UNIVERSITI TEKNOLOGI MARA

DEVELOPMENT OF A MODIFIED ROAD SAFETY RISK ASSESSMENT MODEL (iRAP@HIGHLANDS) FOR MOTORCYCLISTS ALONG THE MOUNTAINOUS ROAD NETWORK OF CAMERON HIGHLANDS

FATIN NAJWA BINTI MOHD NUSA

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FATIN NAJWA BINTI MOHD NUSA

Thesis submitted in fulfilment
of the requirements for the degree of
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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 30th October 2025 to conduct the final examination of Fatin Najwa Binti Mohd Nusa on her Doctors of Philosophy thesis entitled "Development of A Modified Road Safety Risk Assessment Model (iRAP@Highlands) for Motorcyclists along the Mountainous Road Network of Cameron Highlands" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiners recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

Abdul Rauf Abdul Rasam, PhD
Associate Professor
Faculty of Built Environment
Universiti Teknologi MARA
(Chairman)

Noor Azreena Kamaluddin, PhD
Senior Lecturer
Faculty of Civil Engineering
Universiti Teknologi MARA
(Internal Examiner)

Kasem Choocharukul, PhD
Professor
Faculty of Engineering
Chulalongkorn University
(External Examiner)

PROFESSOR DR HJH ZURAEDA IBRAHIM
Dean
Institute of Postgraduates Studies
Universiti Teknologi MARA

Date: 26 March 2026

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Name of Student	:	Fatin Najwa binti Mohd Nusa
Student ID. No.	:	2021902405
Programme	:	Doctor of Philosophy in Transport and Logistics – LT990
Faculty	:	Malaysia Institute of Transport
Thesis Title	:	Development of a Modified Road Safety Risk Assessment Model (iRAP@Highlands) for Motorcyclists along the Mountainous Road Network of Cameron Highlands
Signature of Student	:	……………………………………………..
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ABSTRACT

Motorcycle crashes in mountainous regions remain a persistent road safety challenge due to complex terrain, variable weather conditions, and demanding road geometry. In Malaysia, motorcyclists constitute a significant proportion of road fatalities, yet existing studies have rarely examined their vulnerability within mountainous environments. Previous research often isolates roadway design from broader safety dimensions, overlooking the combined influence of road engineering, rider behaviour, and environmental factors. This study addresses this gap by developing a modified road safety risk assessment model, iRAP@Highlands, specifically tailored for motorcyclists navigating the mountainous road network of Jalan Simpang Pulai to Blue Valley in the Cameron Highlands, Malaysia. This study are structured into four objectives: (1) to identify the thematic structure and key factors contributing to road crashes in mountainous road networks; (2) to develop a road crash data profile for the Cameron Highlands mountainous road network; (3) to establish road condition reports for the main road that captured the highest fatal crash frequency in Cameron Highlands; and (4) to propose a modified road safety risk assessment model for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands. A Systematic Literature Review (SLR) synthesized 34 sub-factors related to road engineering, 18 to rider behaviour, and 7 to environmental factors. The secondary crash data (2015 to 2018) from RMP were analysed using Tableau 10.4, while road survey data were collected by the researcher via a RADIS-equipped vehicle and assessed using MiREV and ViDA software. The star rating risk map was produced to visualise high-risk zones. The modified Multiple Linear Regression (MLR) model showed an increase in adjusted R^2 from 0.248 (before the intervention) to 0.433 (after the intervention), indicating that the modified model explains a substantially greater proportion of variance in the Star Rating Score (SRS). This study contributes theoretically by localising global iRAP principles through statistical modelling, and practically by enabling quick-win countermeasure planning. The iRAP@Highlands model provides a scalable, data-driven tool for enhancing motorcyclist safety in high-risk mountainous regions, with potential applications in similar geographies worldwide.

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Abbreviations

AAA	Australian Automobile
AAM	Automobile Association Malaysia
ADB	Asian Development Bank
AI	Artificial Intelligence
ARRB	Association Australian Road Research Board
ATJ	Arahan Teknik Jalan
AusRAP	Australia Road Assessment Programme
ChinaRAP	China Road Assessment Programme
DTSP	Department of Transport of Shaanxi Province
FIA	Federation International Automobile
FSI	Fatality and Serious Injury
GIS	Geographic Information Systems
GPS	Global Positioning System
IoT	Internet of Things
iRAP	International Road Assessment Programme
IRF	International Road Federation
IT IS	Integrated Traffic Information System
JKJR	Malaysian Road Safety Department
MCO	Movement Control Order
MiReV	MIROS Road Engineering Video System
MIROS	Malaysian Institute of Road Safety Research
MITRANS	Malaysia Institute of Transport
MLR	Multiple Linear Regression

M-ROADS	Malaysian Road Safety Research Information System
MyIPO	Intellectual Property Corporation of Malaysia
MyRAP	Malaysia Road Assessment Programme
NGO's	Non-Government Organisations
PPE	Personal Protective Equipment
PWD	Public Work Department
RADIS	Road Attribute Data-Logger and Inspection System
RMP	Royal Malaysia Police
RPS	Road Protection Scores (RPS)
SLR	Systematic Literature Review
SRIP	Safer Road Investment Plans
VIF	Variance Inflation Factor (VIF)
VMS	Variable Message Systems
VRU	Vulnerable Road User
WHO	World Health Organization
WoS	Web of Science

CHAPTER 1
INTRODUCTION

1.1 Research Background

Road crashes on mountainous road networks are at an alarming stage for global road safety, impacting developed and developing countries. Mountainous regions are characterised by unique driving challenges with a combination of steep inclines, sharp curves, and highly unpredictable weather conditions (Jiménez et al. 2023). The combination of these factors generates a complex and risky driving environment that leads to a high frequency of road crashes (Peng et al. 2021). The World Health Organization (WHO) has highlighted a concerning trend where unsafe vehicles and unsafe road infrastructure often experience higher road crash risk, severe injuries, and fatalities in mountainous areas compared to flat terrains (WHO, 2023). Limited visibility due to fog or other extreme weather events, narrow roadways, and the ever-present hazard of landslides and rockfalls further worsen the risk of road crashes in these regions (Abrari Vajari et al. 2020). Globally, various stakeholders, such as governments, Non-Government Organisations, and road safety organisations, have made rigorous efforts to mitigate these risks. These strategies include upgrading road infrastructure, implementing stricter traffic regulations, and promoting driver education and training tailored to mountainous driving challenges (Moomen et al. 2020).

Malaysia has an estimated population of about 34.1 million people, and the national roadway system comprises both federal and state roads, totaling approximately 202,198 kilometres nationwide (DOSM 2024; PWD 2023). Road traffic fatalities in Malaysia rose to 6,473 in 2023, continuing the upward trend observed after 2021 and exceeding the figures reported in 2021 and 2022, thereby indicating a post-pandemic rebound in fatal crash outcomes (RMP, 2024). Most vehicle crashes are attributable to network capacity, non-separation of opposing flows, high intersection density, and roadside conditions (RMP, 2024). The Department of Statistics Malaysia (DOSM, 2024) identifies transport accidents as the fourth leading cause of death, accounting for 3.5% of all fatalities in 2023, with a significant impact on individuals aged 15 to 40, where it is the leading cause of death at 20.1%. Unlike chronic diseases such as pneumonia, ischemic heart disease, and diabetes, which primarily affect older populations, transport accidents disproportionately affect younger, working-age individuals and are mainly preventable incidents in Malaysia. Although Malaysia continues to record a high number of road traffic fatalities, recent national statistics do not differentiate crash outcomes by road terrain, including mountainous areas. This lack of disaggregated data may underestimate the safety risks inherent to mountainous roadways. Consequently, targeted interventions specifically designed for hilly and mountainous environments, such as improved road engineering, stricter enforcement, and enhanced rider and driver awareness, are urgently required to reduce preventable fatalities and associated socio-economic costs in Malaysia.

Road crash cases in mountainous regions are also a rising concern in Malaysia, mainly due to the growing popularity of these areas as viral vacation locations, tourist destinations, and vital economic centres (Barrow et al., 2005; Rusli, 2017). Malaysia's diverse topography features create numerous mountainous regions with a unique and complex ecosystem of main roadways connecting to rural and urban communities (Barrow et al. 2005). However, navigating these types of roads poses significant safety challenges for drivers. Studies by He et al. (2012) and Moomen et al. (2020) have reported that road crashes involved in these areas are often more severe due to challenging driving conditions. Sharp bends, steep inclines, and frequent adverse weather conditions like heavy rain and fog are all factors that impact a higher occurrence of road crashes in mountainous areas (Diyaljee, 2008). Additionally, as traffic volume increases, mountainous roads may not be adequately able to handle the strain, further aggravating the problem (Yusoff et al. 2022).

The Cameron Highlands, a magnet for tourist destinations in Malaysia, has a worst-case scenario of the road safety challenges faced in mountainous regions (Ahmad, 2019). This area, renowned for its breathtaking panoramas, enchanting landscapes, and cool climate, attracts approximately 1,368,383 visitors yearly (Tourism Pahang Malaysia, 2023). However, the main roads leading to and within Cameron Highlands are treacherous and accident-prone for their steep climbs, narrow passages, and sharp curves. This combination, coupled with the presence of heavy tourist traffic, agricultural transport vehicles, and local commuters, creates a dangerous hazard that significantly increases the risk of road crashes. Reports indicate that accidents in this region are often severe, resulting in fatalities and serious injuries (Ahmad, 2019). Landslides and rockfalls further worsen the safety issues for mountainous areas, and addressing these problems through improved road design, enhanced safety measures, and targeted driver education programs is essential (Jangpangi et al. 2019; Jiménez-Ramos et al. 2023).

Efforts are growing to address the issue of road crashes in the mountainous region. What is the road safety risk assessment condition for existing road infrastructure that captured the highest road crash frequency in Cameron Highlands' mountainous areas? By examining the factors contributing to road crashes in mountainous road networks globally, specifically in Malaysia, and focusing on the Cameron Highlands as a research location, this research developed a modified road safety risk assessment model to understand the challenges for mountainous road networks comprehensively. This knowledge will be beneficial in implementing proactive action and practical strategies to enhance road safety in these regions and ensure a smoother, safer journey for all travellers.

1.2 Research Motivation

The motivation for this research arises from the persistent and serious issue of road crashes, particularly in mountainous environments, which pose significant risks to human life, property, and economic stability. Globally, mountainous road networks are widely recognised as high-risk corridors due to their steep gradients, sharp horizontal and vertical curves, limited sight distance, unpredictable weather conditions, and exposure to natural hazards such as landslides and rockfalls (Rashid et al. 2017). Despite the implementation of various general road safety measures, crash severity in mountainous regions remains disproportionately high, often resulting in fatal and serious injuries (Arévalo-Támara et al. 2020). The World Health Organization (WHO) has consistently emphasised the need for targeted, context-specific interventions to improve road safety in complex and high-risk driving environments rather than relying solely on aggregated national-level strategies (WHO, 2023). As shown in Table 1.1, Malaysia recorded a consistently high number of road crashes and casualties between 2010 and 2024, including fatalities, serious injuries, and minor injuries.

