OPEN ACCESS

Journal of Infrastructure and Construction Innovation | Vol. 1 No. 2 (2025)

Research Article

A Model for Assessing Road Safety in Mountain Tourist Areas: The Case of Mount Bromo

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Received:	Revised:	Accepted:	Online:
June 20, 2026	July 24, 2026	July 28, 2026	July 30, 2026

Abstract
Road safety in mountainous tourist areas is a critical concern due to winding, steep terrain and heavy tourist traffic. This study develops a road safety assessment model for access routes to Mount Bromo, integrating blackspot analysis, driver perception, and system dynamics modeling. A quantitative, evaluative design was applied across the three main access corridors through Probolinggo Regency. Primary data came from a road condition survey using International Road Assessment Program (iRAP) attributes and a driver perception survey combining iRAP indicators with the Driver Behavior Questionnaire (DBQ). Secondary data included accident records from 2020 to 2024, tourist visitation figures, and road infrastructure data. Analysis relied on the Equivalent Accident Number (EAN), Accident Equivalent Rate (AEK), Equivalent Property Damage Only (EPDO), Importance Performance Analysis (IPA), and Customer Satisfaction Index (CSI) methods, along with system dynamics modeling in Vensim. Results show 269 accidents occurred between 2020 and 2024, with a steadily rising trend. Blackspot analysis identified eight accident-prone locations across the three corridors. Most respondents were tourists driving private vehicles with relatively high driving experience. The Vensim causal loop model revealed a reinforcing loop linking infrastructure, driver perception, and risky behavior, in which drivers tend to perceive roads as safer than their actual iRAP rating, sustaining rising accident risk. An education and intervention loop offsets this by realigning perception with actual conditions. Integrating blackspot analysis, driver perception, and road safety attributes yields a comprehensive framework linking infrastructure, behavior, and accident risk, offering a foundation for sustainable road safety policy in mountain tourist areas.

Keywords: Blackspots, Driver Perceptions, iRAP, Mount Bromo, Road Safety

1. Introduction

Road safety is a global issue that continues to be a key focus, particularly in tourist areas with high traffic volumes. According to World Health Organization (2023), Road traffic accidents remain the leading cause of death worldwide, with 1.19 million fatalities each year. Indonesia, with its rapid growth in the number of motor vehicles, faces serious challenges in the transport sector, particularly in popular tourist destinations. Access roads to tourist sites often experience a surge in traffic volume during the holiday season, which can increase the risk of accidents due to a combination of factors including infrastructure, road quality and driver behavior (Kurohman & Student, 2024).

Mount Bromo is one of East Java's national tourist icons. *Balai Besar Taman Nasional Bromo Tengger Semeru* (BB TNBTS) have recorded that there are more than 321,732 visits in 2025, an increase of 58,785 visitors compared to 2024. The roads leading to the mountainous area are generally narrow, winding and congested with private vehicles and tourist transport during the peak season (Narwastuti et al., 2024; Sandy & Gunawan, 2022; Ilnytska-hykavchuk, 2025; Beltramo et al., 2022). The high volume of traffic in that area often leads to congestion, accidents and safety issues due to a lack of facilities such as road signs, guardrails and street lighting (Sulistyono et al., 2024). This situation is reinforced by the fact that a bus accident once occurred in the Mount Bromo tourist area, killing nine people due to the steep gradient of the road and a lack of safety facilities. This fact demonstrates that an increase in visitor numbers, if not matched by adequate infrastructure and safety facilities, has the potential to heighten the risk of accidents; consequently, a comprehensive evaluation of road safety performance in the tourist area is required.

