Johor (27.50%) and Kuala Lumpur (16.0%). The respondents are highly educated, with the vast majority reporting University studies (Under Graduate) as their highest level of education (74.40%). In terms of Driving Experience, the distribution shows concentration at the extremes, with high frequencies in the shortest (1 < year: 18.5%) and longest (10 > years:28.1%) driving experience categories. Furthermore, a substantial proportion of respondents drive Daily (44.6%), confirming frequent road exposure. Finally, while most respondents reported never involved in a road accident (54.50%), a notable 45.50% indicated Yes, suggesting a significant number of participants have direct experience with road accidents.

Hypothesis Testing

The Path Coefficient is a fundamental statistical measure integral to the hypothesis testing of structural models. Analogous to the beta weight in traditional regression analysis, it quantifies the strength of the linear relationship between variables within the model. Its value ranges from -1 to +1. A value approaching zero signifies a weak or negligible relationship, while values near -1 or +1 indicate a strong negative or positive correlation, respectively. The determination of the coefficient's significance relies on several statistical indicators: its Standard Error (SE), which gauges the precision of the estimate (smaller SE indicates higher precision); and the T-Value and P-Value, which determine statistical significance. Specifically, a P-value less than the predetermined significance level (set at 0.001 for this research) confirms a statistically significant relationship. This rigorous assessment paves the way for researchers to draw confident and useful conclusions from the structural model. For instance, **Figure 3** schematically illustrates the relationships among the latent variables Human Factor, Environment Factor, Regulatory Strategy, and Sustainable Road Safety by structure model

The structural model analysis reveals the direct influence of the antecedent factors on the endogenous variables, quantified by the standardized path coefficients (β). The Human Factor exhibits the strongest direct influence on Regulatory Strategy (β = 0.516), indicating that variations in human-centric issues are highly effective in driving regulatory changes. Concurrently, the Environment Factor shows an equally robust direct influence on

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Sustainable Road Safety (β = 0.516), emphasizing that environmental considerations are paramount to safety outcomes. Furthermore, Regulatory Strategy exerts a significant, direct positive effect on Sustainable Road Safety (β = 0.328), suggesting that effective policies serve as a crucial mechanism for achieving safety goals. The comparatively smaller but still positive paths from the Environment Factor to Regulatory Strategy (β = 0.169) and the Human Factor to Sustainable Road Safety (β = 0.187) suggest that while all factors contribute, the identified paths of β =0.516 are the most dominant relationships in the proposed theoretical structure. The results of all direct and indirect mediation path relationships are presented in **Table 6.**

Table 6: Direct and Indirect Mediation Path Relationship Analysis Result

Hypotheses	Relationships	Beta	SD	T statistics	P values	Decision
H1	Human Factor -> Sustainable Road Safety	0.187	0.066	2.827	0.005	Supported
H2	Environment Factor -> Sustainable Road Safety	0.283	0.061	4.607	0.000	Supported
H3	Human Factor -> Regulatory Strategy -> Sustainable Road Safety	0.169	0.042	4.002	0.000	Supported
H4	Environment Factor -> Regulatory Strategy -> Sustainable Road Safety	0.055	0.021	2.592	0.010	Supported

Note: all hypothesized paths received significant support (p< 0.01),

RQ1: Does the road accident factors directly impact on sustainable road safety

RQ2: Does the mediator regulatory strategy impact on road accident factors and sustainable road safety