Table 1.1
Road Crashes with Type of Casualties Reported in Malaysia

Year	Road Crashes	Type of Casualties			
		Death	**Serious**	**Minor**	**Total**
2010	414,421	6,872	7,781	13,616	28,269
2011	449,040	6,877	6,328	12,365	25,570
2012	462,423	6,917	5,868	11,654	24,439
2013	477,204	6,915	4,597	8,388	19,900
2014	476,196	6,674	4,432	8,598	19,704
2015	489,606	6,706	4,120	7,432	18,258
2016	521,466	7,152	4,506	7,415	19,073
2017	533,875	6,740	3,310	6,539	16,589
2018	548,598	6,284	2,964	5,377	14,625
2019	567,516	6,167	3,022	5,855	15,044
2020	418,237	4,634	2,840	9,762	17,236
2021	370,286	4,539	3,480	15,050	23,069
2022	545,586	6,080	4,306	29,730	40,116
2023	599,967	6,473	3,068	30,799	40,340
2024	638,060	6,464	3,128	29,281	38,873

Source: Royal Malaysia Police (RMP, 2024)

In Malaysia, road traffic crashes continue to pose a significant public safety concern, including in states with mountainous and highland tourism corridors such as Cameron Highlands. National statistics published by the Royal Malaysia Police (RMP) indicate that the overall burden of road crashes and casualties has remained high and, in recent years, increased markedly following the post-pandemic recovery period. However, these official statistics are reported in aggregate form and do not distinguish between flat terrain, urban roads, and mountainous or hilly environments.

Specifically, national road crash fatalities increased from 4,539 deaths in 2021 to 6,080 deaths in 2022 and further to 6,473 deaths in 2023, before marginally decreasing to 6,464 deaths in 2024. Over the same period, the total number of casualties rose sharply from 23,069 in 2021 to 40,116 in 2022 and 40,340 in 2023, followed by a slight reduction to 38,873 casualties in 2024. Despite this modest decline in 2024, both fatalities and total casualties remain substantially higher than pre-pandemic levels, indicating that road safety risks persist under normal traffic conditions. The absence of disaggregated data by road environment continues to mask the actual road safety performance of high-risk corridors such as mountainous roads, where crash consequences are typically more severe due to terrain and geometric constraints. Further insights can be observed from Figure 1.1, which illustrates the relationship between total road crashes and road fatalities in Malaysia between 2010 and 2020.

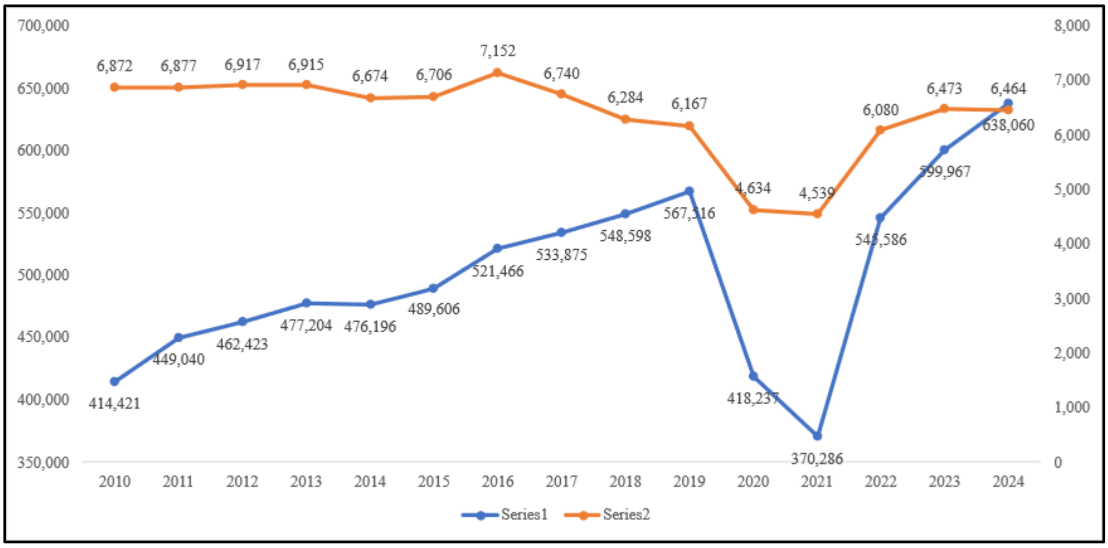

Figure 1.1 Statistics on Road Crashes versus Road Fatalities in Malaysia

Source: Malaysian Road Safety Research (MIROS, 2020)

During this period, reported road crashes increased steadily from 414,421 cases in 2010 to a peak of 567,516 cases in 2019, before declining sharply to 418,237 cases in 2020 as a result of the Movement Control Order (MCO). Road fatalities fluctuated over the same period, reaching a peak of 7,152 deaths in 2016 before decreasing to 4,634 deaths in 2020. While this temporary reduction reflects reduced mobility rather than structural safety improvements, the data reinforce that fatality risk remains substantial once traffic volumes return to normal, highlighting the need for interventions beyond nationwide averages.

At the state level, Table 1.2 shows that Perak consistently recorded a high number of road crashes and casualties between 2017 and 2021. In 2021 alone, Perak reported 28,148 road crashes, resulting in 575 deaths and 2,231 injuries, yielding a total of 2,806 casualties. These figures are particularly concerning because Perak contains critical access routes to major highland destinations, including the Jalan Simpang Pulai corridor leading to Cameron Highlands. Although the state-level data again do not explicitly distinguish mountainous road segments, the concentration of severe crashes along highland access routes suggests a heightened risk profile associated with these road environments.

Table 1.2
Road Crashes with Type of Casualties Reported in Perak

Year	Road Crashes	Type of Casualties		
		Injury	**Death**	**Total**
2017	38, 587	1,018	711	1,729
2019	39, 720	1,060	667	1,727
2020	30, 669	1,903	491	2,394
2021	28, 148	2,231	575	2,806

Source: Royal Malaysia Police (RMP, 2021)
Note: Injury refers to both minor and serious injuries

The persistently high number of fatalities and injuries in Perak underscores the urgent need for location-specific road safety assessments, especially on mountainous corridors that support tourism, agriculture, and logistics activities. These routes are characterised by steep gradients, sharp curves, heavy mixed traffic, and frequent adverse weather conditions, all of which increase crash severity. The aggregated nature of existing crash statistics limits the ability of policymakers and road authorities to identify the underlying risk factors unique to mountainous terrain, thereby constraining the effectiveness of conventional safety countermeasures.

Cameron Highlands is therefore selected as an appropriate and strategic case study for this research. Compared with other mountainous areas in Perak, such as Bukit Larut (Maxwell Hill), the Bintang Range, Gunung Korbu, and Gunung Yong Belar within the Titiwangsa Range, Cameron Highlands experiences substantially higher traffic volumes, particularly during peak tourism seasons. The combination of intensive tourist activity, diverse vehicle composition (including private cars, motorcycles, tour buses, and freight vehicles), narrow and winding road geometry, steep gradients, and frequent fog and heavy rainfall makes the area especially vulnerable to severe road crashes. In contrast, other mountainous locations attract lower traffic demand and consequently exhibit fewer recorded crash occurrences.

Given these characteristics, Cameron Highlands represents a high-exposure, high-risk mountainous road environment that is both representative and critical for in-depth road safety investigation. The lack of disaggregated mountainous road safety statistics at the national and state levels further strengthens the motivation for this research, as it aims to bridge this knowledge gap by identifying key risk factors and evaluating targeted interventions tailored specifically to mountainous road conditions.

1.3 Problem Statement

Studies related to road crashes in mountainous areas pose a significant challenge due to the unique topographical, environmental, and infrastructural conditions in these regions (Dadlani, 2017; Ming & Zawawi, 2021; Moomen et al., 2020). Winding roadways, steep gradients, and adverse weather conditions often increase driving complexity, leading to a higher risk of road crashes (Dianliang & Yujia, 2011; Takar & Kumar, 2019; Theofilatos & Yannis, 2014). Despite various efforts, the incidence of road crashes in mountainous areas remains alarmingly high, resulting in severe fatalities and injuries (RMP, 2018; Shaadan et al., 2021). In Malaysia, Cameron Highlands represents a mountainous region with complex road geometry and high traffic exposure from tourism activities. While national crash statistics do not explicitly disaggregate fatalities by mountainous terrain, reports from the Royal Malaysia Police (RMP) and the Malaysian Institute of Road Safety Research (MIROS) indicate that winding alignment, steep gradients, and adverse weather conditions commonly present in highland areas contribute to elevated crash risk, thereby justifying the need for targeted research and intervention strategies in such regions.

The inherent complexity of mountainous road networks necessitates a comprehensive understanding of the multiple interrelated factors that contribute to road crashes in such environments. These factors include, but are not limited to, road geometric design, driver behaviour, vehicle condition, weather influences, and surrounding environmental hazards (Al-Balbissi, 2003; Amalia et al., 2022; Staton et al., 2023; Yuan et al.,2021). Although these factors have been widely examined in general road safety literature, there remains a lack of studies that systematically categorise and synthesise them specifically within the context of mountainous road environments (Martinelli et al. 2023; Varhelyi, 2016). Given the distinct operational and geometric characteristics of mountainous roads, identifying the thematic structure and key crash-contributing factors in these settings is essential for developing terrain-specific safety interventions, rather than directly extrapolating findings from non-mountainous or flat road conditions.

The Cameron Highlands, Malaysia, a popular tourist destination and a transport and logistics hub for agricultural activities, is experiencing frequent road crashes due to its challenging mountainous terrain and high traffic volume (RMP 2024; Barrow et al. 2005; Nhu et al. 2020). However, the absence of a detailed and systematic road crash data profile hinders practical analysis and road safety intervention (Dadlani, 2017; Johnston, 2010; Mehar & Agarwal, 2013; Varhelyi, 2016). Developing a road crash data profile, including type of vehicle, crash severity frequency, type of collision, light condition, type of weather, crash and blackspot locations, road geometric design, traffic system, spatial map distribution pattern with road crashes contributing factors, is crucial for understanding the scope of the problem and planning effective road safety measures (Sunkpho & Wipulanusat, 2020). This road crash data profiling will serve as a groundwork and benchmark for targeted road safety recommendations and countermeasures in the Cameron Highlands, Malaysia's mountainous region.

Blackspot areas, or accident-prone zones, are locations with a consistently high concentration of road crashes that warrant targeted mitigation measures to reduce crash risk and improve road safety performance (AlKheder & AlRukaibi, 2020; Laliberté & St-Laurent, 2020). Based on road crash records reported by the Royal Malaysia Police (2021), the main access corridor from Jalan Simpang Pulai to Tanah Rata in the

Cameron Highlands has been identified as a recurrent crash-prone route, with repeated occurrences of reported crashes involving varying levels of severity over multiple years. These crash patterns are consistent with the challenging mountainous road environment, characterised by sharp horizontal curves, steep gradients, constrained sight distance, and high tourist traffic exposure. Establishing a road safety star rating score and corresponding risk map along this corridor will provide a quantifiable and systematic measure of road safety performance (Bhavsar et al., 2019; iRAP, 2013; Mcinerney & Fletcher, 2013; MIROS, 2017; Murozi et al., 2022). The resulting star ratings can support evidence-based prioritisation of road safety interventions, optimise allocation of improvement resources, and enable monitoring of the effectiveness of implemented countermeasures over time by stakeholders, including government agencies, local communities, tourists, and road users.

