Journal of the Society of Automotive Engineers Malaysia
Volume 10, Issue 1, pp 40-51, January 2026
e-ISSN 2550-2239

A Comprehensive Analysis of Road Safety in Sumatera Utara: Challenging Global Standards through the Lens of Local Driving Culture

E. L. Mahyuni*[1], Y. Satria[2], F. Lamin[3] and A. Omar[3]

[1] Occupational Safety and Health, Faculty of Public Health, Universitas Sumatera Utara, Indonesia
[2] PT. PP Persero TBK, Civil Engineering and Infrastructure, Indonesia
[3] Vehicle Safety and Biomechanics Research Centre, Malaysian Institute of Road Safety Research, Malaysia

*Corresponding author: eka.lestari@usu.ac.id

ORIGINAL ARTICLE *Open Access*

Article History:

Received
28 Oct 2025

Accepted
15 Dec 2025

Available online
1 Jan 2026

ABSTRACT – Road safety in Sumatera Utara presents a complex and multidimensional challenge. This study aims to analyze traffic accident patterns in the region to identify key contributing factors and derive implications for advancing vehicle safety and infrastructure toward international standards. The research employs a multi-faceted methodology, comprehensively exploring the relationship between secondary data, direct observation, and interviews. Quantitative analysis of traffic accident data from 2021 to 2024 was conducted to identify trends and characteristics of vulnerable vehicles. This analysis was reinforced by in-depth interviews with police investigators and direct observation of road conditions and driving behavior in Medan. The findings reveal an alarming upward trend in accident rates, with the total number of cases rising significantly from 5,616 in 2021 to 6,850 in 2024. Data show that motorcycles significantly dominate accident incidents, involved in over 70% of total cases. Furthermore, accidents involving passenger cars and cargo vehicles in consecutive collisions also contribute substantially to the rising numbers and severity. This vulnerability is rooted in a unique and unsafe driving culture, characterized by reckless behavior, high speeds, and a pervasive disregard for traffic regulations. These factors are exacerbated by situational impulses like being rushed or careless. This culture directly challenges the fundamental assumptions of global safety standards and the effectiveness of modern safety technology. Therefore, improving road safety in Sumatera Utara requires a progressive approach that involves infrastructure improvements, stricter law enforcement, and the adoption of active safety technologies that are adaptive to the local cultural context.

KEYWORDS: Technology, driving culture, global standards, road safety, traffic accidents

Journal homepage: www.jsaem.my

1. INTRODUCTION

Road safety is a significant global issue, with over 1.3 million people dying annually from traffic accidents. The problem is particularly acute in low- and middle-income countries (LMICs), where nine out of ten road traffic deaths occur, despite these countries having only 60% of the world's vehicles. This vulnerability is further compounded by aggressive driving tendencies and complex traffic conditions. It is predicted that by 2030, traffic accidents will become the fifth leading cause of death globally (WHO, 2023; Taheri et al., 2025).

In Indonesia, these challenges are exacerbated by a rapidly growing vehicle population and inadequate infrastructure. Despite various government initiatives, accident and fatality rates remain high, indicating that infrastructure improvements alone are insufficient (Undang-Undang RI, 2009). Data from the Indonesian National Police confirms that human factors are the main cause of accidents, accounting

for 61% of incidents, followed by road infrastructure (30%) and vehicle conditions (9%) (Kementerian Perhubungan RI, 2017). The high number of traffic accidents each year is a serious concern, not only because they cause material losses but also because they result in fatalities and injuries. This highlights the urgency of improving road safety amidst the high fatality rate (KORLANTAS POLRI, 2024). Among the provinces in Indonesia, Sumatera Utara is included in the top 10 provinces with the highest number of accidents in Indonesia consistently from year to year (Kementerian Perhubungan RI, 2023a, 2023b).

The heavy reliance on human factors as the primary cause highlights a significant knowledge gap in applying global safety standards. Current vehicle safety protocols, such as those governing ASEAN NCAP, prioritize structured crash tests focusing on frontal and idealized side-barrier impacts. These protocols implicitly assume a high-compliance driving environment. However, the pervasive influence of the local driving culture in Sumatera Utara, characterized by aggressive behaviors such as Close-Quarters Overtaking (CQO) and selective compliance, suggests that the dominant crash mechanisms are not the idealized frontal impacts but rather lateral and secondary collisions resulting from chaotic, low-predictability maneuvers. This mechanism is inherently less survivable and is often underrepresented or inadequately addressed in current standardized vehicle testing, leading to a systemic mismatch between vehicle safety design and real-world risk.

This research aims to address the knowledge gap by examining the fundamental misalignment between global vehicle safety standards and the unique local driving culture in Medan, using a mixed-methods approach. The study's purpose is to analyze traffic accident patterns in the region, identify key contributing factors, including the influence of driving culture, and formulate the implications of this culture for future vehicle safety standards and infrastructure. It contributes to formulating implications that challenge the current global vehicle safety paradigm, advocating for a localized, integrated approach that prioritizes behavioural dynamics in future safety standards and infrastructure design in environments defined by high risk and low compliance.

