International Journal of Asian Social Science
ISSN(e): 2224-4441
ISSN(p): 2226-5139
DOI: 10.55493/5007.v16i4.5929
Vol. 16, No. 4, 209-223

URL: www.aessweb.com

A conceptual framework of the road safety index for motorcyclists among school students in Malaysia based on a systematic literature review

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Article History
Received: 8 December 2025
Revised: 30 January 2026
Accepted: 24 February 2026
Published: 6 March 2026

Keywords
Motorcycle user
Road safety
Safe system
Safety index
School student
Malaysia.

ABSTRACT

Motorcycle accidents contribute substantially to road fatalities in Malaysia, particularly among school-aged motorcyclists. Despite the implementation of various road safety initiatives, accident statistics continue to rise, indicating the limited effectiveness of existing interventions. Road safety indices are widely used to assess safety performance and identify areas for improvement; however, most existing indices focus on general road users and lack specificity for school students. To address this gap, this study proposes a Road Safety Index (RSI) that measures road safety among school-aged motorcyclists in Malaysia. A systematic literature review (SLR) is conducted using Scopus, Web of Science, MyCite, and Google Scholar to identify relevant studies related to road safety and motorcycle safety in the context of school students. Following the PRISMA guidelines, 22 articles published between 2021 and 2025 are identified. Based on the review, a multidimensional conceptual framework for the proposed RSI is developed, grounded in the Safe System Approach advocated by the World Health Organization (WHO). The framework comprises five key components: safe users, safe vehicles, safe environments, policy and education, and post-crash management. The proposed RSI is aligned with national and global road safety visions, including the Malaysia Road Safety Plan 2022-2030 and Sustainable Development Goal target 3.6.

Contribution/ Originality: This study introduces a novel and multidimensional RSI framework that is designed specifically for school-aged motorcyclists by filling a critical gap in the recent indices. The framework integrates the Safe System Approach by the WHO with context-specific behavioral, infrastructural, and policy indicators.

1. INTRODUCTION

Road accidents are a major global concern, causing over 1.19 million deaths annually. They are also recognized as the primary cause of mortality among individuals aged 5 to 29 years old. Unlike other larger vehicle occupants, motorcyclists are particularly vulnerable to road accidents due to the minimal physical protection motorcycles provide in a crash and their high exposure on the road, especially in low- and middle-income countries (LMICs), where motorcycles are a common economical mode of transport. Malaysia also shares a similar concern regarding road safety involving motorcyclists, whereby Royal Malaysia Police (PDRM, 2020) reports that 60% of all road traffic

fatalities in the country are caused by motorcyclists, including students. In response, the government implements the Malaysia Road Safety Plan (MRSP) 2022-2030 (Ministry of Transport Malaysia, 2022), which is mainly structured based on the Safe System Approach. Despite institutional efforts, statistics show a rising trend in road accidents, highlighting the importance of other crucial factors, including behavioral ones, contributing to accidents and fatalities, especially among young motorcyclists.

Road safety indices are introduced to evaluate and monitor safety performance in countries across various regions. For example, the Road Safety Performance Index (RSPI) is used to measure and compare road safety performance across European countries. As for Asian countries, common indices include composite indices based on fuzzy logic, Data Envelopment Analysis (DEA), and Multi-Criteria Decision-Making (MCDM). However, these indices only focus on macro-level safety performance, i.e., at the national level, and overlook critical factors such as behavioral, infrastructural, and educational factors that contribute to the risk of accident injuries and fatalities, specifically among school-aged motorcyclists. Therefore, there is a compelling need to develop a comprehensive framework that addresses the safety of school-going motorcyclists.

This study identifies the gap through a systematic literature review (SLR) that synthesizes empirical and theoretical findings on road safety indices, motorcycle risk factors, and riding behavior among adolescents. A conceptual RSI framework for school-aged motorcyclists in Malaysia is then proposed by integrating the principles of the Safe System Approach with quantitative index-construction methods drawn from established models, including the WHO Road Safety Maturity Index (RSM) and Al-Haji's Road Safety Development Index (RSDI). Using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, the review addresses the following research questions.

i. What are the major factors influencing road safety among school-aged motorcyclists?
ii. What are the indicators and measurement approaches applied in the present road safety indices in the context of school-aged motorcyclists?
iii. What constitutes a comprehensive Road Safety Index for school-aged motorcyclists?

The proposed index contributes significantly to the existing body of knowledge on road safety and fundamentally guides effective road safety policies and practical interventions to reduce road accidents and fatalities, especially among school-aged motorcyclists.

2. LITERATURE REVIEW

Traffic accidents are consistently linked with human, environmental, vehicular, and systemic factors in many previous road safety studies. Therefore, developing a RSI to effectively measure and monitor safety performance necessitates the integration of theoretical perspectives and empirical evidence from behavioral science, engineering, and policy studies. Early accident theories often attribute road incidents to human error or chance events, which include the Domino Theory by Heinrich (1931). This theory proposes that a chain of interconnected factors leads to accidents. The chains or 'domino' as termed by Heinrich (1931) include unsafe acts, environmental hazards, and human failings, whereby according to the theory, accidents can be prevented by eliminating one "domino". Wilde (1998) suggests that perceived risks determine an individual's behavior, which potentially undermines the effectiveness of safety interventions. Ajzen (1991), through his Theory of Planned Behavior, explains that cognitive and social factors substantially influence safety outcomes, as attitudes, social norms, and perceived behavioral control are closely associated with riding intentions and actions. These classical theories highlight the importance of understanding human decision-making by emphasizing the behavioral and systemic factors contributing to road accidents.