Effective road safety management in mountainous regions necessitates the application of robust road safety risk assessment models capable of predicting and evaluating crash risks under complex roadway conditions. Existing models, however, often lack specificity in capturing the unique geometric, operational, and environmental characteristics of mountainous roadways, as well as the distinct risk exposure of vulnerable road users such as motorcyclists, who are disproportionately represented in crash and fatality statistics in Malaysia (Arévalo-Támara et al., 2020; Shallam et al., 2022). Developing and adapting modified, simpler, and more efficient road safety risk assessment methodologies that explicitly account for mountainous road characteristics and motorcyclist-related risk factors such as horizontal curvature, gradient, roadside hazards, and loss-of-control scenarios is therefore vital for long-term proactive safety planning (iRAP, 2014; Razelan, 2017; Murozi et al., 2022). The development of a modified road safety risk assessment model for mountainous road networks will enable improved prediction of crash risks involving both general traffic and motorcyclists, identification of high-risk road segments, and formulation of targeted, evidence-based safety interventions along the road corridor from Jalan Simpang Pulai to Tanah Rata in the Cameron Highlands.

Addressing the road safety challenges in mountainous areas, particularly in the road network from Jalan Simpang Pulai to Blue Valley in the Cameron Highlands, requires a reliable and accurate approach involving detailed data collection, analysis, risk assessment, and targeted road safety interventions. By identifying key factors contributing to road crashes, developing a road crash data profile, establishing road safety star rating score and risk map for blackspot areas, and developing a modified road safety risk assessment model, this research aims to provide baseline research as an actionable insights and practical solutions to enhance road safety in the mountainous road network in Malaysia.

1.4 Research Aim and Objectives

This research attempts to introduce the International Road Assessment Programme (iRAP) as a modeling tool in road safety risk assessment research. This research aims to propose a modified road safety risk assessment model specifically for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands, by using the modified iRAP@Highlands model. The modified model is designed to quantify the actual motorcycle-relevant roadway infrastructure condition, including motorcycle-focused road safety star rating score and risk map by integrating multiple data sources and incorporating critical road safety factors that influence motorcycle crash risk in mountainous roadway environments. The research objectives for this research are as follows:

a) To identify the thematic structure and key factors contributing to road crashes in mountainous road networks.

b) To develop a road crash data profile for the Cameron Highlands mountainous road network.

c) To establish road condition reports for the main road that captured the highest fatal crash frequency in Cameron Highlands.

d) To propose a modified road safety risk assessment model for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands.

1.5 Research Questions

This research addresses four (4) research objectives by exploring four (4) corresponding research questions. These research questions are detailed as follows, with each question directly linked to a specific research objective:

i) What are the key factors contributing to road crashes in mountainous road networks?

ii) How does the road crash data profile explain the high frequency of crashes within Cameron Highlands' mountainous road network?

iii) Which road segments and infrastructure conditions characterise the main roadway with the highest fatal crash frequency in Cameron Highlands?

iv) How can an existing road safety risk assessment tool be modified to more effectively address motorcyclists' safety along mountainous road networks?

1.6 Research Significance and Novelty

This research falls within the technology and engineering domain, explicitly focusing on the sub-domain of infrastructure and transportation under the basic infrastructure research cluster. This research aligns with Malaysia's 10-10 MySTIE framework, which emphasizes the socio-economic drivers such as smart cities and transportation. This research also contributes to the Shared Prosperity Vision 2030 (SPV 2030) by aiming to reduce road fatalities and improve the safety of transportation networks, fostering a more inclusive and equitable society. Furthermore, this research addresses the United Nations' Sustainable Development Goals (SDGs), particularly SDG Goal 3 (Good Health and Well-being) and SDG Goal 11 (Sustainable Cities and Communities), by enhancing road safety and reducing traffic-related injuries and deaths.

Output from this research will significantly impact the deliverables across the Quintuple Helix stakeholders: society, academicians, researchers, government, industry, and the environment. For society, mainly local and international tourists, it will improve road safety in mountainous areas, reduce road crashes and fatalities statistics, and enhance public health and road safety. Academicians and researchers will benefit from new insights, tools, and methodologies for evaluating road safety in challenging terrains, contributing to the body of knowledge in road safety and infrastructure engineering. Government policymakers will gain various types of data-driven insights to formulate effective road safety regulations and interventions, supporting the National Transport Policy (2019-2030) and the 12th Malaysia Plan (2021-2025), which emphasize smart mobility and infrastructure improvements. The industry can use the research outcomes to inform the design and construction of safer road networks, while the environment will benefit indirectly through reduced emissions from fewer road crashes and improved traffic flow within Jalan Simpang Pulai to Blue Valley, Cameron Highlands.

In Malaysia, iRAP road safety star rating assessment data are only available for expressway inter-urban expressway road networks covering the North-South Expressway route by PLUS Malaysia Berhad. The research findings have potential applications in several areas of road safety research for mountainous roadways in Malaysia. Developing data profiles and risk assessment models can lead to the creation of advanced tools for evaluating and improving road safety in mountainous regions. This research can inform the implementation of iRAP practical road safety engineering solutions and infrastructure improvements, reducing road crash injuries and fatalities, thus supporting Malaysia's smart mobility and tourism aspirations. Additionally, the insights gained from this research can help to shape effective road safety policies and strategies, aligning with the latest United Nations Decade of Action for Road Safety (2020-2030), which aims to reduce road crashes deaths and injuries by at least 50%. The methodologies, models, and tools developed during this research have already been approved and obtained from the Intellectual Property Corporation of Malaysia (MyIPO) with the copyright titled "An iRAP@Highlands Model for Road Safety Star Rating (iRoSStar@Highlands)" *(Please refer to Appendix 1)*. This research will not only provide significant commercialization opportunities but also contribute to the advancement of the knowledge economy in the field of road safety. As a result, this research will significantly contribute to road safety in mountainous areas, aligning with national and global development agendas while providing valuable applications and intellectual property opportunities.

1.7 Research Limitations

This section will declare and discuss the limitations encountered throughout the process of completing this research. Acknowledging these limitations is crucial for contextualising the findings and providing guidance for future studies in the field of road safety, particularly in mountainous regions. Geographically, this research attempts to cover a tourist city located in the mountainous road network within Peninsular Malaysia. Although ideally, the research should cover all tourist cities located in the mountainous road network in Peninsular Malaysia, the constraint of time and resources led to selecting only one location that is rich with available and ready data and lower cost to the researcher and team to execute research. Due to several distinguishing factors, Jalan Simpang Pulai to Blue Valley, Cameron Highlands, Malaysia has been selected as the research location to represent mountainous areas in Peninsular Malaysia. As a major tourist destination, Cameron Highlands attracts a high volume of traffic, including tour buses, private vehicles, and motorcycles, which increases the complexity of managing road safety. This region's challenging terrain, characterised by steep slopes, sharp bends, and narrow roads, poses significant risks and makes it an ideal setting for evaluating road safety measures.

Additionally, frequent landslides and heavy rainfall in Cameron Highlands exacerbate road safety hazards, providing valuable insights into mitigating natural disaster risks. This region's economic activities, particularly in tourism, wholesaler and retail shops, local transportation services, and agriculture, involve transporting goods by heavy vehicles, adding another layer of road safety complexity. Furthermore, Cameron Highlands has a rich history of road crashes, offering extensive data for analysis and the opportunity to study trends and the effectiveness of safety interventions. The diverse community, including the local residents, tourists, and migrant workers, combined with varied infrastructure from urban areas to remote villages, provides a broad spectrum of scenarios for road safety research. Compared to other mountainous regions like Genting Highlands, Fraser's Hill, and Mount Kinabalu, Cameron Highlands stands out due to its high traffic volume, economic activities, and environmental challenges, making it a matched choice for in-depth road safety studies.

In terms of methodological limitations, this research relies on ITIS and M-ROADS databases to obtain road crash data. Additionally, reliance on secondary data sources may have introduced inconsistencies or gaps in terms of data format and keywords used in the dataset. Data discrepancies or missing information could have impacted the analysis and conclusions explicitly drawn where crash data for the years of 2019, 2020, and 2021 is void due to abnormal patterns during the COVID-19 pandemic. The study focused on the Cameron Highlands region, which may limit the generalisability of the findings to other mountainous areas with different geographic, climatic, or infrastructural characteristics. The SLR techniques, Tableau 10.4 software handling, and iRAP@Highlands model using Multiple Linear Regression (MLR) analysis employed in the study may have inherent biases or limitations that could influence the accuracy of evaluating road safety star ratings and risk assessments. While robust, the statistical methods and analytical techniques used in the study have certain limitations. For instance, predictive models may have limited accuracy in forecasting road safety outcomes under varying conditions. This research also faces limitations regarding the number of image references and videos captured using RADIS 2.0 equipment and system, which will be analysed using MiREV software. The internet connection issue in the mountainous areas during data collection is the major issue that made the system unstable. The solution for this issue is to back up data with Google Street View using the Google Maps website to recover data at the affected locations. However, with help from the iRAP expert team in MIROS, the researcher has thoroughly done the data coding process to ensure that valid data is chosen for further analysis. These solutions may impact the actual visuals and videos at the site location due to the probability of recent cases occurring in terms of road closure due to natural disasters reported, the on-going road rehabilitation process implemented, and the improvement of recent infrastructure at the site location. The recommendations made for the Jalan Simpang Pulai to Blue Valley, Cameron Highlands, may not directly apply to other mountainous regions without adjustments and justification of details. Resources, including time, budget, and personnel, constrained this research may impact limitations to the scope and depth of the study.

Varying environmental and weather conditions in Jalan Simpang Pulai to Blue Valley, Cameron Highlands, can significantly influence road safety and the applicability of the research findings. The researcher considered factors such as fog, rain, and landslides, but their unpredictable nature adds complexity to the analysis. The data analysis may not fully account for any new laws or road safety measures implemented during the research. Engaging stakeholders, including local communities, authorities, and other relevant parties, posed challenges. Limited input from these stakeholders may have influenced the comprehensiveness of the recommendations. The researcher carefully managed ethical constraints related to data privacy and the involvement of human subjects. Still, this research may have restricted certain aspects of the data collection and analysis *(Please refer to Appendix 2)*. The researcher may vary the available options and adopt advanced technologies using RADIS 2.0 equipment and systems to collect data in this research across the research area due to the road infrastructure situation. Rapid technological advancements could affect the relevance or applicability of the findings using other equipment over time. Future research should address these limitations by expanding the research location to another main route of Cameron Highlands, such as Jalan Sungai Koyan to Tanah Rata, Cameron Highlands (Pahang Border), Jalan Gua Musang to Lojing, Cameron Highlands (Kelantan Border) and Jalan Tapah to Tanah Rata, Cameron Highland (Perak Border) and another geographical scope of the research to include other mountainous regions to improve data quality and completeness, and incorporating more advanced analytical techniques other than using iRAP or MyRAP.