One method of road safety evaluation that can be used is black spot analysis, which involves identifying accident-prone locations based on traffic accident data. This method has proven effective in determining priority locations requiring safety interventions (Sulistyono et al., 2024; Prihantono & Siregar, 2023). Most research into black spot analysis still focuses on urban and inter-city routes, whilst its application in tourist areas with distinctive road conditions, such as steep gradients and sharp bends, remains relatively limited. In addition to black spot analysis, road condition assessments can also be carried out using iRAP. In the Mount Bromo tourist area, iRAP has also been implemented (Firdaus et al., 2025; Umariyadi, 2025; Affani, 2025) , However, this assessment has not yet fully incorporated the aspect of driver perception as a key factor in safety evaluation. The factor of driver perception is considered crucial because each individual has a different view of what constitutes a safe or unsafe situation and exhibits varied reactions to potential hazards (Pires et al., 2025). An understanding of these perceptions is important for providing a comprehensive picture of the potential for accidents and the effectiveness of safety interventions (Sayed et al., 2022; Cordazzo et al., 2014).

The analysis of motorists' perceptions in this study was carried out using the Importance–Performance Analysis (IPA) and the Customer Satisfaction Index (CSI) methods. The IPA method was used to assess the level of importance and performance of road safety attributes such as road markings, lighting, traffic signs, road width and bends, thereby identifying priorities for improvement based on the results of mapping these attributes into a four-quadrant matrix (Martilla & James, 1977). The CSI method is used to measure motorists' overall satisfaction with road conditions (Fornell et al., 1996). The results of this IPA–CSI analysis were integrated into a dynamic system model (Vensim) as behavioral variables to simulate the influence of motorists' perceptions on risky behavior and accident rates in the Mount Bromo tourist area.

A gap between perceptions and the reality of road safety arises when motorists feel safe despite infrastructure conditions that do not yet meet safety standards (e.g. a 2-star iRAP rating). In the dynamic system, this gap is represented by a reinforcing loop between infrastructure, perceptions and motorists' behavior, which can lead to an increase in accidents. To counterbalance this effect, a balancing loop is implemented via the variables 'Education' and 'Intervention', which serve to correct perceptions so that they better align with the actual risk levels on the ground.

A dynamic systems approach using Vensim software can be used to model the relationships between variables such as infrastructure, driver behavior, and safety policies. According to Zhang et al. (2021) and Suryani et al. (2020) emphasise that dynamic system modelling is effective for evaluating and projecting the long-term impacts of safety policies, as it takes into account the complexity and interactions between factors. The integration of black spot analysis results and motorists' perceptions with the Vensim dynamic system approach in the context of road safety in tourist areas is still rarely undertaken; it therefore needs to be developed as a more comprehensive methodology (Ram & Chand, 2016; Hamzaoui et al., 2025).

This study offers an integrative approach by combining black spot analysis and driver perceptions to evaluate road safety in the Mount Bromo tourist area. This approach is expected to provide a comprehensive overview of the interaction between infrastructure, driver perceptions and potential safety policies. Academically, this study contributes to the development of integrated safety evaluation methods, whilst in practical terms it provides data-driven recommendations to improve transport safety at strategic tourist destinations in Indonesia.

2. Literature Review

2.1. Tourism

According to a study by UNWTO (2021) defines tourism as a human activity involving travel to and a stay in a destination outside one's everyday environment for the purposes of leisure, business and other reasons. Based on the above theoretical concept of tourism, it can be concluded that tourism can be understood as a social and economic phenomenon encompassing a series of travel activities undertaken by individuals or groups outside their usual living environment, with the primary aim of gaining recreational, cultural, professional or commercial experiences. These activities take place through interactions between tourists and service providers, comprising local communities, business operators, and central and local government bodies. Thus, tourism is not merely a matter of moving from one place to another, but a multidimensional process involving movement, service provision, and interconnections between various parties within a destination.

2.2. Road Infrastructure

Based on Law of the Republic of Indonesia No. 2 of 2022 with regard to roads, a road is a means of land transport comprising all parts of the road, including connecting structures and ancillary structures, whether located below ground level or above water level, with the exception of railway tracks, lorry tracks and cable routes (UU RI, 2022). Based on Kementerian Pekerjaan Umum (2006) or Ministry of Public Works about roads and Law of the Republic of Indonesia No. 22 of with regard to road traffic and transport, roads can be categorised according to: (1) intended use, (2) the road network system (SJJ), (3) road status, (4) road function, (5) road classification, which comprises road infrastructure provision specifications (SPPJ) and road user classes (UU RI, 2009).