2. METHODOLOGY

This research adopts a mixed-methods sequential explanatory design, integrating quantitative findings with subsequent qualitative data to provide a holistic and culturally contextualized understanding of traffic accident severity in Sumatera Utara. (Creswell, 2014). This design allows for a holistic investigation into the quantitative phase, which establishes *what* the patterns are (accident patterns and severity trends), while the qualitative phase explores "*why*" these patterns persist through the lens of local driving culture. This integration strengthens the argument against conventional, technology-centric safety standards.

Quantitative data were collected from official Notifiable Traffic Accident Records provided by the Satuan Lalu Lintas (SATLANTAS) of the Sumatera Utara Regional Police, covering the period from 2021 to 2024. The data includes key variables such as location, time, vehicle type, collision type, and severity outcome (death, severe injury, minor injury). The study analyzed the full census of recorded accidents within the scope. The total sample size for the analysis, encompassing all valid cases after cleaning, is reported as: 2021: 5,616 incidents; 2022: 6,465 incidents; 2023: 6,739 incidents; 2024: 6,850 incidents. This transparency meets the requirement to detail the annual sample size. A strict data-cleaning procedure was implemented using specific criteria. Inclusion Criteria focused exclusively on multi-vehicle accidents involving at least one injury (e.g., minor injury, severe injury, and death/fatality). This ensures the sample directly reflects vehicle-to-vehicle dynamics relevant to safety standards. Exclusion Criteria systematically removed single-vehicle accidents without injury, and property damage-only incidents remain on the mechanisms that escalate human trauma.

For the qualitative phase, a purposive sampling strategy was employed to ensure maximal variation in perspectives from high-risk road users. The study utilized direct field observation and semi-structure interviews, in-depth interviews with 15 key informants: two experienced traffic police investigators to gain expert perspectives on human factors, two long-haul truck drivers that representing high-mass disparity and time pressure operators, eight high exposure drivers including public transport, minibus and city bus drivers as agents of sudden maneuver, and three online transportation drivers including online motorcycle and taxi drivers representing the most vulnerable and high frequency collision group. Additionally, direct observations were conducted on major roads and intersections in Medan to

document unsafe driving behaviors, such as lane violations and aggressive maneuvers. This variety ensures the triangulation of perspectives – enforcement, high-risk operators, and direct experience.

Quantitative data were analyzed using descriptive analysis to identify trends and distributions of accidents by year, location, and type. The chi-square test was used to assess the statistical association between Collision Type and Severity Outcome. A significant result ($p < 0.05$) will validate the hypothesis that lateral mechanisms are significantly more severe. Binary Logistic Regression is utilized to determine which factors predict the probability of a fatal outcome. The resulting Odds Ratios (ORs) provide evidence of causal relationships, linking specific behaviors to high fatality risk.

Qualitative data from interviews and observations were analyzed using thematic analysis to identify recurring behavioural patterns and cultural norms (Guest et al., 2011). The core of this research lies in integrating these two data types: qualitative findings serve as an explanatory framework for the quantitative patterns. This approach strengthens the argument that road safety is a complex issue influenced by cultural and behavioural factors, a point often overlooked in conventional, technology-centric safety standards.

The statistically significant quantitative trends (e.g., dominance of lateral collisions) are explained and enriched by the validated qualitative themes (e.g., CQO driven by time pressure), thereby strengthening the argument that local culture directly influences crash mechanics and severity.

The core themes of "unsafe driving culture" and "selective compliance" were validated using a combination of methods. Thematic Saturation was ensured by continuing interviews until no new behavioural concepts emerged. Crucially, Triangulation was performed by cross-referencing qualitative narratives (e.g., driver accounts of CQO and time pressure) directly with the quantitative data showing the statistical dominance of Front-Side and Side-Side Collisions. This process directly substantiates the cultural framing of the study.

3. RESULTS AND DISCUSSION

The findings of this research present a comprehensive view of traffic accident dynamics in Sumatera Utara, particularly in Medan, by integrating both quantitative and qualitative data analysis. This study argues that the high number of accidents is not merely an infrastructure problem but a manifestation of the complex interaction between physical road conditions and a unique unsafe driving culture.

3.1. Accident Trends and Patterns in Sumatera Utara

An analysis of official traffic accident data from the Sumatera Utara Regional Police reveals an alarming upward trend in accidents from 2021 to 2024. The total number of incidents increased from 5,616 in 2021 to 6,850 in 2024, indicating a significant deterioration in road safety. A more detailed quantitative analysis uncovers several key patterns:

a. *Motorcycle Dominance:* Motorcycles are the most frequently involved vehicles in accidents. This finding is consistent across the period, reflecting the inherent vulnerability of two-wheeled riders and indicating that the pressure from rising vehicle volumes is not matched by adequate infrastructure and behavior (Li et al., 2025).