Initially reactive, road safety management adopts a more preventive and systemic approach nowadays, such as the application of the Safe System Approach (SSA), which is recognized by the World Health Organization (WHO) and the United Nations Decade of Action for Road Safety. The Safe System Approach (SSA) acknowledges the

inevitability of human error and the need for effective transport regulations to minimize the consequences of those errors. Comprising five key pillars of safe road users, safe vehicles, safe roads and mobility, post-crash response, as well as road safety management, the SSA provides the conceptual basis for the MRSP 2022-2030, which prioritizes the protection of vulnerable road users, particularly motorcyclists and young riders.

Several indices are used to monitor and benchmark road safety. Europe's cross-country RSPI identifies fatalities, enforcement, and infrastructure factors in measuring road safety. To provide a multidimensional assessment of road safety, indices in Asia mostly employ advanced analytical models of fuzzy logic, DEA, and MCDM (Cheng, Sayed, & Lee, 2025). As for the Road Safety Maturity (RSM) Index developed by the World Health Organization, it applies content analysis and binary scoring to numerically evaluate national road safety strategic implementation across five main aspects of road safety management, safer roads and mobility, safer vehicles, safer road users, and post-crash response. Another widely-recognized road safety index is Al-Haji (2007) Road Safety Development Index (RSDI), encompassing three key road safety domains: 1) people-related factors (which include behavior, education, and enforcement); 2) system-related factors (which include vehicle safety, road infrastructure, and institutional frameworks); and 3) product-related outcomes (which include fatalities, injuries, and exposure). This quantitative road safety index proves effective in distinguishing different safety development levels between countries with comparable vehicle registrations, as evidenced in the thirteen European and Southeast Asian countries implementing this index.

This index calculates a single composite score that represents a nation's overall safety maturity by combining individual indicators from its three domains using a weighted and normalized approach. To ensure reliability of the evaluation, RSDI features four different weighting methods, which include equal weighting, expert-based weighting, experience-based weighting, and statistical weighting using PCA. The RSDI formula is expressed as follows, where the final score is obtained by summing the weighted normalized values of all indicators.

$$RSDI = \sum_{i=1}^{n} w_i \times N_i \quad (1)$$

Statistically, motorcyclists account for a substantial proportion of traffic fatalities, with the majority aged 13 to 19 (PDRM, 2020). Numerous factors are conclusively linked to the increase in accident risks among these young riders. In addition to lack of riding experience, training, and supervision, peer influence adversely encourages school-aged motorcyclists to engage in various dangerous riding behaviors, especially speeding, not wearing a helmet, and using mobile phones (Fatima, Gupta, & Kumar, 2024; Firmansyah et al., 2024). Damaged road surfaces, inadequate lighting, insufficient signage, and lack of motorcycle lanes create unsafe riding conditions for riders, resulting in accidents. Moreover, ineffective policy implementation and road safety awareness programs lead to a decline in safety compliance and awareness, thereby increasing the risk of accidents among school-aged motorcyclists.

The currently available road safety indices primarily concentrate on national-level data, thereby lacking specificity regarding the targeted group of road users and contributing factors. To fill this gap, the study proposes an index that multidimensionally assesses road safety specific to school-aged riders in Malaysia. This index is developed based on the Safe System Approach and adapts the WHO Road Safety Maturity (RSM) Index as well as Al-Haji's Road Safety Development Index (RSDI). It comprises five domains of road safety, namely behavioral, vehicle-related, environmental conditions, policy and education, and post-crash preparedness. Each dimension consists of its own set of indicators, which collectively contribute to a composite score ranging from 0 to 100. The score reflects the overall safety level of school-aged motorcyclists and highlights areas of road safety requiring improvement. The index is formulated as follows:

$$RSI_{school} = \sum_{j=1}^{m} w_j \times N_j \quad (2)$$

Where N_js is the normalized value of dimension j, w_j represents its relative weight assigned to dimension j, and m denotes the total number of dimensions included in the index $(m = 5)$.

The proposed index theoretically complements the currently available road safety indices by providing a multidimensional assessment of critical factors contributing to road safety among school-aged motorcyclists, specifically in Malaysia. It also supports the MRSP 2022-2030 and the Global Plan for Road Safety 2021-2030's

objective of achieving zero fatalities by informing policymakers, educators, and enforcement agencies with practical mechanisms to critically evaluate and improve current road safety conditions and initiatives, in the context of school-aged motorcyclists.

3. RESEARCH METHODOLOGY

Relevant articles are identified from Web of Science (WoS), Scopus, Google Scholar, and MyCite and are reviewed in accordance with the PRISMA guidelines. The screening criteria include road accident risk factors in Malaysia, the methodological robustness of studies related to RSI development, and the effectiveness of existing RSI frameworks. Figure 1 presents the PRISMA flow diagram for this study.

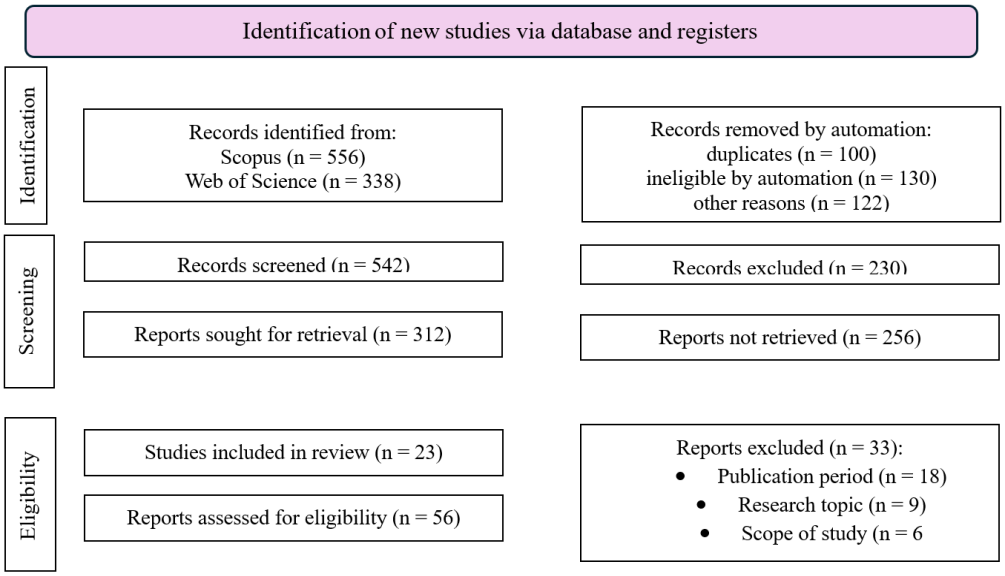

Figure 1. PRISMA protocol flowchart adapted from Page, McKenzie, Bossuyt, Boutron, and Moher (2020).