Figure 2: SEM analysis result by Measurement Model

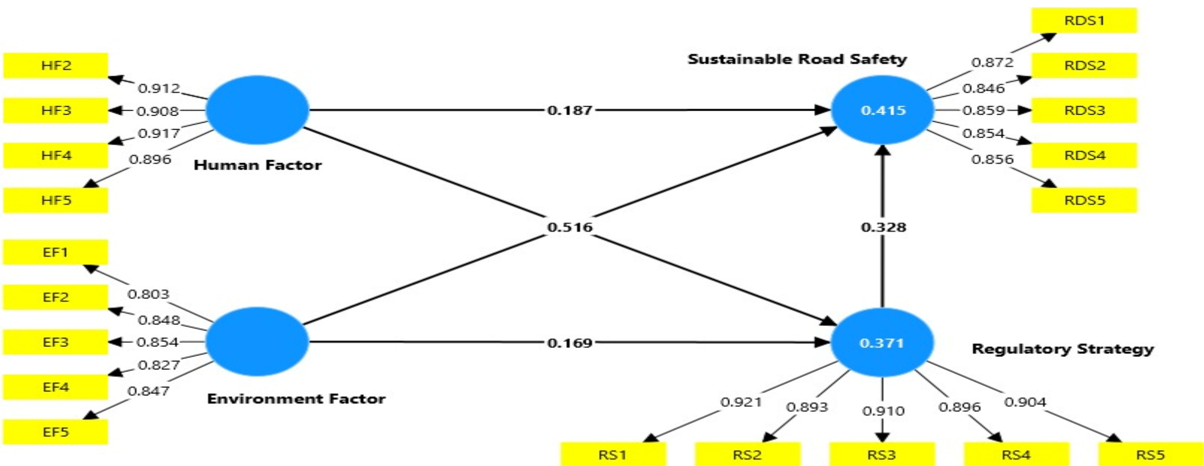

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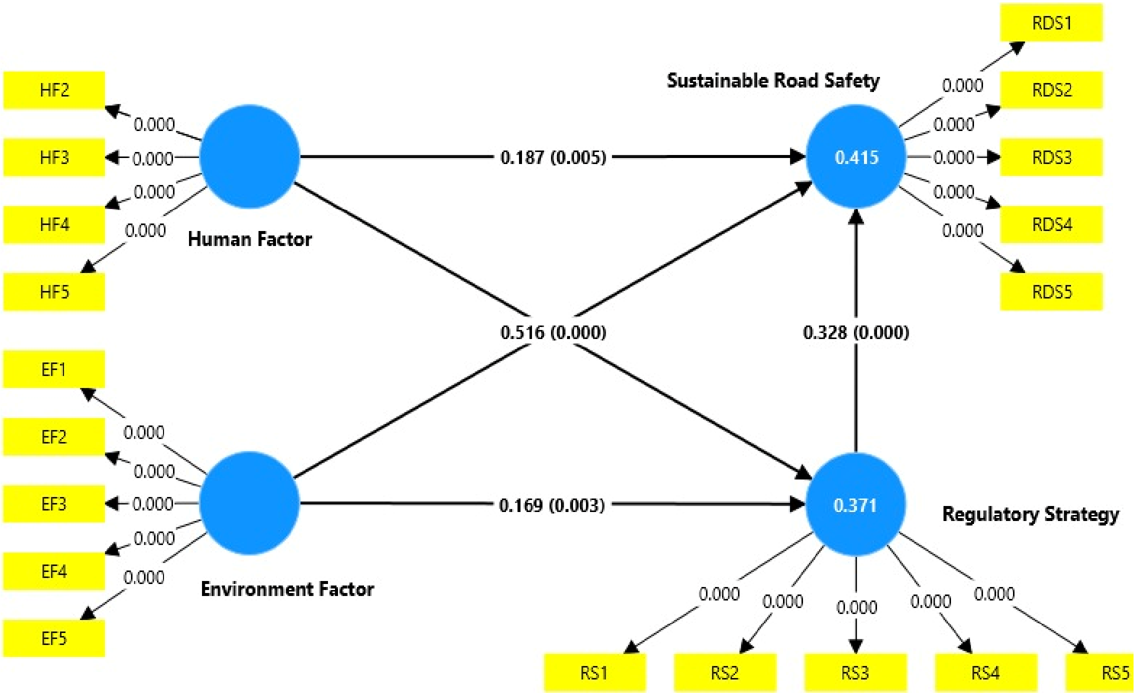
Figure 3: SEM analysis result by Structure Model



5. Discussion

This section elucidates the Research Objectives (ROs) of the study and clearly articulates how the empirical findings effectively meet and satisfy each specified aim.

RO1: To investigate the direct impact of road accident factors on sustainable road safety. The empirical evidence: human factor and sustainable road safety ß= 0.187 ($p<0.001$); environment factor and sustainable road safety ß= 0.283 ($p<0.001$)

RO2: To examine the mediating role of regulatory strategy on the relationship between road accident factors and sustainable road safety. Empirical evidence: indirect effects are as illustrated, human factor and sustainable road safety (ß= 0.169 ($p<0.001$); environment factor and sustainable road safety (ß= 0.055 ($p<0.001$)

The core finding of this research lies in the successful confirmation of the mediating role of Regulatory Strategies. The results of the indirect paths demonstrate that Regulatory Strategies significantly channel the effects of the antecedent variables toward the final outcome of sustainable road safety.

Specifically, the indirect path from the Human Factor to Regulatory Strategies was found to be statistically significant and positive ß= 0.187 < 0.001). This confirms that while human factors are necessary, their full potential for achieving SRS is realized *through* the regulatory structure. In essence, positive human attitudes and practices are translated into systemic road safety improvements when they are formalized and enforced by regulation.