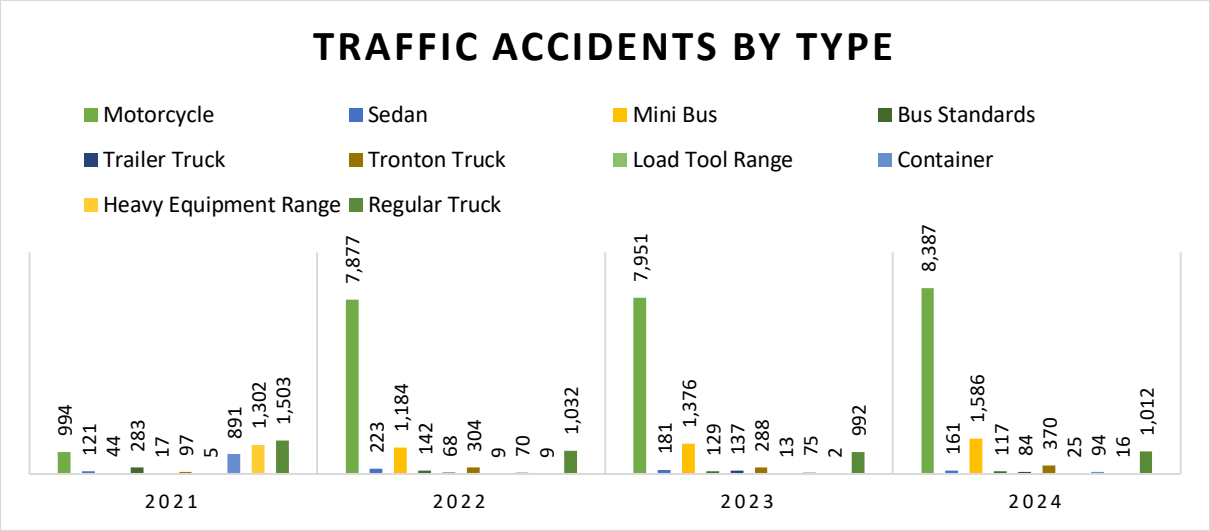

Figure 1: Trend of crashes based on vehicle type

Motorcycles are the decisive dominant factor in crash statistics, consistently accounting for approximately 88,43% of all vehicles involved in accidents between 2022 and 2024. This finding transcends mere population density; it underscores the massive exposure and inherent vulnerability of Vulnerable Road Users (VRUs) within the region's traffic ecosystem (Li et al., 2025). This extreme vulnerability is statistically confirmed by the inferential Binary Logistic Regression model, which identifies motorcycle involvement as the strongest predictor of a fatal outcome, with an exceptionally high Odds Ratio (OR) of 1.29 ($p < 0.001$). This OR figure is critical, as it establishes VRU status as the single greatest risk factor, aligning with global findings of high motorcycle fatality rates in LMICs (Nickenig Vissoci et al., 2020). It is also critical as it establishes that the risk of death is amplified not just by physical vulnerability, but by the confluence of this vulnerability with Aggressive and Impulsive Behaviour (AIB). This extreme dominance is intrinsically linked to the qualitative findings regarding local behaviour; the high mobility of motorcycles is often exploited for aggressive maneuvers, such as Close-Quarters Overtaking (CQO), which are normalized tactics for navigating congestion. These actions directly increase their exposure to the statistically confirmed fatal front-side and side-side collision mechanisms, demanding that safety solutions for aggressive behaviour and severity outcomes move beyond general improvements and focus specifically on mitigating this extreme vulnerability and challenging the corresponding driving culture.

The qualitative data highlights the internalization of time pressure among riders:

> *"We need to be fast, but the cars are moving too slowly... I took the opportunity to overtake wherever a gap appeared. Essentially, I was just impatient because I needed to hurry."*

This narrative explicitly links the need for speed with the impulsive decision-making characteristic of AIB. The rider further normalizes this risk, stating:

> *"That's just how it usually is in Medan. The road is shared space, and despite the roads being small, the traffic volume is very dense."*

This perception of the road as 'shared space' justifies the Close-Quarters Overtaking (CQO) tactic, underscoring the deep-seated non-compliance culture driven by socio-economic pressure. Based on narratives gathered from the samples, motorcycle riders routinely perceive shoulders, narrow gaps between cars, and lane markings as 'optional lanes' that must be exploited to save time. The CQO is identified as the primary tactic; drivers do not overtake because the road is safe, but because they *feel the necessity* to move forward quickly. This behavior has become normalized, with riders leaving only a few centimeters of margin to the vehicle being passed, despite the inherent high risk. The pressure to 'beat' congestion directly leads to the disregard of safe following distances, a behavioral factor statistically validated by the exceptionally high fatality Odds Ratio (1.29) when an incident occurs.