3.1. Identification

To identify the relevant articles, structured search strings are developed based on key terms such as "road safety," "motorcycle users," and "school students," and are applied across multiple databases, including Scopus, Web of Science, MyCite, and Google Scholar, in accordance with PRISMA recommendations. Table 1 presents the keywords and search strings used across these databases to ensure a comprehensive and transparent literature identification process. Notably, all articles related to the main themes are initially collected without quality-based exclusion to maximise coverage prior to the subsequent screening and eligibility assessment stages.

Table 1. Identification of keywords across databases using search strings.

Database	***Search Strings***
Scopus	TITLE-ABS-KEY *(road AND safety OR road AND safety AND index OR motorcycle AND index OR motorcycle AND among AND students OR motorcycle AND safety OR road AND safety AND conceptual OR road AND safety AND model)*
WOS	TS=*(road AND safety OR road AND safety AND index OR motorcycle AND index OR motorcycle AND among AND students OR motorcycle AND safety OR road AND safety AND conceptual OR road AND safety AND model) AND PY=(2021-2025)*
Google Scholar	*Index AND Road safety AND Motorcycle users AND Road accident factors AND School students*
MyCite	index AND road safety AND motorcycle users AND road accident factors AND school students

3.2. Screening

A total of 936 articles (556 from Scopus and 380 from WOS) were identified during the initial search. The identified articles were further screened based on specific criteria: time period (studies published between 2021 and

2025 to reflect recent trends), publication type (journal articles), topics (RSI and risk factors contributing to accidents among motorcycle users), and language (English only), as illustrated in Table 2. Only 54 articles that satisfied the inclusion criteria advanced to the eligibility verification phase.

Table 2. Screening Process Conducted.

Criteria	Included	Excluded
Time period	2021 until 2025	2020 and earlier
Publication Type	Journal articles	News articles, media, dissertations, book chapters
Study Topic	RSI, motorcycle users	Not related to RSI
Language	English	Non-English

3.3. Eligibility

The articles following the screening phase are further assessed in terms of research design, sample size, data credibility, and analytical accuracy. Consequently, only 22 articles that are methodologically valid and relevant remain for detailed analysis of risk factors and unsafe riding behaviors among school-age motorcyclists in Malaysia.

3.4. Quality Assessment of Articles

Final analysis of the systematic literature review (SLR) should only include articles with reliable, sound methods and directly aligned with research objectives (Liberati et al., 2009). In this study, the Mixed Methods Appraisal Tool (MMAT) is employed to assess the methodological quality of articles across different research designs, namely qualitative, quantitative randomized controlled trials, quantitative non-randomized, quantitative descriptive, and mixed methods (Hong, Pluye, Fàbregues, Bartlett, & Vedel, 2018).

The quality assessment is performed based on five areas of a study, including the research questions, the study design, sampling and data collection, data analysis, and ethical and methodological standards. The MMAT is crucial for critically assessing studies with various methodological approaches, such as statistical analyses of accident data and investigations into road users' perceptions.

Table 3. Article quality assessment.

No.	Author(s) (Year)	Country	Study Design	QC1	QC2	QC3	QC4	QC5	Criteria Met
1	Al Feki and Neji (2024)	Tunisia	QNR	√	√	√	√	√	5/5
2	Bella, Gulisano, and Gagliardi (2024)	Italy	QNR	√	√	√	√	√	5/5
3	Cheng et al. (2025)	China/USA	MX	√	√	√	√	√	5/5
4	Elvik (2024)	Norway	QD	√	√	√	√	√	5/5
5	Erieba, Pappalardo, Hassan, Said, and Cafiso (2024)	Egypt	QD	√	√	√	√	√	5/5
6	Fatima et al. (2024)	India	QD	√	√	√	√	√	5/5
7	Firuţi et al. (2023)	Romania	QD	√	√	√	√	√	5/5
8	Firmansyah et al. (2024)	Indonesia	QD	√	√	√	√	√	5/5
9	Garefalakis et al. (2024)	Greece	MX	√	√	√	√	√	5/5
10	Golov, Evtyukov, Protsuto, Evtyukov, and Sorokina (2022)	Russia	QNR	√	√	√	√	√	5/5
11	Grieco, Scattarreggia, Monteiro, and Parisi (2024)	Italy	QD	√	√	√	√	√	5/5
12	Rakonjac, Antić, Pešić, and Pajković (2021)	Montenegro / Serbia	QD	√	√	√	√	√	5/5
13	Hula, Schwieger, and Saleh (2023)	Austria	QD	√	√	√	√	√	5/5
14	Komasi, Nemati, Zolfani, and Taheri (2024)	Iran	QD	√	√	√	√	√	5/5

No.	Author(s) (Year)	Country	Study Design	QC1	QC2	QC3	QC4	QC5	Criteria Met
15	Kraft, Mrkvička, Petříček, and Blažek (2023)	Czech Republic	QNR	√	√	√	√	√	5/5
16	Llagostera, Comas, and López (2022)	Spain	QD	√	√	√	√	√	5/5
17	Na et al. (2024)	Not specified	MX	√	√	√	√	√	5/5
18	Naweed and Blackman (2024)	Australia	QL	√	√	√	√	√	5/5
19	Sekine (2024)	Japan	QD	√	√	√	√	√	5/5
20	Shbeeb (2022)	Jordan	QNR	√	√	√	√	√	5/5
21	Siddiqui, Hussein, and Yang (2025)	Canada	MX	√	√	√	√	√	5/5
22	Zhang, Wang, and Li (2025)	China	QD	√	√	√	√	√	5/5

Note: QC=Quality Criteria; QL=Qualitative; QNR= Quantitative Non-Randomized; QD= Quantitative Descriptive; MX= Mixed Methods.