2.3. Safe Roads

A safe road is a concept in road infrastructure that is designed with the safety of all road users (drivers, pedestrians and cyclists) in mind. Its main principle is to minimise the risk of accidents and reduce the fatality rate should an accident occur. Wegman et al. (2008) explains that there are three main principles that must be applied when designing roads, namely 'Self-Explaining', 'Self-Enforcing' and 'Forgiving Road'.

2.4. Accident-Prone Locations (Black Spots)

Accident-prone locations are areas at junctions or along stretches of road approximately 100–300 metres long, where accidents with relatively similar causes occur within a specific time frame (Departemen Permukiman dan Prasarana Wilayah, 2004). Accident-prone locations are sections of the road network, such as junctions, bridges or short stretches (≤0.3 km), which, over the course of a year, have recorded an accident frequency or number of casualties exceeding the minimum threshold that has been set (Direktorat Jendral Perhubungan Darat, 2007). Accident-prone locations are those with a high accident rate, where accidents occur repeatedly over a specific period of time (Kementerian Pekerjaan Umum & Direktorat Jenderal Bina Marga, 2012).

2.5. International Road Assessment Program (IRAP)

The International Road Assessment Program (iRAP) is an international Program used to assess, map and improve road safety based on data and international standards. Based on iRAP (2021) Methodology Fact Sheet 1: An overview of the main iRAP protocols, covering Risk Mappings, Star Ratings, Safer Roads Investment Plans and Performance Tracking.

2.6. Drivers' Perceptions

A driver's perception is a subjective assessment made by the driver whilst on a journey, including an assessment of the extent to which road conditions support safety and comfort whilst driving. Perceptions may be influenced by experience, knowledge and information received, which may lead to discrepancies in relation to objective conditions and technical audits (Slovic, 1987). According to Sayed et al. (2022) that drivers' perceptions of risk play a key role in determining their driving behavior, including maintaining a safe following distance, reducing aggression and avoiding traffic offences. The study also explains that drivers' perceptions of road safety are influenced not only by individual characteristics but also by the local traffic context, such as road congestion and infrastructure conditions.

2.7. Research Hypothesis

Road safety at Mount Bromo can be analyzed using a dynamic system with the IRAP method.
H1: There are accident-prone areas (black spots) on the route to the Mount Bromo tourist area, influenced by road infrastructure conditions such as road width, sharp bends, gradients, and limited safety facilities.
H2: Drivers' perceptions of road safety on tourist roads have a significant influence on driving behavior, which in turn affects the level of road safety in the area.

3. Methods

This study employs a quantitative approach with an evaluative research design to develop a dynamic road safety system model for the access corridor leading to the Mount Bromo tourist area via Probolinggo Regency. The study area covers three main road segments, namely the Probolinggo City Junction–Tourist Area Monument (22.3 km), the Tongas Junction–Tourist Area Monument (19.2 km), and the Tourist Area Monument–Bromo Ticket Office (17.3 km), which constitute the main routes used by tourists travelling to the Bromo area.

The research data consists of primary and secondary data. Primary data was obtained through a survey of existing road conditions and a driver perception survey. The survey of existing conditions was conducted via field observations to identify road safety attributes based on the International Road Assessment Program (iRAP) guidelines, covering aspects of road geometry, pavement condition, road equipment, safety facilities, and facilities for vulnerable road users. The driver perception survey was conducted using a Likert-scale questionnaire developed by integrating iRAP road safety attributes with driver behavior indicators from the Driver Behavior Questionnaire (DBQ), covering the dimensions of violations, unintentional violations, negligence, and misperceptions.