If CQO maneuvers were performed by a car, the risk might only result in minor damage (*dents*), but when executed by a motorcycle, the severity risk instantly escalates to death or serious injury. The high mobility of the motorcycle, which should be an advantage, is instead weaponized into a high-fatality exposure. Qualitatively, riders often assume their vehicle size allows them to squeeze through tight gaps. However, when confronted with sudden braking or a car making an abrupt turn, reaction time is lost, and the resulting impulsive avoidance maneuver invariably leads to fatal Lateral or Secondary collisions.

Consequently, traffic rules (such as maintaining a safe distance or staying in one's lane) are perceived as secondary obstacles that may be violated to achieve their destination quickly. The motorcycle is viewed as the instant solution to this problem. Unfortunately, this behavioural adaptation creates a structured crash pattern in which the most vulnerable road users (motorcyclists) are also the primary agents in the behaviors that drive both the frequency and severity of accidents.

b. *Location and Temporal Pattern:* Most accidents occur in residential areas, a pattern that holds true from 2021 to 2024. Descriptive analysis of accident victims based on the traffic area fundamentally challenges the conventional perception that safety risk is concentrated on high-speed expressways. This suggests that accidents frequently happen in the context of daily activities on narrow, poorly maintained local roads, not just on main highways (Wang et al., 2021). The data consistently reveal that the majority of accident victims are recorded in environments defined by high friction and low-speed flow, specifically the residential areas and shopping centers/markets.

TABLE 1: Crash Severity based on traffic area in Medan, Sumatera Utara

Traffic Area	Total Occupants 2024 (Death + Severe Injury + Minor Injury)	Total Occupants Percentage (11.887)	Risk Categories
Residential Areas	6,540	55.02%	Highest risk
Shopping Centers/Markets	1,968	16.56%	High friction
Subtotal	**8,508**	**71.58%**	

In 2024, Residential Areas alone accounted for 6,540 victims (55.02% of total victims), highlighting these areas as critical accident hotspots. Collectively, Residential Areas and Shopping Centers/Markets recorded 8,508 victims in 2024, representing 71.58% of total casualties. The number of severe and minor injuries in residential areas has steadily increased, especially in 2024. While fatalities remain relatively low compared to severe and minor injuries across all areas, each death represents a significant loss. Shopping malls/areas and shopping centers/markets also register a substantial number of victims, primarily in the minor injury category.

This pattern provides crucial validation of the qualitative findings, suggesting that the high incidence in these local zones is the direct consequence of the culturally normalized behaviour of CQO. The high incidence in these constrained, low-speed zones is the direct consequence of the culturally normalized behaviour of CQO. The narrow confines, uncontrolled access points, and complex maneuvers typical of residential and market roads force drivers into aggressive passing attempts, serving as the behavioural trigger for the statistically confirmed fatal mechanisms. This evidence suggests that the current focus of safety policy, which often prioritizes high-volume highway infrastructure, misallocates resources, and the real urgency lies in redesigning safety standards and enforcing discipline on the local road networks where the majority of severe incidents actually originate (Mkwata & Chong, 2022).

The temporal pattern found that the peak of accidents occurs at night, specifically from 6:00 PM to 12:00 AM. Night-time accidents are more closely linked to environmental conditions like poor lighting and human factors such as driver fatigue, while daytime accidents are more influenced by traffic congestion and careless driving behaviour (Querfurth et al., 2025). Table 2 shows that the accident peak hours at 07:00 (481 cases) and 17:00 (406 cases) coincide with dense commuter hours (risk patterns). This statistical surge is the quantitative outcome of environmental pressure meeting behavioral response (07.00: drivers rushing against time pressure to start their workday or school and 17.00: phase of maximum driver frustration and fatigue): high traffic volume (daytime 29,05% the highest risk exposure),

combined with time pressure (late night risk 18,29% nearly matching the morning peak with major spike at 23:00(359 incident), maximizes the demand and opportunity for aggressive CQO maneuvers. Unlike the morning peak, the late-night incidents occur when roads are less congested. This suggests that dominant risk shifts from “friction-based risk” to “speed-based risk”.

TABLE 2: Crash Distribution based on Time Period 2021-2024

Time Period	Total accident	Percentage
05:00 - 08:59 (Morning Peak)	1,212	17.53%
09:00 - 14:59 (Daytime)	2,008	29.05%
15:00 - 17:59 (Afternoon Peak)	1,075	15.55%
18:00 - 21:59 (Evening/Night)	1,353	19.57%
22:00 - 04:59 (Late Night)	1,264	18.29%

The accident concentration on Local Roads (47.11%) and during Commuter Peak Hours (07:00 and 17:00) provides contextual evidence that incidents are primarily driven by traffic friction and time pressure. Local roads, characterized by *mixed-use* activity and frequent unexpected stops (creating a *High-Friction* environment), are optimal for triggering AIB (Mkwata & Chong, 2022). Impatient drivers engage in AIB to overcome congestion at these times, leading to the dominant Lateral and Secondary collisions. The significant risk shift observed during the Late Night Period (22:00-04:59), peaking at 23:00 (19.01% of total incidents), highlights a duality in the risk profile, with factors shifting entirely toward speeding and severe fatigue (Imran et al., 2024).