3.5. Background of Selected Articles

3.5.1. Year of Publication

A defined publication period enables the review to capture recent trends and methodological developments while ensuring the relevance of the findings to current research contexts (Kitchenham & Charters, 2007; Snyder, 2019). In this study, only articles published between 2021 and 2025 are included, resulting in a total of 22 selected studies. Figure 2 presents the distribution of articles by year of publication, showing a steady increase in research output in recent years, which reflects the growing scholarly interest in road safety indices and motorcycle safety.

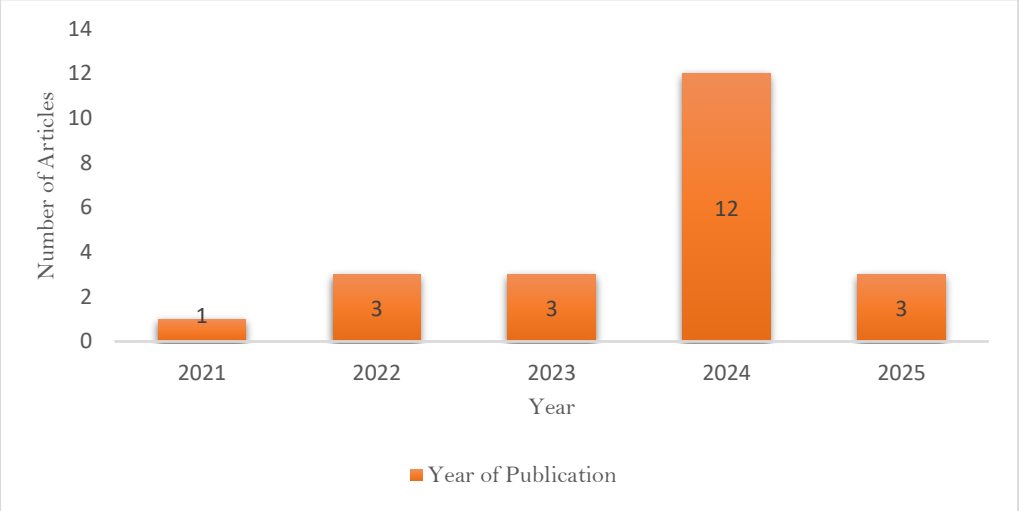

Figure 2. Number of articles published by year.

3.5.2. Study Designs in the Articles

The methodological characteristics of the selected studies are summarized in Table 3. Among the 22 articles, one study adopts a qualitative design (Naweed and Blackman (2024), while the majority employ quantitative approaches. Of these, 15 studies utilize quantitative descriptive methods, including those by Elvik (2024); Firuţi et al. (2023); Llagostera et al. (2022); Hula et al. (2023); Sekine (2024); Fatima et al. (2024); Rakonjac et al. (2021); Komasi et al. (2024); Firmansyah et al. (2024); Grieco et al. (2024); Zhang et al. (2025); Siddiqui et al. (2025); Cheng et al. (2025) and Erieba et al. (2024). Additionally, five publications used a non-random quantitative approach, as seen in the studies by Al Feki and Neji (2024); Bella et al. (2024); Shbeeb (2022); Kraft et al. (2023), and Golov et al. (2022). Finally, two article publications employed a mixed-methods design, namely Na et al. (2024) and Garefalakis et al. (2024). Overall,

the dominance of quantitative approaches indicates a strong emphasis on empirical measurement and modelling in road safety index research.

3.5.3. Distribution of Studies by Country

The geographic distribution of the selected studies is summarized in Table 3 and further visualized by continent in Figure 3. The analysis shows that the studies are conducted across a diverse range of countries. Two studies originated from Italy (Bella et al., 2024; Grieco et al., 2024) and two from China (Cheng et al., 2025; Zhang et al., 2025). In addition, one study each was conducted in Tunisia (Al Feki & Neji, 2024), Norway (Elvik, 2024), Egypt (Erieba et al., 2024), India (Fatima et al., 2024), Romania (Firuţi et al., 2023), Indonesia (Firmansyah et al., 2024), Greece (Garefalakis et al., 2024), Russia (Golov et al., 2022), Montenegro/Serbia (Rakonjac et al., 2021), Austria (Hula et al., 2023), Iran (Komasi et al., 2024), the Czech Republic (Kraft et al., 2023), Spain (Llagostera et al., 2022), Australia (Naweed & Blackman, 2024), Japan (Sekine, 2024), Jordan (Shbeeb, 2022), and Canada (Siddiqui et al., 2025). Furthermore, one study involved collaboration between China and the United States (Cheng et al., 2025), while one study did not explicitly specify a country of study (Na et al., 2024).

Figure 3 illustrates the percentage distribution of the selected studies by continent. In terms of continental distribution, the majority of articles originated from Europe (44%), including studies from Italy, Norway, Romania, Greece, Russia, Montenegro/Serbia, Austria, the Czech Republic, and Spain. Asia accounted for 30%, with contributions from China, India, Indonesia, Iran, Japan, and Jordan. African studies, represented by Tunisia and Egypt, comprised 9% of the total. North America also accounted for 9%, represented by Canada and the United States through collaborative publication, while Oceania contributed 4% with one study from Australia. Another 4% of the selected studies did not specify the country of study.