Additionally, increased stakeholder engagement and consideration of emerging technologies will enhance the applicability and impact of future studies. In conclusion, while this research provides valuable insights into road safety in mountainous areas, it is essential to consider the limitations discussed. Recognising these constraints helps to contextualise the research findings and highlights the need for ongoing research to further refine and expand the understanding of the road safety risk assessment model in challenging terrains at other locations. Despite these limitations, the study significantly contributes to the road safety field and offers a foundation for future investigations.

1.8 Research Scope

There are four (4) primary routes to Cameron Highlands, namely (i) Jalan Sungai Koyan to Tanah Rata, (ii) Jalan Gua Musang to Lojing, (iii) Jalan Tapah to Tanah Rata, and (iv) Jalan Simpang Pulai to Blue Valley. Jalan Simpang Pulai to Blue Valley has been selected due to its unique and challenging roadway characteristics. This research evaluates the road safety risk assessment model for the mountainous road network segment from Jalan Simpang Pulai to Blue Valley in Cameron Highlands, Malaysia, covering a section of the Perak federal road (F185) from Simpang Pulai to Blue Valley. This research route distance is limited to 55.6 kilometres, from the latitude and longitude of 4°34'58.4"N 101°24'28.5"E to 4.530079607 101.1313696, respectively. This road segment is renowned for its demanding terrain, high traffic volume, and significant tourist activity, which increases the risk of road crashes. Additionally, this road network segment is prone to frequent natural hazards, including rockfalls, landslides, and heavy rainfall, further complicating driving conditions and heightening the risk of road safety issues.

Moreover, historical data recorded by RMP from 2015 to 2018 indicate that Jalan Simpang Pulai to Blue Valley, Cameron Highlands, records a high number of fatal injury cases annually, as evidenced in Table 1.3. This data underscores the critical need for targeted road-safety interventions and a robust risk assessment model tailored to the specific conditions of this route.

Table 1.3
Route Name and Number of Fatal Injuries per Year for Motorcyclists

Route Name	**Number of Fatal Injuries per Year**				
	2015	**2016**	**2017**	**2018**	**Total**
Jalan Tapah – Tanah Rata, Cameron Highlands	4	5	0	2	11
Jalan Simpang Pulai - Jalan Keramat Pulai – Blue Valley, Cameron Highlands	5	9	4	5	23
Jalan Ringlet - Kampung Raja - Blue Valley, Cameron Highlands	2	1	5	1	9
Jalan Gua Musang – Lojing – Blue Valley, Cameron Highlands	0	2	1	1	4

Source: Royal Malaysia Police (RMP, 2018)
Note: Crash data for 2019, 2020, and 2021 void due to abnormal patterns during the COVID-19 pandemic.

This research utilises secondary data from Web of Science (WoS), Scopus, Springer Nature, Elsevier, and the American Society of Civil Engineers (ASCE) library online database to identify the thematic structure and key factors contributing to road crashes in mountainous road networks using the Systematic Literature Review (SLR) method. Then, road crash data obtained from the Royal Malaysia Police (RMP) via the

M-ROADS database were analysed in Tableau 10.4 to develop a road crash data profile of the Cameron Highlands. Next, the researcher employed primary data collection through a road survey to establish a road safety star rating and a risk map for the blackspot areas identified along Jalan Simpang Pulai to Blue Valley, Cameron Highlands, using the iRAP methodology. Finally, this research proposes a modified road safety risk assessment model tailored for mountainous road networks by incorporating new risk factors from supporting data such as road engineering factors, driver behaviour factors, environment factors, and road crash data profiling using a Multiple Linear Regression (MLR) model. The model was validated using historical crash data and real-time traffic observations to ensure model accuracy and reliability. Additionally, this research evaluated the effectiveness of existing road safety measures in the Cameron Highlands and identified high-risk locations (blackspots) within the road network, recommending targeted road safety interventions.

This research proposed strategies for the proactive action and continuous monitoring of the road safety risk assessment model to ensure its effectiveness in enhancing road safety in mountainous road networks. Based on the findings, a Safer Road Investment Plan (SRIP) was also provided to local authorities and stakeholders, aiming to improve road safety regulations, infrastructure planning, and enforcement strategies in mountainous regions. *Arahan Teknik Jalan (ATJ),* "Guidelines for Road Safety Audits" issued by the Public Works Department (PWD), and Malaysian Environmental Traffic Road Audit (MeTRA) Guide Book by MIROS, used by road safety auditors, engineers, and road safety researchers in Malaysia, guided the recommendations for road safety countermeasures. This research also identified research gaps and suggested areas for future research to ensure the continuous improvement of road safety measures and risk assessment models for mountainous road networks.

1.9 Structure of Thesis

This thesis consists of six chapters. The thesis structure is as follows:

Chapter 1: Indicates the research background, research motivation, problem statement, research aim, research objectives, research questions, research significance, research novelty, research limitations, research scope, and structure of the thesis.

Chapter 2: Embodies a critical understanding of road safety frameworks, risk factors, and assessment methodologies relevant to mountainous road networks. It begins with the definition of key terms and an overview of iRAP, followed by a localized examination of Malaysia's road safety initiatives through MyRAP. The chapter then delves into crash risk factors specific to mountainous terrain, supported by global and national evidence. It discusses key infrastructure-related risk contributors such as alignment, road surface condition, signage, and vehicle flow characteristics. A detailed analysis of the iRAP Star Rating Model follows, with breakdowns of each core component and its relevance to road safety outcomes. The chapter concludes by introducing the conceptual foundation of the proposed iRAP@Highlands model, bridging gaps in current risk assessment practices and setting the stage for model development and validation in subsequent chapters.

Chapter 3: Outlines the methodological framework adopted to achieve the research aim of developing the iRAP@Highlands model, a modified road safety risk assessment model for motorcyclists along the Jalan Simpang Pulai to Blue Valley mountainous road network. This chapter is structured into four key research stages: (i) a Systematic Literature Review (SLR) to identify critical risk factors in mountainous road safety, (ii) road crash data profiling using Tableau software for analytical insight, (iii) road survey and inspection guided by the iRAP methodology to generate star ratings and risk maps, and (iv) model development using Multiple Linear Regression (MLR) to quantify the relationship between infrastructure attributes and safety performance. This chapter also describes the use of triangulation techniques, GIS mapping, data coding using ViDA software, and justification for focusing on motorcycle quick-win road safety countermeasures due to their overrepresentation in fatal crashes. Each methodological step is carefully aligned with the research objectives and supported by international standards, particularly the iRAP Road Attribute Coding Manual and global protocols, ensuring both academic rigor and practical relevance.

Chapter 4: Presents the analytical findings of the Systematic Literature Review (SLR) and road crash data profiling specific to the Cameron Highlands roadway network. The chapter begins by identifying critical road safety risk factors in mountainous regions, categorised into three key domains: road engineering (34 sub-factors), driver behaviour (19 sub-factors), and weather conditions (7 elements). The researcher employs Tableau software to perform data visualisation and descriptive analytics on road crash trends between 2015 and 2018. It explores various dimensions, including vehicle type involvement, crash severity by year, traffic systems, geometric characteristics, lighting and weather conditions, and spatial distribution patterns. Data gathered in this chapter will support the development of a modified road safety risk assessment model tailored to the unique terrain and safety challenges of the Cameron Highlands.

Chapter 5: Outlines the results and discussion of the modified iRAP@Highlands model, developed to assess road safety risk assessments for motorcyclists along the Jalan Simpang Pulai to Blue Valley road networks in Cameron Highlands. It includes star rating results before and after the implementation of iRAP quick-win countermeasures, detailed blackspot analysis of three critical zones, and spatial risk profiling to identify high-risk segments. The chapter also applies Multiple Linear Regression (MLR) analysis to quantify the relationship between road engineering attributes and road safety performance outcomes, validating key predictors that influence the Star Rating Score (SRS). The findings demonstrate how data-driven road safety interventions can significantly enhance motorcyclist safety in mountainous terrain, supporting the targeted prioritization of road infrastructure upgrades at the research location.

Chapter 6: Concludes the thesis by summarising key findings according to each research objective, detailing the practical and policy implications of the iRAP@Highlands modified model, and recommending future research directions. It proposes a Hierarchy of Control framework tailored for mountainous road safety interventions. It emphasizes the importance of integrating data-driven decision-making into road safety planning for vulnerable road users, specifically motorcyclists.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter aims to inclusively review the subject matter, laying the foundation for this research. The literature review covered five (5) key areas, including (i) definitions and terminologies used in road safety research for mountainous regions, followed by (ii) the International Road Assessment Programme (iRAP) and Malaysia Road Assessment Programme (MyRAP) overview, (iii) the factors contributing to road crashes along mountainous road networks, (iv) the iRAP star rating research model guiding this research and (v) proposed Road Safety Risk Assessment Model for Mountainous Road Network (iRAP@Highlands). Various factors contributing to road crashes in mountainous regions, including road engineering, driver behaviour, geometric design, environment, and vehicle factors, were discussed. Understanding these factors is essential for developing targeted road safety interventions. The iRAP star rating research model is the backbone of this research, guiding the research design, methodology, and analysis. It outlines the proposed iRAP@Highlands model's theoretical foundations and key components, illustrating how different factors and variables are interconnected. This literature review sets the stage for an in-depth exploration of road safety issues, particularly in the context of Cameron Highlands mountainous road networks, by establishing a clear understanding of definitions, reviewing key road assessment programs, examining crash factors, and presenting a robust conceptual framework.

2.2 Definition and Terminologies

The researcher chose Cameron Highlands as a study location in this research context. Cameron Highlands is classified as a mountainous roadway area due to its elevation of 1,829 meters above sea level, an average height of 1,452.48 meters, and an average slope gradient of 18.80 degrees (Department of Town and Country Planning, 2009; Ming & Zawawi, 2021). This classification is further supported by the region's rugged topography, characterised by steep inclines, sharp bends, and narrow roads that wind through dense forests and tea plantations surrounding Cameron Highlands. These geographical features make driving challenging and contribute to soil erosion and landslides, obstructing roadways and posing additional hazards.

The climate of Cameron Highlands, which is colder and wetter than the surrounding lowlands, can lead to slippery road conditions, particularly during the monsoon season. Urbanization and increased tourism in the area have exacerbated these challenges, leading to a rising trend in road crashes. Reported cases of road crashes have increased from about 20 to 26 between 2015 and 2016, and from 18 to 25 between 2017 and 2018 (Polis Diraja Malaysia, 2018). The influx of tourists who are unfamiliar with mountainous driving conditions and increased traffic volume further elevates the risk of road crashes in Cameron Highlands.

Positioned at an elevation of approximately 1,500 meters above sea level, Cameron Highlands is surrounded by forest-covered peaks reaching heights of up to 2,032 meters (Barrow et al., 2005). The region is renowned for its cool climate and ecotourism appeal, making it a popular destination for both domestic and international visitors. The area supports a thriving horticultural economy, including the cultivation of vegetables, fruits, and flowers, many of which are exported. In addition, speculative building construction and agricultural expansion are growing, further contributing to traffic density and road safety concerns (Nhu et al., 2020). These factors underscore the urgent need for robust, sustainable road safety measures that balance human mobility with environmental and economic sustainability.