> *“I once had an accident; it happened around 5:20 PM. That was peak hour, the traffic jam at the Setiabudi-Dr. Mansyur intersection was terrible. The traffic light at that intersection is useless. Everyone scrambles to overtake each other, causing massive congestion and scattering. As I moved forward, the Pajero next to me was moving too slowly, and there was an Innova in front of it. I was squeezed, and just as I tried to take the left side, suddenly, there was a motorcycle riding against the traffic. We collided.”*

Violations like this are common during peak hours, when drivers are unwilling to lose even a second. In this state, there is a collective assumption that rules can be temporarily set aside in order to reach one's destination. This confirms the activation of AIB (impatience, non-compliance, CQO) in the high-friction local intersection during commuter rush hour. It was different from the accidents that happen at night. The cause of the collision is influenced more by driver fatigue and driving far above the speed limit. This is triggered by the quiet road conditions, making drivers feel unrestricted, consequently leading to much higher fatality severity.

> *“My incident happened in Sibolangit. There was a truck carrying vegetables coming down without headlights on. It was a sharp curve, and the road was pitch black because there were no streetlights. It was unavoidable; my front bumper was destroyed, and the headlights were shattered. I got dragged to the roadside. The other car was dented on the left side too. I had severe scrapes on my arm, and my ankle was slightly displaced. How could it not be severe? We were both speeding.”*

It validates the shift in risk profile. The quiet, dark environment encourages high speed, resulting in high-velocity collisions (Frontal/Side-Swipe). Even though the frequency of accidents is lower at night, the qualitative evidence confirms that the severity of fatalities is much higher due to the combination of high speed, low visibility, and fatigue.

c. *Collision Types:* The most consistently dominant collision types are “Front-Side” and “Side-Side”, which account for a substantial share of all accidents in Medan. This consistent dominance of side-impact and front-side collisions across multiple years provides strong statistical evidence of behavioural factors at play, such as a lack of lane discipline and aggressive overtaking. The dominant crash mechanisms provide direct empirical validation that accidents are largely driven by AIB and associated traffic rule violations.

The combined dominance of lateral (37.05%) and secondary (27.18%) collisions in Table 3 critically supports the hypothesis that most accidents are driven by AIB and non-compliance with traffic rules. The high frequency of secondary (rear-end) collisions is the direct result of two AIB components, i.e., failure to maintain safe longitudinal distance (impatient, rushing drivers) and sudden braking without signaling by the lead vehicle (an impulsive, non-compliant action). This sudden braking behavior is a significant trigger for chain-reaction accidents in high-friction environments (Ali et al., 2021). On the other hand, lateral (side) collisions are the mechanical consequences of failed CQO or sudden avoidance maneuvers. Rushing drivers performing CQO often operate with minimal margins. When faced with an obstacle or opposing traffic, impulsive avoidance, such as swerving laterally, results in a side-impact collision. This mechanism explicitly links CQO to the dominant, frequently occurring crash type, fulfilling the need for specific behavioral causality (Almaskati et al., 2024). While Lateral and Secondary collisions dominate frequency (epidemiological risk), their lower OR (0.93 vs. Frontal 1.00) confirms a risk duality, AIB drives high incidence rates, but high-speed Frontal collisions (though rarer) drive the highest severity (Evans, 2004).

TABLE 3: Frequency and causality of dominant crash mechanisms (2021-2024)

Crash Type	Total Frequency (%)	Odds Ratio (vs. Frontal)	AIB Causality
Lateral (Side/Side-Swipe)	37.05%	0.93	Failed CQO / Sudden Avoidance Maneuvers
Secondary (Rear-End)	27.18%	-	Tailgating / Sudden Braking without Signal (Impulsive)
Frontal (Head-On)	10.88%	1.00 (Baseline)	Highest Mechanical Fatality Risk

3.2. The Role of Road Infrastructure in Accident Dynamics

Road conditions in Sumatera Utara are a significant factor in accident dynamics, as the region's infrastructure is characterized by high heterogeneity and poor maintenance. Many roads, especially in rural and intercity areas, are not well-maintained, with conditions such as potholes, cracks, and uneven surfaces. The poor quality of the infrastructure serves as a situational trigger, forcing drivers, particularly motorcyclists, to perform dangerous maneuvers. Poor road conditions not only damage vehicles but also directly shaped driving behavior, making it more aggressive and unpredictable. Roads in several areas of Sumatera Utara, especially on local roads, are still marred by potholes, cracks, and uneven surfaces. This condition poses a significantly greater problem for motorcycle riders compared to cars (Figure 2).