Generally, the high number of road safety studies in Europe indicates a strong focus on transport safety research in this region, while the increasing number of studies in Asia reflects growing research attention toward road safety issues. The limited number of studies from Africa and Oceania highlights the need for further road safety research in these regions.

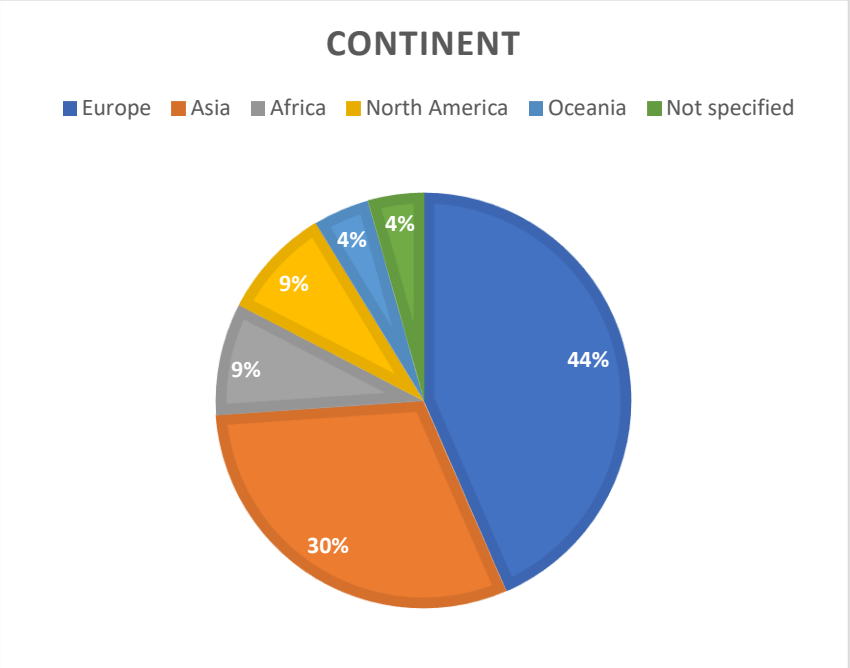

Figure 3. Percentage distribution of studies by continent.

3.5.4. Published Journal

The distribution of the selected articles across publication outlets is presented in Table 4. The reviewed studies are published in a wide range of reputable journals covering transportation, engineering, safety science, and interdisciplinary research domains. Several journals, such as IATSS Research and Transportation Research Procedia, contribute more than one article, while the remaining studies are dispersed across diverse journals including Accident Analysis and Prevention, Ain Shams Engineering Journal, and European Transport Research Review. This distribution demonstrates the multidisciplinary nature of road safety index research and indicates broad academic interest in motorcycle safety and road safety assessment.

Table 4. Articles by journals and authors.

Journal	Article Authors	Number of articles
IATSS research	Firmansyah et al. (2024); Sekine (2024)	2
Expert systems with applications	Na et al. (2024)	1
International journal of disaster risk reduction	Grieco et al. (2024)	1
Ain Shams Engineering Journal	Erieba et al. (2024); Komasi et al. (2024)	2
Promet-traffic & transportation	Rakonjac et al. (2021)	1
Periodica polytechnica transportation engineering	Fatima et al. (2024)	1
Transportation Research Procedia	Hula et al. (2023); Golov et al. (2022)	2
Science of the total environment	Llagostera et al. (2022)	1
Moravian geographical reports	Kraft et al. (2023)	1
European transport research review	Garefalakis et al. (2024)	1
Cogent engineering (Civil & environmental engineering)	Shbeeb (2022)	1
Sensors (MDPI)	Firuţi et al. (2023)	1
Accident analysis and prevention	Bella et al. (2024)	2
Journal of Engineering Research	Al Feki and Neji (2024)	1
Transportation research part F: Psychology and behaviour	Naweed and Blackman (2024)	1

4. RESEARCH FINDINGS

Research Question 1: What are the major factors influencing road safety among school-aged motorcyclists?

Compared to other vehicles, motorcycles are a more economical and convenient form of transportation, particularly for school students, as they cost less to purchase, maintain, and fuel (Firmansyah et al., 2024). However, frequent motorcycle use exposes school-aged motorcyclists to more traffic risks. Moreover, unsafe behaviors such as not wearing helmets and ignoring speed limits are often associated with low safety awareness and weak enforcement of traffic rules by authorities, consequently leading to a higher risk of accidents involving school-aged motorcyclists (Bella et al., 2024).

These unsafe riding behaviors among school students are also significantly linked to a lack of community-wide safety culture. Generally, motorcycles are regarded as a convenient mode of transport. However, in certain social settings, this mode of transportation can also represent independence and social status, especially for teenagers. As a result, many adolescents, including school-aged motorcyclists, often engage in risk-taking riding behaviors to gain social recognition and assert their identities among peers (Naweed & Blackman, 2024). Such reckless behaviors commonly involve speeding, dangerous overtaking, and riding without proper safety gear.

Studies highlight that poor infrastructure, such as the absence of motorcycle lanes, uneven road surfaces and potholes, and a lack of signage or lighting, greatly compromise road safety levels (Elvik, 2024; Erieba et al., 2024; Firmansyah et al., 2024; Grieco et al., 2024). Navigating such challenging infrastructure often forces road users to perform risky maneuvers, thereby increasing the likelihood of accidents and injuries.

Psychological factors of road safety encompass cognitive wellbeing (e.g., overconfidence), personality traits (e.g., thrill-seeking), and social influences (e.g., peer pressure). These interrelated factors often lead them to view riding as an opportunity to display their skills, while neglecting personal safety (Bella et al., 2024). The adverse effects of these psychological behaviors are linked to ineffective road safety education in schools, which may compel students to rely on informal and unreliable sources of information to guide their riding practices (Naweed & Blackman, 2024).