The study population comprised all motor vehicle drivers travelling along the access routes to the Mount Bromo tourist area. The sampling technique employed purposive sampling, with respondents selected based on the criteria that they had previously visited or were currently visiting the Bromo tourist area, were using a mode of transport to reach the location, and were willing to complete the questionnaire of their own accord. The sample size was determined using the Isaac and Michael formula at a 5 per cent error rate, resulting in a minimum requirement of 384 respondents.

Secondary data included road traffic accident data, tourist visitation data, as well as maps and road infrastructure information obtained from relevant agencies such as the Police, the Tourism Office, the Public Works and Public Housing Office, and the Central Statistics Agency (BPS). Data analysis was carried out in several stages. Firstly, validity tests were carried out using Pearson's correlation and reliability tests using Cronbach's Alpha coefficient to ensure the quality of the research instruments. Subsequently, driver perception data were analysed using Importance Performance Analysis (IPA) to identify safety attributes prioritised for improvement, as well as the Customer Satisfaction Index (CSI) to measure drivers' satisfaction levels with road safety conditions.

Accident analysis was carried out to identify accident-prone locations (blackspots) based on incident frequency and the Poisson distribution. Road segments were then classified into the categories of non-prone, potential blackspot and blackspot. The results of the IPA, CSI and blackspot analyses were subsequently integrated to identify the dominant factors influencing road safety.

The final stage of the research involved building a dynamic system model using Vensim software through the development of a Causal Loop Diagram (CLD) and a Stock and Flow Diagram (SFD). The model was used to simulate the influence of driver risk factors, road safety conditions, and traffic characteristics on the number of accidents. The model was validated using structural verification tests to confirm consistency between the model structure and the underlying theoretical and empirical basis of the system, together with behavior reproduction tests to compare simulated accident trends against historical accident data for the 2020–2024 period, thereby ensuring that the model's dynamic behavior adequately reflected real-world conditions before being used for scenario simulation. Following the validation process, various policy scenarios were simulated to evaluate the effectiveness of improvements to safety infrastructure, the reduction of driver behavior risks, and traffic management in lowering accident rates on the access routes to the Mount Bromo tourist area.

4. Results and Discussion

4.1. Current Situation

Road traffic accident data is used as a basis for identifying the factors causing accidents and determining locations with a high risk of accidents. In this study, the data analysed comprises records of road traffic accidents on the access roads leading to the Mount Bromo tourist area during the period 2020–2024. This data includes the number of accidents that occurred in each year of the observation period and is used as the basis for analysing the characteristics and accident risk levels at the study locations.

Table 1. Accident Data for the Mount Bromo Tourist Access Route for the Period 2020–2024

No.	Year	Number of Accidents	%	The Victim's Condition			Number of Victims	%
				MD	LB	LR		
1.	2020	39	14.50	15	4	43	62	16.06
2.	2021	51	18.96	12	2	52	66	17.10
3.	2022	52	19.33	10	4	59	73	18.91
4.	2023	59	21.93	14	0	64	78	20.21
5.	2024	68	25.28	15	0	92	107	27.72
Total		269	100	66	10	310	386	100

Source: South Jakarta Traffic Police Corps (2025)

Based on the road traffic accident data in Table 1 for the period 2020–2024, there were 269 accidents recorded, involving a total of 386 victims: 66 fatalities, 10 seriously injured and 310 with minor injuries. The number of accidents shows an upward trend, rising from 39 incidents in 2020 to 68 incidents in 2024, with 2024 being the year with the highest number of accidents and casualties, accounting for 25.28% and 27.72% of the total, respectively. Meanwhile, those with minor injuries constituted the largest group, accounting for approximately 80.31 per cent of the total number of casualties. This indicates that the risk of accidents on the access roads leading to the Mount Bromo tourist area remains relatively high and has tended to increase over the observation period.

Figure 1. Location of the Black Spot

The results of the analysis indicate the presence of eight black spot locations along the access roads to the Mount Bromo tourist area. The distribution of these black spot locations and road sections is presented in detail in Table 2.