This situational pressure is captured vividly in the driver's account:

> *"Weish... that was terrifying. I slipped because I was trying to avoid a pothole in the road. My head was so close to the wheel of the truck carrying palm oil. I fell onto the road just as a truck was passing by. My motorcycle tire condition was already poor when I hit the pothole, making it unstable. The distance to other vehicles was definitely unsafe because it was crowded at the time. I was very close to other motorcyclists. Because we were all trying to overtake each other, he swerved, I became unstable, lost control of the handlebars, and fell. I ended up in the middle of the road, facing a truck coming from the opposite direction. There was a car behind us too."*

The unavoidable act of swerving to avoid both visible and hidden potholes (often concealed by poor drainage) directly triggers Lateral collisions with other vehicles. Accidents also occur because motorcycle tires lose traction (*hydroplaning*) on uneven, wet surfaces, causing them to become highly unstable and slip instantly. Consequently, the probability of fatal accidents increases because poor road conditions have a far greater impact on motorcycle stability, thus amplifying the high Odds Ratio of death.

FIGURE 2: The Trans Sumatera road network map and poor road infrastructure condition

This not only obstructs traffic flow but also directly increases the risk of accidents. Poor drainage often leads to standing water during rain, which hides dangerous potholes and makes roads more unsafe (Mkwata & Chong, 2022). Research indicates that poor road surface conditions have a much greater impact on motorcycle accidents than on four-wheeled vehicles, directly increasing the probability of a crash. Severe road damage, particularly in high-speed and wet weather conditions, can disrupt vehicle stability (Li et al., 2025). This is further exacerbated by phenomena like hydroplaning (tires losing traction), which significantly increases the risk of losing control. Although poor roads can make drivers more cautious, the risk of accidents increases due to sudden maneuvers, such as swerving to avoid a pothole, which can lead to collisions with other vehicles.

Additionally, secondary factors such as faded, unclear, or missing road markings, inadequate traffic signs, inadequate lighting at night, and a lack of regular maintenance further contribute to the rising number of accidents (Wei et al., 2017). These visual obstacles compel drivers to slow down, which, ironically, only increases the frustration and impatience of those following behind them. In an effort to save time (a manifestation of AIB), drivers resort to performing Close-Quarters Overtaking (CQO) in inadequate gaps, precisely because they are already aggravated by road conditions that impede their progress.

3.3. Thematic Analysis of Unsafe Driving Culture in Sumatera Utara

The quantitative data on accident patterns are explained and contextualized by qualitative findings from direct observation and interviews with traffic officials. A thematic analysis reveals a pervasive, deeply ingrained "unsafe driving culture" that shapes driver behaviour in Sumatera Utara. This culture is not merely a collection of reckless acts but a set of established social norms that prioritize expediency and aggression over safety and compliance. The qualitative analysis found three key themes:

3.3.1 Aggressive Maneuvers and Disregard for Norms

Thematic analysis reveals a dominant pattern of aggressive and non-compliant driving. This theme is characterized by a "get ahead" mentality, in which drivers are impatient with congestion and resort to dangerous maneuvers. The dominance of front-side and side-side collisions (37,05%) in the quantitative data is directly explained by this behaviour, which includes forceful overtaking in narrow spaces, frequent and sudden lane changes without signaling, and a general disregard for right-of-way rules at intersections (Sheykhfard et al., 2024). Furthermore, the high number of rear-end collisions (27,18%) is a direct consequence of this theme, as drivers habitually fail to maintain a safe following distance and rely on sudden braking, creating a high-risk domino effect. This behaviour is a form of learned adaptation to chaotic traffic conditions and is not considered abnormal within the local context.

3.3.2 The Inextricable Link Between Human Behavior and Infrastructure

A second key theme identified is the symbiotic, and often negative, relationship between human behavior and infrastructure. Drivers adapt their behavior to the poor quality of the roads, which in turn exacerbates accident risks. While uneven road surfaces, potholes, and poor drainage are objective hazards, driver responses to them, such as swerving abruptly to avoid damage, often introduce new risks, including collisions with other vehicles (Adamidis et al., 2021). This theme highlights that the problem is not just the poor road, but how drivers navigate and respond to its imperfections. The lack of clear road markings and signage further encourages this behavioral adaptation, as drivers feel less obligated to follow rules that are not clearly defined or enforced.

3.3.3 Selective Compliance and the Influence of Social Norms

The most striking theme is selective compliance, where drivers adhere to certain safety rules while blatantly ignoring others. This is a crucial insight into the complex motivations behind local driving behavior. The direct observation of three teenagers on a single motorcycle, all wearing helmets, provides powerful empirical evidence for this theme (Figure 3).