Therefore, to improve road safety among young motorcyclists in Malaysia, it is essential to identify the key determinants of risky riding behavior that would also effectively guide future road safety interventions.

Research Question 2: What are the indicators and measurement approaches applied in the present road safety indices in the context of school-aged motorcyclists?

Numerous road safety indices are available across different countries and contexts, each focusing on significant indicators of road safety. One of these indices is the Road Network Hazard Index (RNHI), which links accident probability with accessibility to emergency medical services (EMS). This index asserts that roads with high accident risk in rural or underserved areas become significantly more hazardous when EMS accessibility is limited (Firuți et al., 2023).

The RSPI, as described by Llagostera et al. (2022), identifies infrastructure conditions as one of the Safety Performance Indicators (SPIs) for measuring the safety performance of a road transport system. Among the road infrastructure indicators are the proportion of safe road segments, road engineering quality, and the presence of pedestrian and cyclist infrastructure. Erieba et al. (2024) further emphasized the significance of infrastructure quality in the road system when evaluating the risk index across Europe.

In their RSI, Fatima et al. (2024) employed the Logarithmic Goal Programming Model to prioritize six key road safety factors, namely road design, vehicle design, law enforcement, the judicial system, medical response, and public awareness. The index enables authorities to identify critical factors requiring attention and implement targeted initiatives for road safety. Elvik (2024) evaluated the long-term impact of Norwegian road safety policies between 1980 and 2021 using the Road Safety Policy Index (RSPI-Norway). Using the multi-step methodological approach, the study identified significant road safety indicators of motorway length, seatbelt usage, adoption of vehicle safety features (for example, airbags, ESC), traffic law citations, and the real value of penalties. The study concluded that stronger road safety policies contribute to improved safety for road users.

Naweed and Blackman (2024) examined the adoption of Advanced Rider Assistance Systems (ARAS) in motorcycles and found that, aside from anti-lock braking systems (ABS), most features lack proven safety benefits. The study highlights that technology adoption in vehicles contributes significantly to road safety. In addition to technology, several studies have examined how behavioral factors influence road safety. Using survival and logistic regression models, Bella et al. (2024) indicated that taking longer overtaking times and disregarding vehicle clearance lead to unsafe maneuvers, risking accidents. Garefalakis et al. (2024) identified numerous risky riding behaviors among motorcycle riders such as harsh braking, aggressive acceleration, and fatigue, through the use of using machine learning algorithms. As for Firmansyah et al. (2024), the study identified dangerous riding behaviors in mixed traffic, including frequent lane changes, close following, and unsafe overtaking, via data-driven classification models.

Road safety among motorcyclists can also be significantly indicated by infrastructural factors. This is demonstrated by Golov et al. (2022), who evidently found uneven road surfaces increase instability and accident risk. The relevance of this dimension of road safety is proven by Hula et al. (2023) as their study demonstrated that environmental and road conditions measured using the satellite-based IRUS index provide quantifiable measures for assessing motorcycle safety. Similarly, Sekine (2024), using probe motorcycles in the study, emphasized road maintenance as a measurable infrastructure indicator of road safety.

Various approaches are employed by studies examining road safety. Komasi et al. (2024) applied the quantitative approach by introducing an interval-rough multi-criteria model to assess uncertainty in road network safety from the environmental, geometric, and traffic domains. Similarly, Zhang et al. (2025) also approached road safety

quantitatively by employing spatial and temporal proximity in their Emergency Index (EI) to determine vehicle interaction risk. Another study employing a quantitative approach to road safety is by Al Feki and Neji (2024). This study explored how driver behavior, vehicle conditions, and urban environments correlate with increased accident risk using correspondence and logistic regression.

The application of data-driven approaches is illustrated by the study conducted by Siddiqui et al. (2025), in which Random Forest and SHAP (Shapley Additive exPlanations) techniques are used to analyze vehicle trajectory data and identify high-risk road clusters along with contributing factors. Similarly, Cheng et al. (2025) demonstrated that certain traffic violations tend to cluster in space and time, and these patterns are significantly associated with increased crash risk. The study further suggests that such spatiotemporal information could be employed as an early warning system for hazard zones and as a foundation for real-time traffic safety monitoring.

Rakonjac et al. (2021) applied a conceptual framework in developing the Grey Road Safety Composite Indicator, which evaluates safety across three domains: human behavior, vehicle-related factors, and systemic conditions. Another method for examining road safety is bibliometric analysis, as demonstrated by Grieco et al. (2024). In their study, prominent themes in road safety studies are identified, including behavioral analytics, AI integration, and data-driven safety management.

These studies highlight advancements in road safety studies, which contribute significantly to the development of key indices for assessing road safety, particularly among motorcyclists, over the years.

Research Question 3: What constitutes a comprehensive Road Safety Index for school-aged motorcyclists?

As previously mentioned, numerous factors are evidently linked to the increase in accident risks among school-aged motorcyclists. Therefore, a multidimensional RSI integrating behavioral, infrastructural, technological, policy, and educational components enables a comprehensive assessment of risk and the design of interventions tailored to the specific needs of school-aged riders (Al Feki & Neji, 2024; Hula et al., 2023).

The behavioral dimension in a road safety index specifically examines high-risk actions impacting road safety. Key indicators for this dimension include helmet use, adherence to speed limits, and avoidance of distractions while riding (Garefalakis et al., 2024; Kraft et al., 2023). Impacting this dimension are the educational factors. A comprehensive road safety index can measure this dimension of road safety by specifically evaluating the effectiveness of structured road safety education programs and riding environments simulation implemented by relevant authorities in strengthening students' safe riding habits and practical skills in managing real-world hazards (Firmansyah et al., 2024).