Table 2. Distribution of Black Spot locations

No.	Location	Segment
The section between the Probolinggo City T-junction and the Tourist Area Monument		
1.	Blackspot 1	KM SBY 99+000
2.	Blackspot 2	KM SBY 102+000
3.	Blackspot 3	KM SBY 103+000
The Tongas T-junction – Tugu Tourist Area section		
1.	Blackspot 4	KM TGS 0+000
2.	Blackspot 5	KM TGS 3+000
3.	Blackspot 6	KM TGS 15+000
The Tugu Tourist Area Section – Bromo Ticket Office via Probolinggo		
1.	Blackspot 7	KM SBY 127+000
2.	Blackspot 8	KM SBY 128+000

4.2. Drivers' Perceptions

An analysis of drivers' perceptions was carried out to identify the factors influencing road safety based on the experiences and assessments of road users. This analysis covered the characteristics of respondents, accident history, driving behavior, and perceptions of risk regarding road conditions and the traffic environment. Furthermore, the results of the IPA and CSI analyses for each blackspot area were categorised into lower-risk blackspots (BS 1–BS 6) and higher-risk blackspots (BS 7–BS 8), and then interpreted alongside the iRAP Star Rating results to obtain a more comprehensive picture of road safety conditions, both from the perspective of road users' perceptions and the objective state of the infrastructure.

The characteristics of the study's respondents indicate that road users travelling to the Mount Bromo tourist area are predominantly male (75%) and belong to the productive age group of 18–35 years (61%), who have high mobility and a relatively high travel frequency. The majority of respondents had a secondary school or equivalent qualification (33%) or a bachelor's degree (26%), and were employed as self-employed individuals (30%) or civil servants/private sector employees (26%), reflecting a relatively diverse socio-economic background. In terms of travel experience, the majority of respondents were first-time visitors (42%) or had visited 2–3 times (39%), with the main purpose being a holiday (89%). The most commonly used mode of transport was private two-wheeled vehicles (54%), followed by private four-wheeled vehicles (34%), indicating the dominance of private vehicle use for journeys to the tourist area. Furthermore, the majority of respondents had considerable driving experience, namely 7–10 years and more than 10 years (31% each), meaning that their assessment of road safety was based on sufficient driving experience. Regarding accident history, the highest number of respondents who had been involved in an accident was found at the survey locations KM SBY 99+000 (67 respondents) and KM SBY 102+000 (43 respondents), whilst the fewest were recorded at KM SBY 127+000 and KM SBY 128+000 (12 respondents each). These accident histories do not indicate the locations where the accidents occurred, but rather the respondents' personal experiences of accidents, which may influence their perception of risk and level of vigilance whilst driving.

4.3. Analysis of Driver Behavior

An analysis of driver behavior on the access roads to the Mount Bromo tourist area was conducted using a Likert-scale questionnaire to identify aggressive behavior, human error and traffic offences that could potentially affect road safety. The results show that the three variables had relatively similar average values across all study locations, with aggressive behavior tending to have the highest scores at several points, indicating that such behavior is still quite common amongst drivers. To determine its impact on accident risk, a binary logistic regression analysis was carried out based on the respondents' accident history. The regression analysis was conducted using the full respondent sample (n = 384), with accident involvement history (coded as a binary outcome: 1 = had experienced an accident, 0 = had not) as the dependent variable, and aggressive behavior, human error, and traffic violations as the independent predictor variables. The analysis results indicate that all variables have a risk odds ratio (Exp(B) > 1), meaning that an increase in aggressive behavior, human error or traffic violations will increase the likelihood of an accident occurring. Generally, traffic violations and aggressive behavior contribute more significantly to risk than human error, with the highest increase in accident probability found for the traffic violation variable at KM SBY 128+000. These findings indicate that human factors play a significant role in road safety; consequently, accident prevention efforts must be undertaken not only through infrastructure improvements but also through safety education, raising road user awareness, and the enforcement of traffic regulations. These results were subsequently used as the basis for developing risk factors within a dynamic system model to analyse the influence of driver behavior on the number of accidents at the study site.