The International Road Assessment Programme (iRAP) is a charity organisation based in England that governs road assessment models and assists countries worldwide in undertaking road assessment activities (iRAP, 2021a; MIROS, 2017a). iRAP comprises experts in road safety engineering worldwide who work in partnerships with governments, private organizations, automobile clubs, NGOs, and a host of stakeholders in the road safety arena (iRAP, 2017). Up until now, iRAP activities have been undertaken in more than 100 countries by local teams trained by iRAP and its partners. The Malaysian Institute of Road Safety Research (MIROS) is one of the iRAP centers of excellence that leads iRAP-related activities in Malaysia. The output of the iRAP assessment includes safety star ratings of road and road safety improvement plans (MIROS, 2017).

ViDA, an acronym for "Visualisation of Data Analysis" and meaning "life" in Spanish, is a sophisticated online software platform developed by iRAP (iRAP, 2017). It plays an indispensable role in global road safety enhancement efforts by enabling detailed analysis and visualization of road inspection data. ViDA assesses over 50 critical attributes, including intersection design, lane markings, roadside hazards, and pedestrian and cyclist infrastructure, all of which significantly impact the likelihood and severity of road crashes. The platform's analyses are foundational to the iRAP star rating research model, which classify roads on a safety scale ranging from one to five stars, where five stars denote the highest safety standards. Additionally, ViDA supports the development of Safer Road Investment Plans (SRIP), which offer strategic recommendations for infrastructure improvements aimed at minimizing crash risks. These plans help policymakers prioritize interventions that are both effective and resource-efficient. By integrating inclusive data analysis with practical safety solutions, ViDA not only enhances road infrastructure planning but also aligns with iRAP's overarching goal of significantly reducing road fatalities and injuries worldwide (iRAP, 2017).

The Road Attribute Data Logger and Inspection System (RADIS) is a road assessment tool jointly developed by MIROS and Universiti Teknikal Malaysia Melaka (UTeM) to collect and analyse road infrastructure data systematically (iRAP, 2021; MIROS, 2017). It consists of a road survey system and a data coding system. The road survey system allows for recording geo-referenced images and road geometrics. The features of the data coding system include the image viewing panel, the coding panel, and the survey tracking maps (iRAP, 2017). This tool is integral to the detailed inspection of road attributes that affect the likelihood and severity of road crashes. Using RADIS, trained teams can meticulously record various road features, such as lane markings, roadside hazards, and pedestrian facilities. The data gathered is crucial for producing iRAP's Star Ratings, which provide a simplified assessment of road safety levels for different road users. These ratings help to identify high-risk road sections and are pivotal in formulating Safer Road Investment Plans (SRIPs), which propose cost-effective measures for enhancing road safety. RADIS ensures that iRAP's recommendations are grounded in comprehensive and accurate data, thereby supporting the design of safer new roads and improving existing ones. This tool is vital to iRAP's mission to reduce global road fatalities and injuries through informed, data-driven safety interventions.

2.3 Motorcyclist-Friendly Safety Barriers: International Practices and Relevance to Mountainous Roads

Motorcyclists are highly vulnerable in roadside crashes, especially when encountering unprotected or poorly designed safety barriers. This risk is amplified on mountainous roads where horizontal curves, elevation changes, and limited shoulders increase the likelihood and severity of loss-of-control events. Conventional safety barriers, while effective for restraining vehicles, can pose fatal risks to motorcyclists due to hard impact surfaces, exposed posts, or the absence of under-run protection systems. Consequently, many countries have developed and implemented motorcyclist-specific safety barrier countermeasures to address these challenges, particularly in high-risk corridors and scenic mountainous routes.

2.3.1 International Approaches to Motorcycle-Friendly Barrier Good Practices

Spain is a global leader in the implementation of Motorcyclist Protection Systems (MPS), particularly along curves and rural roads. These systems, regulated under UNE 135900, are retrofitted beneath standard W-beam guardrails to prevent motorcyclists from sliding beneath and striking support posts. Spanish authorities have installed over 300 km of such barriers, demonstrating a significant reduction in injury severity on mountainous routes (Nicol et al., 2012).

Figure 2.1 Spanish Guardrail That Meets Motorcycle Safety Standards
(Nicol et al., 2012)

Norway introduced the Vision Zero Motorcycle Road project near Oslo, integrating motorcycle safety into road design. Along a 15 km mountainous section, Norwegian engineers applied MPS-equipped guardrails, improved sight distances, and better pavement markings. This project showcases how national safety visions can directly benefit motorcyclist safety in terrain-challenging settings (Nicol et al., 2012).

New Zealand's "Safer Rides" project on the Coromandel Loop, a popular mountainous tourist route for riders, involved installing motorcycle-friendly railings, shoulder sealing, debris control, and enhanced curve delineation. The initiative was designed to provide a more forgiving roadside environment and effectively reduced motorcycle crashes and fatalities (NZ Transport Agency, 2025).

Before Countermeasures | After Countermeasures

Figure 2.2 Photographs Showing the Changes in Site Location Before and After Countermeasures (NZ Transport Agency, 2025)

2.3.2 Implications for Mountainous Roads in Malaysia

Given the high incidence of motorcycle crashes along mountainous road networks such as Jalan Simpang Pulai to Blue Valley, Cameron Highlands, the integration of motorcycle-specific safety barriers is a crucial engineering countermeasure. Based on international best practices, the following recommendations are relevant (i) Install Motorcyclist Protection Systems (MPS) under existing W-beam barriers on curves and steep descents, (ii) Use crashworthy terminals such as energy-absorbing or flared-end designs, (iii) Avoid wire rope barriers unless modified with under-run nets or deflection control systems, (iv) Enhance maintenance and visibility, including debris removal, shoulder sealing, and reflective guidance and (v) Implement motorcycle-focused safety audits along high-risk segments, similar to New Zealand's Safer Rides assessment model. These practices align with iRAP recommendations on barrier safety attributes and support Malaysia's broader vision of reducing motorcycle fatalities in highland regions.

2.4 An Overview of the International Road Assessment Programme (iRAP)

The Global Plan for the Decade of Action for Road Safety (2021-2030) is a strategic initiative initiated by the United Nations that provides a comprehensive framework for reducing road crashes and injuries worldwide (WHO, 2024). This plan aligns with the objectives of the International Road Assessment Programme (iRAP), a global charity dedicated to saving lives by eliminating high-risk roads. iRAP's approach, which involves inspecting roads, developing Star Ratings, Risk Maps, and Safer Roads Investment Plans, complements the Global Plan's focus on a multifaceted approach to improve road safety worldwide. In mountainous areas, where complex terrain, steep gradients, and variable weather conditions exacerbate risks, the Global Plan and iRAP offer complementary strategies. The Global Plan encourages the implementation of resilient infrastructure and advanced technology, while iRAP provides tools and methodologies for assessing road safety risks and identifying targeted interventions.

The International Road Assessment Programme (iRAP) is a non-profit charity institution registered in England with support funds from the Federation International Automobile (FIA) Foundation for automobile and road safety. iRAP has introduced many developed countries to champion the safe system of road safety approach concept which acknowledge driver behaviour or human does make a mistake but should not deserve to die from road crashes. iRAP has established itself as a global road safety player by making efforts to assess and improve road infrastructure in challenging environments such as mountainous roadways. As a non-profit organisation, iRAP tremendously emphasizes upgrading the road safety environment for low- and middle-income countries to lessen the global death rate due to road crashes (MIROS, 2017b). The iRAP methodology involves comprehensive road safety inspections and the generation of road safety star ratings, which provide a standard measurement of road safety for various user groups (iRAP, 2021g). These ratings, ranging from one to five stars, are essential for identifying high-risk areas and guiding targeted interventions.

An outstanding aspect of iRAP's global outreach is the establishment of regional Road Assessment Programmes (RAPs) across multiple countries, each tailored to local road safety contexts. These include AusRAP (Australia), IndiaRAP (India), MyRAP (Malaysia), BrazilRAP (Brazil), KiwiRAP (New Zealand), SARAP (South Africa), UKRAP (United Kingdom), BrazilRAP São Paulo (State of São Paulo, Brazil), KSARAP (Korea), TanRAP (Tanzania), usRAP (United States), ChinaRAP (China), MexiRAP (Mexico), and ThaiRAP (Thailand) (Bhavsar et al., 2019; McInerney & Smith, 2009). In Asia, four (4) types of AsiaRAP collaboration are ChinaRAP, IndiaRAP, ThaiRAP, and MyRAP, which were launched in October 2019 (Bhavsar et al., 2019). Each RAP operates under the same iRAP framework, ensuring data collection and assessment consistency and addressing specific regional challenges and safety issues. The iRAP aims to systematically identify and mitigate high-risk road segments to achieve at least three-star safety standards. These proactive initiatives will allow local government agencies to partner with technology companies or institutions to actively eliminate one-star and two-star rating roads and ensure new road construction meets higher safety standards (McInerney & Smith, 2009).

For instance, in mountainous areas, these RAPs play a vital role in evaluating the unique risks of road engineering factors posed by steep gradients, sharp curves, and variable weather conditions. Using the Road Attribute Data Inventory System (RADIS), these programs collect detailed data on roadside features such as lane markings, signage, guardrails, surface conditions, roadside hazards, hazard distance, vehicle flow, vehicle speed limit, intersections, and Vulnerable Road User (VRU) features. This data is then analysed to produce actionable insights and address road safety concerns using Safer Road Investment Plans (SRIPs), which prioritise interventions like undertaking vegetation management, including cutting down trees, improved signage, installation of safety barriers, and enhancements in road geometry that pose potential hazards and obstructing visibility to road users.

The collaboration across these regional programs facilitates the sharing of best practices and successful strategies, contributing to a global reduction in road fatalities and injuries. For instance, initiatives like AusRAP and MyRAP have successfully implemented road safety measures in rural and urban areas. At the same time, BrazilRAP and MexiRAP have focused on addressing urban traffic complexities. The broad spectrum of RAPs under iRAP's umbrella demonstrates the program's adaptability and effectiveness in various geographical and socio-economic contexts.

The iRAP global network of regional RAPs is indispensable in promoting road safety worldwide. The program rigorously applies a data-driven assessment model, making it particularly effective for evaluating the complexities of mountainous roadways and ensuring that safety improvements are targeted and effectively implemented. This program helps reduce road crashes and fosters a culture of road safety transcending borders, making it a concrete foundation in the global road safety landscape.

2.4.1 An Overview of the Malaysia Road Assessment Programme (MyRAP)

The Malaysia Road Assessment Programme (MyRAP) represents a pivotal national effort within the International Road Assessment Programme (iRAP) organisation to enhance road safety across a diverse type of roadways, including mountainous and non-mountainous regions. Shell Malaysia funded the MyRAP project in early 2016, and the Malaysian Institute of Road Safety Research (MIROS) manages the road safety project. The project has conducted comprehensive safety assessments on over 10,000 kilometres of high-traffic roads in Semenanjung Malaysia, Sabah, and Sarawak for three (3) years (MIROS, 2017a; Murozi et al., 2022). In its first phase, MyRAP evaluated four major inter-urban expressways, including the North-South Expressways (E1 and E2) and the East Coast Expressways (LPT1 and LPT2), identifying more than 1,000 critical locations for safety improvements. Another FIVE (5) expressways were assessed in 2018, and safety improvement plans were implemented in 2020 (iRAP, 2021; MIROS, 2017). Remarkably, using MyRAP, over 70% of these locations have since been upgraded by the respective concession companies, significantly reducing high-risk sections and enhancing the safety of road users. Road safety interventions and improvements reduced the number of high-risk sections, thereby enhancing the safety of road users. MyRAP’s evaluations help prioritize the implementation of safety measures, such as the installation of guardrails, improved road surfacing, and enhanced signage tailored to the specific needs of these areas.