A comprehensive road safety index should include the infrastructural dimension as one of its critical components. In addition to the assertion by Rakonjac et al. (2021) to incorporate infrastructure and environmental indicators in the composite road safety index, Bella et al. (2024) have also evidently proven that infrastructural aspects, indicated by roadway design and lane configuration, significantly influence motorcyclist safety and increase accident risk. To complement the index, Grey Relational Analysis can be utilized to prioritize the most critical infrastructural factors affecting school-aged motorcyclists' road safety.

A road safety index should also comprise a technological dimension, which focuses on the advanced safety features ensuring road safety, such as ABS and ARAS (Naweed & Blackman, 2024). This dimension of road safety index emphasizes the importance of making such advanced technologies accessible to enhance riders' safety. Another significant dimension constituting a comprehensive road safety index is policy and enforcement. Key indicators of this dimension include helmet laws, age-appropriate licensing, and speed enforcement. The Norway's Vision Zero exemplifies the application of policy and enforcement dimensions in ensuring road safety, making Norway one of the safest countries in the world for road users (Elvik, 2024).

Complementing relevant domains in a comprehensive road safety index is the appropriate approach. Numerous approaches to studying road safety have been employed over the years. For example, Siddiqui et al. (2025) employed a data-driven framework using trajectory information for road safety analysis, and Garefalakis et al. (2024) employed

machine learning models such as Random Forest and Multilayer Perceptron Neural Networks to predict risky driving behaviors. To further extend road safety studies, future research can integrate these approaches with real-time sensor data and spatiotemporal analysis to enable early identification of accident-prone locations, providing a basis for strategic road safety interventions.

Currently available road safety indices for motorcyclists present several limitations. Studies reveal that present indices lack comprehensive data on adolescent riding behaviors and the factors contributing to road accidents, making them inadequate for identifying high-risk behaviors and guiding evidence-based interventions (Firuți et al., 2023; Hula et al., 2023). Additionally, suggested modern safety technologies to ensure road safety, such as ARAS, are largely inaccessible due to the high cost, therefore impractical. Also, this recommendation requires coordinated interdisciplinary collaboration among transport engineers, behavioral scientists, educators, and policymakers, which can be difficult to realize.

To conclude, an effective Road Safety Index for school-aged motorcyclists should be multidimensional, evidence-based, and adaptive in order for it to comprehensively assess risks and guide targeted strategies to improve road safety among school-aged riders.

5. DISCUSSION ON RESEARCH FINDINGS

5.1. Proposed Conceptual Framework for a Road Safety Index for School-Aged Motorcyclists

The proposed RSI assesses school-aged motorcyclists from five key domains, namely safe users, safe vehicles, safe environment, policy and education, and post-accident management, each with its own indicators. The safe user dimension focuses on road-user riding behaviors. This includes helmet use, speed compliance, distraction handling, and safety training participation. This dimension is relevant to be included in the proposed road safety index as studies suggest that compliance behaviors, such as consistent helmet use and adherence to traffic rules, significantly increase an individual's road safety (Firmansyah et al., 2024; Kraft et al., 2023). In the proposed road safety index, the safe user indicators can be empirically identified through observations, enforcement records, and school-based evaluations.

The safe vehicle dimension evaluates technological advancements and safety features of a vehicle that contribute to road-user protection, particularly school-aged motorcycle users. In the proposed road safety index, the key indicators of a safe vehicle are the presence of technological safety features such as ABS, ARAS, Daytime Running Lights (DRLs), and the frequency of maintenance (Naweed & Blackman, 2024). As for the safe environment dimension, it assesses infrastructure supporting motorcyclist safety, such as dedicated motorcycle lanes, road signs, street lighting, and protected pedestrian crossings, as highlighted in several studies (Bella et al., 2024; Rakonjac et al., 2021).

The policy dimension examines how regulations and enforcement influence road safety. This dimension can be indicated by helmet laws, licensing requirements, speed enforcement, and school-based safety programs. Incorporating this dimension in a road safety index is significant, as it is empirically evidenced by Norway's Vision Zero (Elvik, 2024) and aligns with national road safety strategies outlined in the MRSP 2022-2030. The last dimension to be included in the proposed road safety index is the post-accident management. This dimension reflects readiness of emergency response systems and timely medical care, which is indicated by ambulance response times, access to first-aid resources, and school-level accident reporting procedures (Hula et al., 2023).

The proposed RSI contributes to a multidimensional understanding of road safety contextualized to Malaysian school-aged motorcyclists. Moreover, it provides relevant authorities with evidence-based insights to implement collaborative road safety initiatives, specifically tailored for school-aged motorcyclists. The findings and recommendations also support the zero road fatalities goal aspired by the MRSP 2022-2030 and the Global Plan for Road Safety 2021-2030. Figure 4 illustrates the conceptual framework of the proposed Road Safety Index (RSI) for school student motorcyclists, highlighting its key domains and structure.