4.4. Analysis of Motorists' Risk Perceptions

An analysis of motorists' risk perceptions was carried out to assess the level of importance and performance of various road safety indicators on the access roads to the Mount Bromo tourist area, using the Importance-Performance Analysis (IPA) and Customer Satisfaction Index (CSI) methods. The results of the analysis revealed a discrepancy between the safety conditions perceived by motorists and the expected levels of importance, thereby identifying a number of indicators that should be prioritised for improvement. At KM SBY 99+000, the aspects requiring the most attention include guardrails, road shoulders, blind bends, speed control, entry and exit traffic, roadside parking, and visibility along the access route. At KM SBY 102+000, the top priorities include road shoulders, speed limits, the width of passing lanes, uncontrolled junctions, and vehicle speeds in pedestrian areas. Meanwhile, at KM SBY 103+000, improvements are focused on bends, guardrails and road shoulders.

At KM TGS 0+000, aspects requiring improvement include the central reservation, access entry and exit activities, uncontrolled junctions, and access sight distances. At KM TGS 3+000, priority factors are dominated by road geometry, safety facilities, and the road environment, which have the potential to increase the risk of accidents. At KM TGS 15+000, the key indicators requiring attention include bends, guardrails, lane width, bend warning signs (chevron), and access entry and exit points. Meanwhile, at KM SBY 127+000 and KM SBY 128+000, improvement priorities focus on curve warning signs, speed control, access activities, and pedestrian safety. Overall, the IPA results indicate that road geometry, safety facilities, speed management and access management are the factors that most influence drivers' perception of risk and should be prioritised in efforts to improve road safety on the route to the Mount Bromo tourist area.

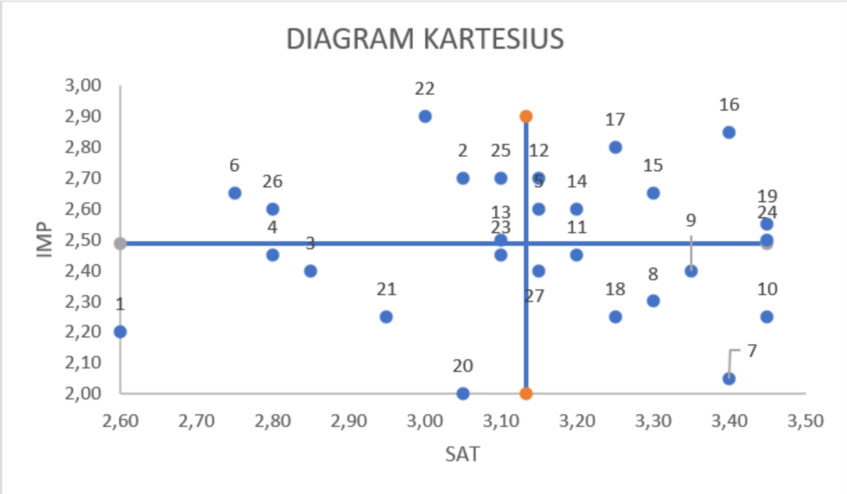

Figure 2. Cartesian Diagram KM SBY 128+000

Based on Figure 2, the indicators included in Quadrant A (top priority) are Question 2 (Guardrails), Question 6 (Curve Signs/Chevrons), Question 22 (Speed in Pedestrian Areas), Question 25 (Uphill and Downhill Sections), and Question 26 (Barriers against Motorcycles). These indicators are considered highly important by motorists, yet their performance levels remain below average, thus requiring further attention and action. These results indicate that safety aspects relating to road infrastructure, the geometric conditions of mountain roads, and protection for motorcyclists remain key concerns for road users. Therefore, improvements to safety facilities such as guardrails, warning signs, vehicle speed management, and the provision of safety features on uphill and downhill sections, as well as in areas with motor vehicle interactions, need to be prioritised to enhance road safety at the study sites.