The origins of the MyRAP program in Malaysia can be traced back to a pilot study conducted in 2007 by an international team from the AusRAP project, involving key stakeholders such as the Automobile Association Malaysia (AAM), the Malaysian Road Safety Department (JKJR), MIROS, the Australian Automobile Association (AAA), and the Australian Road Research Board (ARRB) group of non-profit company. The Malaysian government supported the pilot project through the Ministry of Works, Ministry of Transport, private entities that are the highway concessionaires for the North-South Expressways (PLUS) project, and ANIH Berhad (formerly known as MTD Prime Sdn. Bhd., the research and education institutional body, Universiti Putra Malaysia, and Kumpulan IKRAM Sdn. Bhd. The results discovered that 91% of federal roads and 13% of rural expressways were rated three (3) stars and below for vehicle occupants (MIROS, 2017). This pilot study was supported by the Malaysian government and private sector entities, utilised advanced video processing technology to survey 3,687 kilometres of federal roads and expressways. The findings indicated that 91% of federal roads and 13% of rural expressways were rated three stars or below for vehicle occupants, underscoring the critical need for targeted road safety improvements. However, (MyRAP) focuses exclusively on evaluating and assigning star ratings to federal roads and expressways, with the exception of mountainous roadways. This selective assessment approach allows MyRAP to concentrate its efforts on the country's most heavily trafficked and high-risk road segments, ensuring that critical safety improvements are effectively prioritized and implemented where they are most needed.

In addition to addressing immediate safety concerns, MyRAP provides a robust framework for long-term road safety strategies in Malaysia. The program's data-driven approach supports evidence-based policy-making and investment decisions, fostering collaboration among government agencies, road authorities, and the private sector. This comprehensive approach ensures that road safety interventions are responsive and sustainable, ultimately contributing to a reduction in road traffic injuries and fatalities. By continuously improving road safety standards, MyRAP plays a vital role in safeguarding the well-being of Malaysia's road users and advancing the country's commitment to achieving safer road networks.

2.5 The International Road Assessment Programme (iRAP) Star Rating Model

The International Road Assessment Programme (iRAP) Star Rating Model is a comprehensive risk assessment tool designed to evaluate road safety and identify roadway areas of high risk that require improvement to mitigate and reduce road crashes (iRAP, 2022). The iRAP model incorporates a broad group of factors and sub-factors that are meticulously analysed to provide an overall safety rating for roads that range from one (1) to five (5) stars, with five (5) stars indicating the highest level of safety standard (iRAP, 2014). The detailed explanation of each main factor and its sub-factors sheds light on how the iRAP star rating research model functions to enhance road safety as follows:

2.5.1 Traffic Management

Traffic management is a significant factor in the iRAP star rating research model. This factor maintains orderly traffic flow to minimise the potential occurrence of road crashes, which directly correlates with the safety and efficiency of the road network. The iRAP model incorporates several sub-factors under traffic management. Each sub-factor plays a vital role in the broader road safety objective for mountainous or non-mountainous roadways.

2.5.1.1 Speed Limit

The enforcement of precise speed limits is one of the most effective measures for reducing crash severity among road users (Duddu et al., 2020). The iRAP model is designed to evaluate whether speed limits are appropriate for specific road conditions, considering factors such as road geometry, traffic volume, and environmental characteristics (Mcinerney & Fletcher, 2013). These factors determine whether speed limits effectively reduce crash risk. When speed limits are inadequately set, either too high or too low, it can increase crash severity, particularly in complex environments such as mountainous roadways. Thus, the iRAP model highlights the importance of context-sensitive speed limits as a foundational element of road safety management. By integrating differential speed limits and dynamic assessments, the iRAP model provides a holistic, evidence-based framework for road safety management that reflects recent advances in traffic safety research.

2.5.1.2 Motorcycle Speed Limit

Motorcycle-specific speed limits, as recommended by the iRAP star rating model, constitute a critical traffic management measure for mitigating the elevated crash risk faced by motorcyclists. The model's emphasis on differentiated speed limits reflects an understanding of riders' vulnerability arising from road geometry, environmental exposure, and mixed-traffic conditions (iRAP, 2021g). The iRAP model simulates motorcycle crash risk by synthesising empirical data and supports a context-sensitive, dynamic, and evidence-based speed management approach. However, the effectiveness of such limits depends on rider behaviour and complementary measures, including improved road infrastructure, targeted enforcement, and public education. As motorcycle safety research advances, it is essential to evaluate the long-term effectiveness of differentiated speed limits and refine them in response to evolving traffic conditions and technological developments, particularly on mountainous roadways (Haque et al., 2009; Waseem et al., 2019). Ultimately, the iRAP model provides a robust framework for improving motorcycle safety and reducing road traffic fatalities and injuries.

2.5.1.3 Truck Speed Limit

Regulating truck speed limits is a critical road safety measure in mountainous environments characterised by steep gradients, sharp horizontal curves, and complex terrain. Owing to their large mass, high centre of gravity, and limited manoeuvrability, trucks require longer stopping distances and exhibit reduced hazard avoidance, particularly under uneven loading conditions (Moomen et al., 2020; Azmi et al., 2021). Speed-related truck crashes are therefore more likely to result in severe injuries, fatalities, and infrastructure damage due to high kinetic energy. The iRAP model adopts a data-driven approach to assess the suitability of truck-specific speed limits by accounting for vehicle dynamics, roadway geometry, and operational risk, with emphasis on high-risk segments such as steep downgrades and sharp curves (Mcinerney & Fletcher, 2013). By promoting differentiated speed limits rather than uniform regulations, the model aims to reduce loss-of-control events while avoiding secondary risks associated with inappropriate blanket limits, including congestion, unsafe overtaking, and exceedance of vehicle operational thresholds on mountainous roadways (He et al., 2012; Jane & Jirapure, 2019).

2.5.1.4 Differential Speed Limit

Differential speed limits, which assign vehicle-specific speed regulations based on vehicle mass, size, and dynamic performance, form a key component of the iRAP model for managing mixed traffic conditions. Uniform speed limits often fail to account for differences in stopping distance, acceleration capability, and manoeuvrability between heavy and light vehicles, increasing collision risk, particularly on roads with complex geometry (Murphy & Morris, 2020). The iRAP model incorporates differential speed limits to align vehicle operating speeds with roadway characteristics such as steep gradients, sharp curves, narrow lanes, and limited sight distance, thereby reducing speed differentials and high-risk overtaking manoeuvres (iRAP, 2014; Rahimi et al., 2020). By accounting for vehicle dynamics and road context, this approach mitigates loss-of-control and rollover risks associated with heavy vehicles on mountainous roads, while promoting smoother traffic flow. Although implementation challenges exist, including enforcement and driver compliance, the evidence supports differential speed limits as an effective, context-sensitive strategy for improving safety and operational efficiency on high-risk road segments (Aarts & Van Schagen, 2006; He et al., 2012).

2.5.1.5 Speed Management or Traffic Calming

Speed management or traffic calming extends beyond posted speed limits to include physical roadway interventions designed to regulate operating speeds and reduce crash risk. Within the iRAP model, traffic calming measures such as speed humps, rumble strips, chicanes, bends, pedestrian refuges, and roundabouts are evaluated as effective tools for moderating vehicle speeds, enhancing driver alertness, and improving safety on both mountainous and non-mountainous roads (Lav et al., 201; Zavala-Reyes et al., 2019). Empirical studies consistently show that these measures reduce vehicle speeds, crash frequency, and crash severity by introducing physical and psychological constraints on driver behaviour, particularly in areas with vulnerable road users or limited enforcement capacity (Elvik & Katharina, 2023). The iRAP model places particular emphasis on roundabouts and horizontal deflection features, which reduce conflict points, limit high-speed manoeuvres, and lower the likelihood of severe collisions at intersections and along high-risk road segments (Manikandan et al., 2019; iRAP, 2015). The effectiveness of such measures is further enhanced when combined with enforcement and public awareness initiatives, highlighting the importance of an integrated speed management strategy tailored to road geometry, traffic conditions, and local context, especially in mountainous and tourist-intensive corridors.

2.5.1.6 School Zone Warning

School zones constitute a critical focus area in road safety management due to the heightened vulnerability of children, who have limited perceptual and decision-making capabilities in traffic environments (Logan et al., 2013). The iRAP model adopts a data-driven approach to assess school zone safety by evaluating the adequacy and effectiveness of warning systems, including signage, pavement markings, reduced speed limits, and traffic calming measures, across both mountainous and non-mountainous contexts. Empirical evidence indicates that targeted interventions such as flashing warning lights, pedestrian crossings, speed humps, and raised crosswalks are effective in reducing vehicle speeds and crash risk near schools, particularly during peak arrival and departure periods (Ha et al., 2023; Yusoff et al., 2022). Recognising the limitations of passive measures alone, the iRAP model promotes an integrated strategy that combines visual warnings with physical traffic calming and enforcement to address site-specific risk factors identified through crash history, traffic volume, and pedestrian activity. This comprehensive approach supports systematic risk reduction in school zones and aligns with the iRAP objective of protecting vulnerable road users through targeted, evidence-based interventions.

2.5.2 Traffic Characteristics

Traffic characteristics are a fundamental aspect of road safety risk assessment. They provide insight into the factors that influence how vehicles interact on road networks in both non-mountainous and mountainous regions. Recognising their importance in identifying high-risk crash locations and blackspots, and in implementing targeted road safety interventions, the iRAP model evaluates key traffic-related factors to assess and mitigate crash risk.

2.5.2.1 Vehicle Flow

a) Average Annual Daily Traffic (AADT) represents the average number of vehicles passing at a specific point on a road each day over a year. This metric is critical because higher traffic volumes are often associated with increased road crash frequencies due to more significant vehicle interactions and congestion levels (Travesset-Baro et al., 2015). The iRAP model uses AADT as a baseline indicator to assess the likelihood of road crashes and the potential severity of collision incidents. Roads with high AADT figures require more robust traffic management and infrastructure measures to accommodate the volume of road user vehicles and reduce the risk of road crash incidents. Studies have shown that as the value of AADT increases, so does the probability of road crashes, emphasizing the necessity for capacity improvements or alternative traffic calming strategies on heavily trafficked routes (Manikandan et al., 2019).

2.5.2.2 Motorcycle Percentage

a) Motorcyclists are among the most vulnerable road users due to the vehicle's limited physical protection compared to occupants of four-wheeled vehicles. The proportion of motorcycles within the traffic mix is a critical factor in the iRAP model's road safety risk assessment, as higher motorcycle traffic volumes will correlate with an increased risk of crashes and fatalities, particularly in developing countries where motorcycles constitute a significant mode of transport (Alvisyahri et al., 2020; Chen & Pai, 2019). This iRAP model synthesizes motorcycle percentage data to understand the risks associated with two-wheeled vehicles in different traffic scenarios. Research indicates that motorcyclists are more prone to severe injuries or fatalities in the event of a traffic collision, which justifies the need for targeted road safety interventions such as dedicated motorcycle lanes or specific speed limits for these vehicles (Haque et al., 2009; Murphy & Morris, 2020).