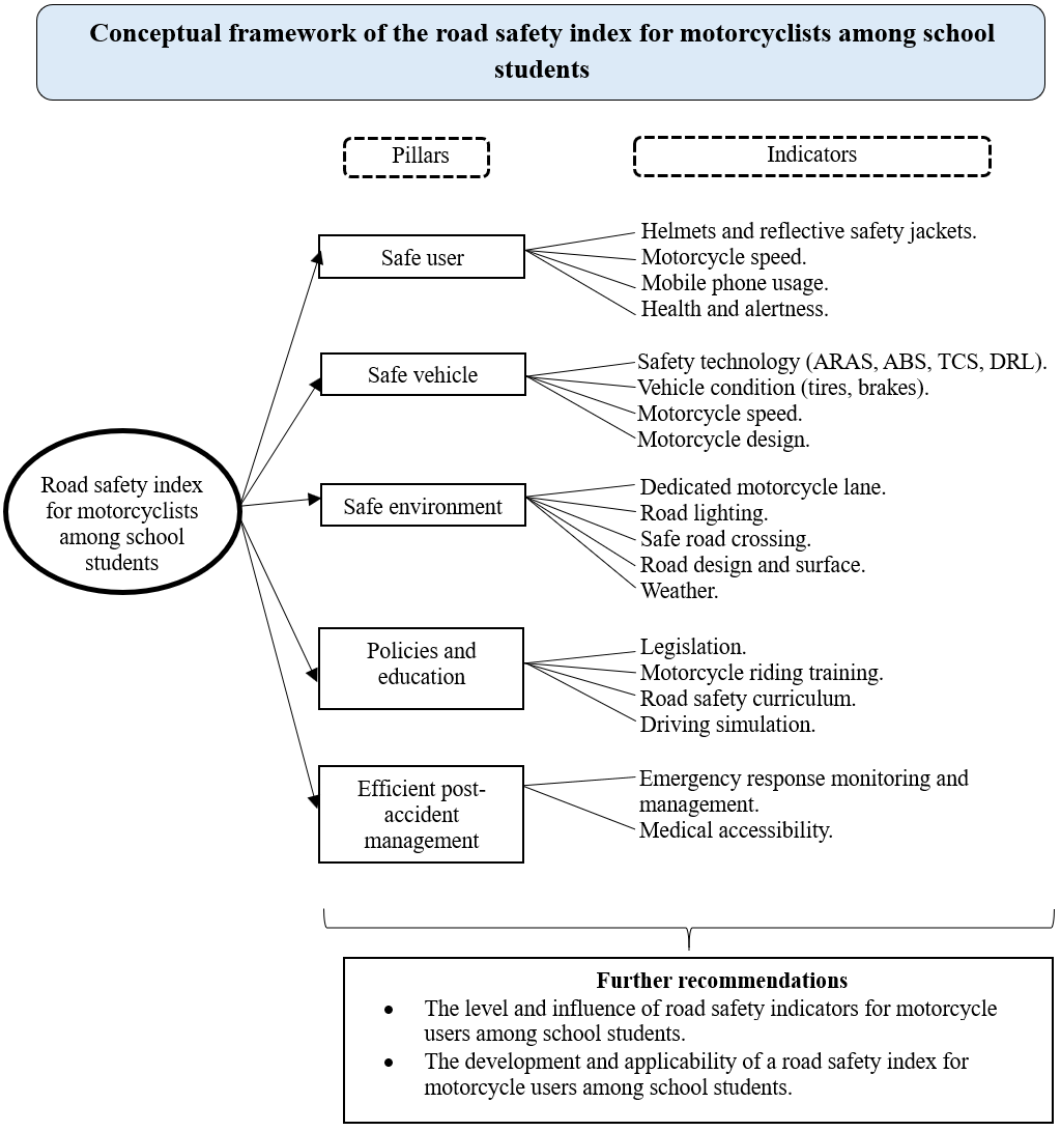

Figure 4. Conceptual framework of the proposed RSI for school-aged motorcyclists.

6. IMPLICATIONS OF THE STUDY

The proposed RSI for school-aged motorcyclists enriches the current theoretical understanding of road safety. It provides a multidimensional and evidence-based approach to increase the road safety level, particularly among this group of motorcycle riders in Malaysia. Such empirical data can be leveraged by relevant authorities to develop and implement targeted interventions that address behavioral, infrastructural, technological, and educational domains of road safety. Examples of measures include providing dedicated motorcycle lanes, improving road lighting and signage, developing affordable safety technologies for motorcycles, and conducting interactive road safety education programs. Notably, the proposed strategic initiatives are evidence-based, thereby making them more practical to implement.

Furthermore, the proposed RSI provides policymakers with comprehensive information on behavioral, infrastructural, technological, and educational indicators in developing, evaluating, and improving the current road safety policies, as well as designing the new ones. Among the significant indicators in relation to road safety for school-aged motorcyclists to be addressed are helmet use, motorcycle training, and speed control in school zones. Also, this index supports the objective of zero road fatalities by the MRSP 2022-2030 and the Global Plan for Road Safety 2021-2030.

The proposed RSI further highlights the significant role of collaborative social initiatives in ensuring road safety among school-aged motorcycle riders. The education authorities, including schools and teachers, can instill road safety awareness and behaviors among students through structured road safety educational programs at school. This educational initiative can be further reinforced by other community members outside school settings, such as parents and local communities, to regularize the safe riding behaviors among school-aged motorcyclists, thereby creating a prevalent safe riding culture in the community.

The proposed RSI significantly serves as a reference for evaluating and improving road safety contextualized to Malaysia. It also contributes to the global effort of increasing road safety, especially for school students.

7. CONCLUSION

This review proposes an RSI to multidimensionally assess the road safety of school-aged motorcyclists in Malaysia. Based on the Safe System Approach, the proposed road safety index identifies five significant domains of road safety, each with its own indicators: safe user, safe vehicle, safe environment, policy and education, and post-accident management. Data for the indicators are retrieved from observations, enforcement records, and school-based evaluations. The proposed RSI can assist relevant authorities in evaluating and implementing targeted safety measures for school-aged motorcyclists in Malaysia. Additionally, it aligns with the zero-fatality objectives outlined in the MRSP 2022-2030 and the Global Plan for Road Safety 2021-2030. Future studies could further improve the RSI by incorporating field data, adjusting indicator weights, and applying real-time analytics to increase both its accuracy and practical relevance.

Funding: This research is supported by the Ministry of Higher Education Malaysia (MOHE) through the Fundamental Research Grant Scheme (Grant number: FRGS/1/2024/SS07/UPSI/02/3).
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Disclosure of AI Use: The authors used OpenAI's ChatGPT (version December 2025) to improve the clarity and language of the manuscript. All AI-assisted content was reviewed and verified by the authors.

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