In addition to IPA analysis, this study also utilised the Customer Satisfaction Index (CSI) method to measure motorcyclists' satisfaction levels with road safety conditions at each study location. The CSI value was derived from a combination of the importance and satisfaction ratings assigned by respondents to all risk perception indicators. The CSI results were used to illustrate the overall level of motorist satisfaction with road safety conditions at each blackspot location. The calculated CSI values are presented in Table 3.

Table 3. CSI Values

No.	Location	CSI Score (%)
1.	KM SBY 99+000	67.47
2.	KM SBY 102+000	65.65
3.	KM SBY 103+000	65.79
4.	KM TGS 0+000	65.76
5.	KM TGS 3+000	62.84
6.	KM TGS 15+000	63.05
7.	KM SBY 127+000	61.21
8.	KM SBY 128+000	62.67

According to Table 3, the CSI values at all study sites ranged from 62.21% to 67.47%. The highest CSI value was recorded at KM SBY 99+000 at 67.47%, whilst the lowest was at KM SBY 127+000 at 62.21%. Generally, all locations had CSI values in the 'fairly satisfied' category, indicating that the road safety conditions perceived by motorists still do not fully meet the expectations of road users.

These results indicate that, although road safety conditions at the study sites have been rated as fairly good by motorists, there are still several aspects that require improvement. Therefore, efforts are needed to improve the priority indicators identified through IPA analysis in order to enhance road users' satisfaction and safety at the study sites.

4.5. A Comparative Analysis of Motorists' Perceptions and Road Safety Conditions

A comparative analysis was carried out to compare the results of the Importance Performance Analysis (IPA), the Customer Satisfaction Index (CSI) and the iRAP Star Rating in evaluating road safety conditions at the study site. These three methods employ different approaches: the IPA is used to identify safety indicators that should be prioritised for action based on motorists' perceptions; the CSI is used to measure motorists' overall satisfaction with road safety conditions; whilst the iRAP Star Rating is used to assess road safety levels based on infrastructure characteristics and accident risks present at the study site.

By comparing these three methods, it is possible to identify both the similarities and differences between motorists' perceptions of road safety conditions and the results of objective assessments based on the iRAP Star Rating. The results of this comparative analysis are used to identify safety aspects requiring priority attention and form the basis for the formulation of safety variables in a dynamic system model to evaluate road safety performance more comprehensively, as shown in Table 4.

Table 4. Comparison of Motorists' Perceptions and Road Safety Conditions

Location	CSI	CSI Category	Star Rating	Number of Indicators in Quadrant A	Priority of Action
KM SBY 99+000	67.47	Quite satisfied	2	8	High
KM SBY 102+000	65.65	Quite satisfied	3	10	High
KM SBY 103+000	65.79	Quite satisfied	3	11	Very High
KM TGS 0+000	65.76	Quite satisfied	2	11	Very High
KM TGS 3+000	62.84	Quite satisfied	3	6	Medium
KM TGS 15+000	63.05	Quite satisfied	3	7	Medium
KM SBY 127+000	61.21	Quite satisfied	2	10	Very High
KM SBY 128+000	62.67	Quite satisfied	2	6	High

According to Table 4, all study locations had CSI scores in the 'fairly satisfied' category, indicating that road users generally consider road safety conditions to be at an acceptable level. However, the results of the objective assessment using the iRAP Star Rating show that several locations namely KM SBY 99+000, KM TGS 0+000, KM SBY 127+000, and KM SBY 128+000 still have a Star Rating below 3 stars.

This situation indicates that the safety perceptions held by road users do not always reflect the actual level of road safety. These findings are consistent with research by Mwaura (2024), which identified a discrepancy between the results of road user perception surveys and safety audits using iRAP, whereby road users tend to rate road conditions as safer than the level of risk indicated by objective assessments of road infrastructure.