2.5.2.3 Observed Flows

a) Observed traffic flows, including the number of motorcycles, bicycles, and other vehicle types during peak hours, provide a real-time understanding of traffic conditions at specific locations. This data is essential for identifying peak traffic congestion periods and the road users' behaviour of different vehicle types under these conditions (Wang et al., 2012). The iRAP model critically analyses observed flow indicators to develop context-specific strategies to alleviate traffic congestion and enhance road safety measures at high-risk locations. For instance, high flows of bicycles or motorcycles during peak hours may necessitate the implementation of segregated lanes dedicated to bicycles and motorcycles to reduce the likelihood of vehicle road crashes (Beiler & Waksmunski, 2015; Ding et al., 2024).

2.5.2.4 Pedestrian Flow

a) Pedestrian flow is a significant factor in the iRAP model, as pedestrians are highly vulnerable to vehicle collision impacts. The model evaluates pedestrian movement across and along roadways, with a focus on peak activity periods. Elevated pedestrian volumes, particularly in urban, sub-urban, and tourist areas such as the Cameron Highlands, Malaysia, increase the risk of vehicle-pedestrian collisions when adequate crossing facilities and road safety countermeasures are not provided (Zhang et al., 2021). The iRAP model assesses pedestrian flow by analysing the provision and layout of crosswalks, pedestrian signals, and pavement markings to guide pedestrian movement and improve visibility for motorists. Empirical studies support dedicated pedestrian infrastructure as a critical measure for reducing pedestrian-related crash risk (Chimba, 2014). In addition, traffic flow data including motorcycles, bicycles, and other vehicle types during peak hours provides insight into congestion patterns and road user behaviour. The iRAP model analyses these flows to support context-specific strategies for congestion management and road safety improvement.

2.5.2.5 Operating Speed

a) Operating speed specifically the 85th percentile speed and mean operating speed is a critical indicator of compliance with posted speed limits and traffic regulations (Maksid & Hamsa, 2014; Martinelli et al., 2023). The iRAP model analyses these speed measures to assess whether prevailing operating speeds are appropriate for roadway design and traffic conditions. Research shows that higher operating speeds significantly increase crash likelihood and injury severity (Uddin & Huynh, 2018; Waseem et al., 2019). By evaluating the 85th percentile speed, representing the speed at or below which most vehicles operate, the iRAP model identifies road segments with excessive speeds where traffic calming countermeasures may be required to mitigate crash risk.

The iRAP model's assessment of traffic characteristics provides a structured framework for understanding how vehicle composition, road users, and traffic volumes influence crash risk. Integrating AADT, motorcycle proportion, observed traffic flow, pedestrian activity, and operating speed enables a holistic risk analysis that supports targeted road safety interventions. While the iRAP model effectively identifies high-risk crash conditions, its reliance on quantitative traffic data indicates that contextual factors, such as driver behaviour and environmental conditions, should also be considered to fully interpret road safety dynamics in both non-mountainous and mountainous regions.

2.5.3 Alignment

Alignment in road engineering design is concerned with the geometric alignment of the road, including safety factors to elements such as curvature, gradients, and sight distances, which significantly influence driver behaviour, vehicle maneuvering, and overall road safety to road users. The right road alignment design is crucial to minimise road crash risks, as it directly impacts how drivers navigate and responds to the road's physical layout. The iRAP model significantly emphasizes on these factors evaluation under alignment, recognising their role in preventing road crashes, reducing crash severity, and improving road safety.

2.5.3.1 Curvature

The element of road curvature, or the degree to which the road bends or turns, is critical in determining the road safety level. Sharper curves pose a higher risk, especially when vehicles travel at higher speeds, requiring greater steering precision and vehicle stability (Chen & Pai, 2019). The iRAP model critically assesses road curvature to identify areas with a higher risk of vehicle losing control or road skidding. Research has proven that sharper curves, such as roads in mountainous regions, increase the likelihood of run-off-road crashes, particularly when drivers fail to adjust their vehicle speed suitably before entering the sharp curve (He et al., 2012; Moomen et al., 2020). Research suggests that implementing appropriate speed limits and adding warning signage for sharp curves can significantly mitigate these risks (Maksid & Hamsa, 2014). This highlights the need for curve-specific interventions in road design similar to road conditions in the mountainous region of Cameron Highlands (He et al., 2012).

2.5.3.2 Curve Quality

The quality of a road's curve pertains to its consistency and smoothness. Maintaining and ensuring road user vehicle stability and control along the roadway is important, especially in mountainous roadways compared to non-mountainous roadways. Irregular or poorly designed curves, characterized by sudden changes in radius or poor transitions, can lead to abrupt maneuvers that increase crash risks (iRAP, 2014; Moomen et al., 2020). The iRAP model evaluates the curves' quality to ensure that these aspects are constructed to facilitate smooth and predictable driving paths for road users by highlighting road safety aspects. Consistent curve design is essential in preventing unexpected vehicle movements, mainly when road surfaces may be slippery in adverse weather conditions compared to mountainous roadways (Rusli et al., 2017). The iRAP model's emphasis on curve quality aligns with findings that smoother curve transitions will reduce the incidence of single-vehicle crashes (iRAP Methodology, 2013; Rusli et al., 2017).

2.5.3.3 Grade

A road's grade, or slope, is another critical aspect of road alignment that affects road user's vehicle handling, especially for heavy vehicles such as trucks. Poor road grade or slope can exacerbate challenges for road users during adverse weather conditions, reducing visibility and impairing vehicle control (Matori et al., 2012; Tang et al., 2023). Steep inclines or declines in road type can compromise a driver's ability to maintain control over the vehicle, leading to circumstances such as brake malfunction while driving on inclines road or loss of tire traction on ascents (Moomen et al., 2020). The iRAP model thoroughly analyses the steepness of road grades to identify specific road segments that may require additional safety measures, such as warning signs, escape lanes for runaway vehicles, or road design adjustments to lessen the slope risk toward road users. Research by Diyaljee (2008) indicates that reducing steep grades or implementing adequate grade warning systems can significantly decrease crash rates involving heavy vehicles on downhill sections.

2.5.3.4 Sight Distance

Sight distance refers to the length of roadway over which a driver can perceive and respond to hazards and is a fundamental determinant of driving safety (Andrade-Catano et al., 2020; Joseph et al., 2023). Adequate sight distance enables timely obstacle detection, safe lane changes, and appropriate responses to changes in road curvature and intersections. The iRAP model evaluates whether sight distance provided by road alignment is sufficient to meet required stopping distances under typical operating conditions. Empirical studies indicate that restricted sight distance, particularly on curved alignments or near vertical obstructions, significantly increases the risk of rear-end and head-on collisions (Liang et al., 2023; Persia et al., 2020). Within the iRAP framework, sight distance is assessed alongside curvature, curve quality, and grade to capture combined effects on driver behaviour and vehicle dynamics. Although the model offers a comprehensive geometric safety assessment, its effectiveness could be enhanced by incorporating real-time traffic behaviour and environmental data. Nevertheless, alignment-based strategies derived from the iRAP model remain essential for improving roadway design and implementing targeted safety interventions on high-risk segments.

2.5.4 Pavement Surface

Pavement surface quality is a crucial determinant of road safety, directly influencing vehicle stability, maneuverability, and brake system performance. In the iRAP Model, a comprehensive evaluation of the pavement surface is performed, emphasizing the following critical aspects:

2.5.4.1 Road Condition

The overall condition of the road surface is meticulously assessed to identify road safety issues such as potholes, cracks, ruts, and surface unevenness. Poor road conditions and maintenance can significantly decrease vehicle handling ability and increase the likelihood of road crashes, especially for vulnerable road users and small vehicles like motorcycles and bicycles that are more sensitive to surface irregularities both at non-mountainous and mountainous roadways (AlKheder & AlRukaibi, 2020; Malik et al., 2023). Studies have shown that deteriorated road surfaces will increase vehicle spare parts' wear and tear durability and contribute to a higher frequency of single-vehicle road crashes due to unexpected loss of vehicle control (Abdul Manan et al., 2016). The iRAP model's focus on road conditions aims to identify these exposures and recommend timely maintenance of road safety interventions to improve road safety outcomes for road users.

2.5.4.2 Skid Resistance

Skid resistance defines a road surface’s ability to provide adequate tire–road traction, particularly under adverse weather conditions (Jameel & Al-Nuaimi, 2020; Peng et al., 2021). The iRAP model evaluates skid resistance to determine whether road surfaces can support effective braking and cornering without loss of control under wet tropical or icy conditions. Research shows that insufficient skid resistance significantly increases crash risk by reducing braking efficiency and increasing stopping distances, especially on steep gradients and sharp curves (Moomen et al., 2020; Yu et al., 2015). This assessment is therefore essential for understanding pavement performance in preventing skidding and hydroplaning, which are major contributors to severe crashes on slippery roads.

2.5.4.3 Surface Friction and Texture

Road surface friction and texture are not always explicitly discussed among researchers. Surface friction and texture are clearly defined factors in the iRAP's model evaluation of pavement surfaces. High-quality textures, such as those created by surface grooving, significantly enhance friction and water drainage, reducing the risk of aquaplaning (Peng et al., 2021). A well-textured road surface is critical in high-risk areas like mountainous regions, such as intersections and pedestrian crossings, where sudden braking or evasive maneuvers are more likely to occur. The model's analysis of these micro-surface features enables targeted interventions to enhance road safety by identifying the most appropriate pavement treatments and rehabilitation strategies necessary to optimize road performance for all users.

2.5.4.4 Road Surface Maintenance

Beyond initial pavement construction quality, the iRAP model emphasises the importance of continuous road maintenance and rehabilitation in sustaining long-term road safety performance. Without systematic maintenance, even high-standard pavements can deteriorate over time, leading to increased crash risk. Empirical studies indicate that timely surface maintenance measures, such as crack sealing and pothole repair, significantly reduce crash occurrence by preserving pavement integrity and consistent driving conditions (Razelan, 2017). The iRAP model evaluates pavement condition by assessing skid resistance, surface texture, and maintenance requirements, providing a comprehensive understanding of how pavement quality influences traffic dynamics and road safety star ratings. Through this integrated assessment, the model supports targeted maintenance and rehabilitation strategies that enhance safety performance, particularly on road sections exposed to adverse weather conditions and high traffic volumes in both mountainous and non-mountainous environments. This evidence-based approach promotes the development of safer, more resilient road infrastructure through proactive pavement management and informed decision-making by road authorities.

2.5.5 Area Type

Area type is another crucial factor in determining traffic patterns and driver behaviour that becomes a road segment's corresponding road safety requirement (Harwood et al., 2010). The road network surrounding the environment and land use will significantly impact road traffic flows and the types of road hazards that may occur for a road segment, mainly on mountainous roadways. The iRAP model provides a comprehensive analysis of area types by examining key factors that influence road safety.