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A similar pattern was observed for the indirect path from the Environment Factor ß= 0.283 ($p<0.001$). This provides strong evidence that investments in the environment must be accompanied by, or embedded within, regulatory mandates to effectively and reliably contribute to SRS. These findings collectively establish that Regulatory Strategies serve as a vital intermediary and are not merely passive recipients of influence but an active mechanism necessary for transforming upstream variables into sustainable road safety performance.

6. Conclusion

The analysis conclusively validated the proposed model for achieving Sustainable Road Safety (SRS) in Malaysia, confirming that all hypothesized structural paths are positive and statistically significant. The direct effect analysis revealed the Environment Factor as the most immediate determinant of SRS (ß = 0.283, $p < 0.001$), signifying that investment in infrastructure and technology provides the strongest direct return on safety. In contrast, the Human Factor showed a strong influence on regulatory mechanisms (ß = 0.187, $p < 0.001$), underscoring the necessity of human compliance in shaping effective governance. Crucially, the study confirms the mediating role of Regulatory Strategies as a vital, active channel linking the antecedent factors to SRS. This is supported by the significant indirect effects, particularly the strong mediation path from the Human Factor (ß = 0.169) and the weaker but significant path from the Environment Factor (ß= 0.055). These findings justify the model's structure, asserting that while infrastructural improvements directly enhance safety, the successful transformation of human-centric interventions into systemic, long-term safety outcomes relies heavily on being formalized and enforced through robust regulatory policies. In conclusion, the achievement of sustainable road safety necessitates a targeted, integrated approach that leverages both substantial environmental upgrades and the active enforcement of regulatory strategies to institutionalize safer behaviours and conditions.

6.1 Theoretical Implication

This study significantly contributes to theoretical frameworks by integrating and extending the foundational concepts of the Theory of Planned Behaviour (TPB) and Systems Theory within the domain of sustainable road safety. The structural model's findings validate the Systems Theory principle of interconnectedness, shifting its application from a conceptual perspective to an empirically validated causal model. By simultaneously assessing the influence of the Human Factor and the Environment Factor, the research formally establishes road safety as an open system where distinct subsystems interact to produce an outcome, confirming that effective safety is not an isolated component but a coherent output of complex interactions Bertalanffy, (1972). More importantly, the findings expand the conventional application of TPB (Ajzen, 2019) by demonstrating how macro-level constructs, specifically Regulatory Strategy, mediate the relationship between human and environment factor sustainably improve sustainable outcome. While TPB traditionally focuses on individual intention (Attitude, Subjective Norm, and Perceived Behavioural Control), this study introduces an essential systemic layer by proving that external regulatory strategy driven by human and environmental inputs serve as a structured manifestation of Perceived Behavioural Control or a subsequent necessary condition for translating system-wide intentions into sustained system performance.

6.2 Practical Implication

The empirical findings of this study offer several practical implications for policymakers, regulatory bodies, and practitioners tasked with enhancing Sustainable Road Safety (SRS) in

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Malaysia. The confirmation of Regulatory Strategies as a significant mediator between the Human and Environment Factors and SRS underscores that efforts should prioritize the strategic design and robust enforcement of regulation. Specifically, regulatory bodies must move beyond generic traffic laws to develop targeted policies that operationalize behavioural and environmental improvements. This includes implementing regulations that mandate the integration of safety technologies (Environmental Factor) and fostering a regulatory culture that emphasizes continuous training and public accountability (Human Factor). Given the high ß value for the direct path from Regulatory Strategies to SRS, resources should be allocated to enhance monitoring capabilities, increase the precision of enforcement, and ensure swift, consistent penalties for non-compliance. Furthermore, the results indicate that programs aimed at improving driver behaviour or infrastructure quality will achieve maximum effectiveness only when they are formalized and supported by a strong legal and enforcement framework, ensuring that positive changes are institutionalized rather than transient.

6.3 Future Research

While this study provides a validated model for the achievement of Sustainable Road Safety (SRS) in Malaysia, it also suggests several avenues for future research. First, this research adopted a cross-sectional design; subsequent studies should consider a longitudinal approach to observe the lagged effects of regulatory strategies and determine the time required for specific regulations to yield measurable improvements in SRS outcomes. Second, while the study analysed the latent constructs of Human and Environment Factors, future work could benefit from disaggregating these factors into more specific, measurable variables, such as focusing exclusively on the impact of distracted driving regulations or the role of Intelligent Transport Systems (ITS) adoption. Third, given the regional variation in road safety standards, future researchers should replicate this model in different geographical contexts within Southeast Asia or other developing nations to assess the generalizability and potential boundary conditions of the mediating role of Regulatory Strategies. Finally, employing qualitative methods alongside the quantitative framework could provide deeper insights into the perception of regulatory compliance among road users and enforcement officers, enriching the understanding of the theoretical mechanism confirmed herein.

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