Furthermore, Useche et al. (2022) explain that road users' safety perceptions are influenced by their experiences, habits and level of adaptation to the road environment; consequently, road users may feel safe even though, objectively, there remains a high level of safety risk.

These findings highlight the importance of combining a subjective approach based on road users' perceptions (IPA and CSI) with an objective approach using the iRAP Star Rating. Consequently, road safety assessment is not based solely on road users' satisfaction levels, but also takes into account the level of risk identified based on road infrastructure conditions. These results also illustrate that locations with relatively high satisfaction levels do not necessarily have adequate safety levels according to international road safety standards.

4.6. Area Classification

Based on the results of the analysis of driver behavior, risk perception, IPA, CSI and the iRAP Star Rating, the study locations were grouped into two main areas: the Lower Area and the Upper Area. This grouping was based on similarities in road geometric characteristics, topographical conditions and traffic characteristics along the tourist route to Mount Bromo. The Lower Area comprises the locations at KM SBY 99+000, KM SBY 102+000, KM SBY 103+000, KM TGS 0+000, KM TGS 3+000 and KM TGS 15+000. Meanwhile, the Upper Area comprises the locations KM SBY 127+000 and KM SBY 128+000. This grouping was carried out to simplify the process of identifying road safety variables to be used in the development of the dynamic system model.

Table 5. Grouping of Research Areas

Area	Blackspot Location
Lower Area	KM SBY 99+000, KM SBY 102+000, KM SBY 103+000, KM TGS 0+000, KM TGS 3+000, KM TGS 15+000
Upper Area	KM SBY 127+000, KM SBY 128+000

5. Conclusion

This study identified eight blackspot locations along the access corridor to the Mount Bromo tourist area, namely KM SBY 99+000, KM SBY 102+000, KM SBY 103+000, KM TGS 0+000, KM TGS 3+000, KM TGS 15+000, KM SBY 127+000, and KM SBY 128+000. The results of the driver perception analysis indicate that all locations fall into the 'fairly satisfied' category, with CSI scores ranging from 61.21% to 67.47%; however, the results of the objective assessment using the iRAP Star Rating system show that some locations still have a low safety rating (2 stars). These findings highlight a discrepancy between road users' perceptions of safety and the actual safety conditions of the infrastructure; consequently, road safety assessments must take both subjective and objective aspects into account simultaneously.

These findings support both research hypotheses. H1, which proposed that blackspots on the route to Mount Bromo are influenced by road infrastructure conditions such as road width, sharp bends, gradients, and limited safety facilities, is supported by the blackspot analysis and iRAP Star Rating results, which identified eight accident-prone locations with several exhibiting low star ratings linked to deficiencies in these geometric and infrastructural attributes. H2, which proposed that drivers' perceptions of road safety significantly influence driving behavior and, in turn, road safety outcomes, is supported by the binary logistic regression results, which showed that aggressive behavior, human error, and traffic violations were all associated with increased accident risk, as well as by the observed discrepancy between drivers' perceived satisfaction and the objective infrastructure conditions at several blackspot locations.

These findings carry several implications. From a policy perspective, the results suggest that infrastructure improvements alone are insufficient to reduce accident risk on mountain tourist roads; interventions should be paired with targeted driver education and awareness campaigns, particularly at locations where perceived safety exceeds actual infrastructure quality, in order to correct the misalignment between driver perception and objective risk. Priority should be given to the locations classified as “Very High” priority for action (KM SBY 103+000, KM TGS 0+000, and KM SBY 127+000), where both perception-based and infrastructure-based indicators point to elevated risk. Methodologically, this study demonstrates the value of integrating blackspot analysis, driver perception surveys, and system dynamics modelling as a combined framework for road safety evaluation, offering a replicable approach for other mountain tourist destinations facing similar infrastructural and behavioral challenges. Future research could extend this model by incorporating seasonal variation in tourist volume and testing the long-term effectiveness of specific policy interventions through further Vensim scenario simulation.

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