FIGURE 3: Overload capacity in motorcycle driving behaviour

Wearing a helmet is widely practiced, possibly due to effective law enforcement and public awareness campaigns. In this case, compliance is driven by a clear external consequence (a fine or penalty). However, the act of overloading the motorcycle, which is equally dangerous but less consistently policed, is perceived as an acceptable norm for convenience or necessity. This behaviour aligns with research that shows social and cultural factors heavily influence whether drivers choose to comply with safety regulations. This thematic analysis reveals that the issue is not a complete lack of safety awareness, but a nuanced and contextualized form of rule-following that is deeply embedded in the local culture. The reasoning behind the practice of overloading a motorcycle is vividly captured in the interviewee's statement that directly validates the theme of selective compliance, where the visible rule is followed due to fear of external consequence, while the invisible or less policed rule (overloading capacity) is disregarded because it has become a normalized social norm.

> *"Yeah, well, we only have one motorcycle. So, we just ride together since we're all going to the same place. Actually, we know it's wrong, but it's done so often. So we wear helmets so we don't get caught by the police. Since we're still teenagers, it's fun riding three people like this. It's not a big problem anyway, our weight isn't that heavy. The reason is also because it saves time and money"*

The primary motivations cited - *'it saves time and saves money'* - further underscore that economic and social expediency consistently override safety principles, even when the risk of collision (AIB) is acknowledged.

The critical point from this research, found in the findings from the research in Sumatera Utara, particularly in Medan, fundamentally challenges the global assumption that road safety can be achieved merely by importing advanced technology designed for a different driving culture. The existence of a profound disconnect between its standardized testing protocols and the on-the-ground reality of driver behaviour in the region. The quantitative data, showing the consistent dominance of front-side and side-side collisions, provides statistical evidence of aggressive and unpredictable maneuvers. This is further supported by the qualitative finding of selective compliance, in which drivers adhere to some rules while ignoring others.

It means that advanced technologies like Automatic Emergency Braking (AEB) and Lane Keeping Assist (LKA), which rely on predictable road behaviour, may be ineffective or even misleading in a chaotic environment. Therefore, the study's findings provide clear evidence that culture is a key variable in road safety. To truly make a difference, it must advocate for a new paradigm that integrates local behavioural factors into safety standards, revise testing protocols to include real-world scenarios such as overloaded vehicles and aggressive maneuvers, and champion a holistic approach that prioritizes behavioural change alongside technological advancement.

4. CONCLUSION

The findings of this research present critical implications for global standards, as they challenge the effectiveness of conventional safety standards in the local context. This research confirms that the traffic accident dynamics in the Sumatera Utara region (2021–2024) are characterized by a duality of risk and a deeply ingrained unsafe driving culture that overrides compliance. The findings establish that motorcycle involvement is the most critical factor, accounting for 88.43% of all vehicle involvements and the strongest predictor of fatal outcomes, as evidenced by an Odds Ratio (OR) of 1.29 ($p<0.001$). This vulnerability is amplified by pervasive Aggressive and Impulsive Behavior (AIB), which directly accounts for the dominance of Lateral (37.05%) and Secondary (27.18%) collisions, mechanisms primarily driven by failed Close-Quarters Overtaking (CQO) and disregard for safe following distances during high-stress periods. This further contextualizes the risk by revealing selective compliance: drivers adhere to rules with clear external consequences while normalizing dangerous acts because of social and economic expediency. This systemic cultural factor, combined with poor infrastructure that acts as a situational trigger for impulsive maneuvers, fundamentally challenges the global assumption that standard technological solutions can be effective in an environment defined by unpredictable behaviour and non-standard crash mechanisms.

The findings from Sumatera Utara necessitate a paradigm shift in global road safety standards, urging the integration of local cultural and behavioral factors. This study recommends that ASEAN NCAP develop and implement three critical protocol revisions:

1. **I**ncorporate crash scenarios that replicate AIB-induced Lateral and Secondary collisions, specifically requiring new testing protocols for Automatic Emergency Braking (AEB) and other assistance systems to perform effectively under *non-linear, aggressive maneuvering* typical of failed CQO.
2. **I**ntroduce a mandatory Overloading and Non-Standard Passenger Capacity Test for motorcycles and other high-risk vehicle types, assessing the impact of normalized social behavior (such as carrying excessive weight/passengers) on vehicle stability during emergency swerving and on crash outcome severity.
3. Establish new safety metrics that are sensitive to VRU-specific risks by assessing passenger vehicles' ability to detect and respond to motorcyclists maneuvering aggressively or operating *outside* standard lane boundaries (e.g., on shoulders or weaving through traffic). Ultimately, this data urges ASEAN NCAP to champion a new globally recognized approach that prioritizes culturally informed behavioral safety alongside technological advancement.

ACKNOWLEDGEMENT

We extend our sincere gratitude to ASEAN NCAP (New Car Assessment Program for Southeast Asian Countries) and MIROS (Malaysian Institute of Road Safety Research) for their invaluable financial support, which made this research on road safety in Sumatera Utara possible. Their commitment to improving road safety is truly commendable and was instrumental in the successful completion of this study. We also extend our sincere gratitude to the Traffic Unit of the Medan Metropolitan Police (POLRESTABES Medan) and the Law Enforcement Unit of the Sumatera Utara Regional Police for their cooperation in providing traffic accident data, which served as the primary source for this research's findings. Furthermore, we deeply appreciate the contributions of the motorcycle riders, public transport drivers, online public transport drivers and riders, bus and truck drivers who willingly shared their personal experiences of past accidents, thereby enriching the qualitative analysis and overall discussion of this study.

REFERENCES

Adamidis, F. K., Mantouka, E. G., & Vlahogianni, E. I. (2020). Effects of controlling aggressive driving behavior on network-wide traffic flow and emissions. International Journal of Transportation, Science and Technology, 9(3), 263–276.

Ali, Y., Zheng, Z., & Haque, M. M. (2021). Modelling lane-changing execution behaviour in a connected environment: A grouped random parameters with heterogeneity-in-means approach. Communications in Transportation Research, 1, 100009.

Almaskati, D., Kermanshachi, S., & Pamidimukkala, A. (2024). Investigating the impacts of autonomous vehicles on crash severity and traffic safety. Frontiers in Built Environment, 10(March), 1–10.

Creswell, J. W. (2014). Research design - pendekatan kualitatif, kuantitatif, dan mixed. Yogyakarta: Pustaka Pelajar.

Evans, L. (2004). Traffic Safety. USA: Science Serving Society.

Guest, G., MacQueen, K. M., & Namey, E. E. (2011). Applied Thematic Analysis. New York, USA: SAGE Publications, Inc.

Imran, M. A. Al, Nasirzadeh, F., & Karmakar, C. (2024). Designing a practical fatigue detection system: A review on recent developments and challenges. Journal of Safety Research, 90, 100–114.

Kementerian Perhubungan RI (2017). LAPTAH_KEMENHUB_2017_FIX.Cetak.FULL PUPR 2017. Jakarta.

Kementerian Perhubungan RI (2023a). Data kecelakaan lalu lintas di Indonesia tahun 2023. Jakarta.

Kementerian Perhubungan RI (2023b). Laporan keselamatan transportasi tahun 2023. Jakarta.

KORLANTAS POLRI (2024). Kecelakaan lalu lintas di indonesia didominasi oleh kendaraan roda dua. Retrieved from https://korlantas.polri.go.id

Li, Z., Tang, R., Li, G., & Xu, C. (2025). Understanding social attitudes towards autonomous driving: a perspective from Chinese citizens. Transportation, 52, 1925–1956.

Mkwata, R., & Chong, E. E. M. (2022). Effect of pavement surface conditions on road traffic accident - A Review. E3S Web of Conferences, 347(01017), 1–10.

Querfurth, L., Rehborn, H., Bernhardt, B., Guan, Y., Huang, W., & Hoffmann, S. (2025). Crash localization and traffic impact assessment via spatio-temporal analysis of connected vehicle data. Accident Analysis & Prevention, 214(107956).

Sheykhfard, A., Haghighi, F., Bakhtiari, S., Moridpour, S., & Xie, K. (2024). International Journal of Transportation Analysis of traffic conflicts with right-turning vehicles at unsignalized intersections in suburban areas. International Journal of Transportation Science and Technology, 16, 34–49.

Taheri, A., Switala, K., Fountas, G., Sheykhfard, A., Dadashzadeh, N., & Müller, S. (2025). An empirical analysis of crash injury severity among young drivers in England: Accounting for Data Imbalance. Applied Sciences (Switzerland), 15(9), 1–23.

Undang-Undang RI (2009). Undang-Undang RI 22 Tahun 2009. 22 Lalu Lintas dan Angkutan Umum § (2009).

Nickenig Vissoci, J. R., Krebs, E., Meier, B., Vieira, I. F., de Andrade, L., Byiringiro, F., Rulisa, S., & Staton, C. A. (2020). Road traffic crash experience among commercial motorcyclists in Kigali, Rwanda. International Journal of Injury Control and Safety Promotion, 27(2), 181–187. https://doi.org/10.1080/17457300.2020.1724158

Wang, K., Shirani-Bidabadi, N., Shaon, M. R. R., Zhao, S., & Jackson, E. (2021). Correlated mixed logit modeling with heterogeneity in means for crash severity and surrogate measure with temporal instability. Accident Analysis & Prevention, 158(106128).

Wei, W., Wang, J., & Wu, L. (2017). International Journal of Transportation Quantifying the impact of road capacity loss on urban electrified transportation networks : An optimization based approach. International Journal of Transportation Science and Technology, 5(4), 268–288.

WHO (2023). Global status report on road safety 2023. World Health Organization.