2.5.5.1 Area Classification (Urban, Suburban, Rural)

The iRAP model systematically classifies the area type into urban, suburban, or rural categories, recognising that each area type setting exhibits unique and dynamic road traffic and road safety challenges. Urban areas characteristically have higher road traffic volumes, more pedestrian activities, and a higher likelihood of complex intersections, elevating the risk of traffic collisions and necessitating more stringent road traffic management measures (Abdullah et al., 2021). In contrast, rural areas experience lower road traffic volumes. This situation frequently involves road safety issues such as higher vehicle speeds violence and causing road users to drive longer distances thus, increasing road crashes' severity (Amalia et al., 2022). Meanwhile, sub-urban areas represent transitional zones with mixed roadway characteristics, where rapid urbanisation can lead to increased road traffic volumes and changing road user behaviour (iRAP, 2015). Understanding these classifications is essential for implementing tailored road safety interventions that address the specific risks inherent to each road area type.

2.5.5.2 Land Use (Driver Side/Passenger Side)

The iRAP model extends its analysis to include land use types on both sides of the roadway, recognising their influence on road safety star ratings through pedestrian activity levels, access density, and traffic conflict potential. Different land use categories residential, commercial, and industrial generate distinct traffic characteristics that affect crash risk. Along the mountainous corridor from Jalan Simpang Pulai to

Tanah Rata in the Cameron Highlands, Malaysia, mixed land use associated with residential settlements, tourism activities, and agricultural transport yields high variability in traffic demand and road-user interactions. Residential areas typically experience increased pedestrian activity, frequent stopping manoeuvres, and the presence of children, necessitating lower operating speeds and enhanced pedestrian crossing facilities (Mofolasayo, 2020). Commercial zones introduce high access frequency and parking-related conflicts, requiring adequate signage, traffic control, and access management strategies to mitigate collision risk (Nematchoua et al., 2020). Industrial areas, by contrast, are characterised by heavy vehicle movements that require geometric and pavement design considerations, such as wider lanes and strengthened surfaces, to accommodate higher axle loads safely (Tang et al., 2023). By incorporating land-use and area-type data, the iRAP model supports a context-sensitive star-rating approach that aligns road safety countermeasures with surrounding environmental characteristics, thereby improving traffic management and reducing crash risk for all road users.

2.5.6 Intersection or Access Points

Intersections and access points are among the most complex and hazardous locations on road networks due to the convergence of multiple road users, including vehicles, motorcyclists, cyclists, and pedestrians, which creates numerous traffic conflict points where streams intersect, merge, or diverge. These features exist in both mountainous and non-mountainous road networks, although their design characteristics and safety challenges differ significantly by terrain. In non-mountainous areas, intersections are typically more frequent and are designed to accommodate high traffic volumes in relatively flat urban or suburban environments, commonly in the form of signalised junctions, roundabouts, or multi-lane crossings (Haque et al., 2009). In contrast, intersections in mountainous road networks are less common due to topographical constraints and limited flat terrain, but when present, they require specialised geometric design to address steep gradients, sharp curves, and restricted sight distance (Diyaljee, 2008; He et al., 2012; Rusli et al., 2017). These conditions reduce drivers' ability to control vehicle speed and perceive conflicts in advance, thereby increasing crash risk. Consequently, intersections and access points in mountainous areas generally present higher safety challenges due to elevation changes, spatial limitations, and environmental constraints. The iRAP model therefore provides a comprehensive assessment of such critical locations by evaluating multiple geometric, operational, and traffic-related factors that influence intersection safety and performance.

2.5.6.1 Intersection Type

The iRAP model conducts an in-depth analysis of various intersection road designs, such as signalised intersections, roundabouts, and uncontrolled junctions, to assess these types of intersection impact on road safety. While the intersection is typically effective in traffic flow management, signalised intersections can still present major risks if they are not designed in a timely manner or if road users ignore traffic signals (Rusli et al., 2020; Zhang et al., 2021). Roundabouts are another option for safer alternatives due to their ability to reduce vehicle speeds and minimise traffic collision at angles location (Hamidun et al., 2019). Uncontrolled intersections, however, pose the highest risk as they rely heavily on driver judgment and consideration, which can lead to unpredictable vehicle interactions and increased road crash likelihood. The iRAP model's assessment of intersection types is crucial for identifying where specific road safety design modifications or traffic control measures might be required to enhance road safety.

2.5.6.2 Intersection Channelisation

Intersection channelisation involves the use of physical features such as turn lanes, traffic islands, or medians to guide vehicles into defined paths at intersections (Anik et al., 2021). The iRAP model evaluates the presence and effectiveness of these channelisation elements due to the best road safety countermeasures in reducing road user and driver confusion, organising traffic movements, and preventing road traffic conflicts. Properly designed channelisation can significantly improve road safety regarding vehicle turning maneuvers and help to segregate pedestrian and vehicular traffic, thereby reducing the chances of traffic collisions at a busy intersection during peak hours and bad weather (iRAP, 2014). The iRAP model's focus on channelisation features reflects its commitment to improving road safety by creating structured and predictable traffic environments that minimise human error.

2.5.6.3 Intersection Road Volume

Higher traffic volume at intersections is a critical contributing factor to crash risk, leading to increased vehicle-to-vehicle and vehicle-to-pedestrian conflicts (Mehrara & Ksaibati, 2021). The iRAP model will thoroughly assess the intersection traffic density to identify the congestion level and its correlation with road crash frequency. High traffic volumes will not only elevate the potential for traffic collisions but also create traffic delays and frustration among drivers, resulting in risky behaviors like red-light running or sudden lane changes by road users. Understanding the intersection road volume will enable the iRAP model to suggest road capacity enhancements or traffic signal adjustments to lessen traffic congestion and enhance road safety at the required location.

2.5.6.4 Intersection Quality

The clarity of signage, suitability of traffic signal timing, and the visibility of road markings are measured to indicate the overall quality of road intersections the iRAP model. Poorly maintained or inadequate intersection infrastructure can lead to driver confusion and misjudgement, thus significantly increasing road crash risk. The iRAP model's analysis considers whether intersections are equipped with clear, visible signals and appropriate timing cycles of traffic signals to facilitate smooth traffic flow and safe pedestrian crossings for road users (iRAP, 2021g). Improving intersection quality is vital to ensure that all road users receive consistent and unambiguous guidance, thereby reducing the probability of road crashes while traveling on the roadway.

2.5.6.5 Property Access Points

Property access points, such as driveways and entrances to residential or commercial properties, are often underestimated yet are significant contributors to road safety risks on both mountainous and non-mountainous roadways (Moomen et al., 2020). In tourism-intensive areas such as Cameron Highlands, these access points are particularly critical due to high traffic volumes and mixed vehicle types, including tourist buses, freight vehicles, and private cars (Barrow et al., 2005). Mountainous terrain, sharp curves, steep gradients, and adverse weather frequently restrict sight distance at access locations, increasing the likelihood of conflicts and crashes. Effective design measures, including deceleration lanes, paved shoulders, controlled-access spacing, and clear signage and pavement markings, facilitate safe vehicle entry and exit. In contrast, traffic-calming measures reduce operating speeds near access points. Given the high levels of pedestrian and cyclist activity, well-defined crossings and dedicated facilities are necessary to protect vulnerable road users. The iRAP model evaluates the number, location, and design of access points, recognising that each additional access introduces conflict zones where vehicles decelerate or merge. Poorly designed access points can disrupt traffic flow, elevate rear-end collision risk, and increase pedestrian exposure; therefore, the iRAP model supports optimised access management strategies to mitigate crash risk while maintaining efficiency.

2.5.7 Roadside Features

Roadside features, also commonly referred to as roadside environment, roadside infrastructure, clear zone elements, roadside hazards, lateral support elements or roadside safety features, play a crucial role in influencing the severity and likelihood of crashes, acting as either protective elements that enhance road safety or as potential hazards that can worsen the impact of collisions (Song et al., 2018). Understanding these features in the context of traffic management and road safety is essential for developing effective road safety strategies and for describing the components adjacent to the main roadway that influence vehicle safety and road crash outcomes. The iRAP model provides a detailed assessment of various roadside elements to understand the roadside features on road user safety and to guide the implementation of targeted road safety interventions.

2.5.7.1 Roadside Severity (Driver Side/Distance)

The iRAP model evaluates roadside hazard severity by assessing the presence, type, and proximity of roadside features on the driver's side of the roadway. Hazards such as cliffs, trees, rigid signposts or poles, rigid structures, unprotected barrier ends, low rigid objects (≥20 cm), aggressive vertical faces, drainage ditches, slopes, and safety barriers (metal, motorcycle-friendly, concrete, or rope) are considered significant risks when located close to traffic lanes (iRAP, 2014). Research indicates that collisions with fixed objects are associated with higher injury severity, particularly at higher speeds or during run-off-road events (Zhang et al., 2021). The iRAP model also evaluates the clear zone width, the lateral distance intended to be free of hazards to ensure adequate recovery space for vehicles leaving the carriageway (iRAP, 2014). Through this assessment, the model supports targeted countermeasures such as hazard removal, barrier installation, and roadside modification to reduce the severity of run-off-road crashes.

2.5.7.2 Vehicle Parking

The iRAP model considers roadside parking management as a critical factor influencing road safety. Roadside parking, particularly on high-traffic or high-speed roads, can obstruct sight lines, reduce effective carriageway width, and increase the risk of rear-end and sideswipe collisions during parking manoeuvres (Kutela et al., 2022). The model evaluates the location, regulation, and adequacy of parking facilities to assess their effects on traffic flow and safety. Poorly managed parking can also contribute to congestion, driver frustration, and elevated crash risk, especially in urban environments with high pedestrian activity and limited parking supply (Ouhmidou et al., 2023). Accordingly, the iRAP model recommends parking control measures such as clear signage, designated parking zones, and parking restrictions in locations with a history of high crash risk.

2.5.7.3 Service Road

Service roads are assessed in the iRAP model for their role in improving road safety by separating local access traffic from mainline traffic, thereby reducing interactions between through vehicles and vehicles entering or exiting the primary roadway (Blazek et al., 2019). In commercial, densely populated, or tourist areas with frequent stopping and turning movements, service roads reduce traffic conflict points and congestion. Studies indicate that well-designed service roads lower crash risk by channeling slower-moving vehicles away from higher-speed traffic streams (Mofolasayo, 2020). The iRAP model evaluates service road design, connectivity, and accessibility to ensure effective operation without introducing hazards. When combined with roadside hazard mitigation, parking control, and clear-zone provision, service roads contribute to a structured traffic environment that reduces crash severity and fatality risk.

2.5.8 Visual Aid

Visual aids are crucial in enhancing driver awareness and maintaining safe driving conditions by providing clear and prompt feedback to road users about their roadway environment and potential hazards while driving (Rolison et al., 2018). The iRAP model thoroughly evaluates various visual aid elements, recognising their significance in reducing road crash risks and improving overall road safety. Each component is analysed to determine its effectiveness in guiding driver behaviour and minimising road crash rates.

2.5.8.1 Street Lighting

Street lighting is a key roadside feature assessed in the iRAP model due to its influence on nighttime driving safety. Adequate lighting enhances visibility under low-light conditions and reduces the likelihood and severity of nighttime crashes associated with limited hazard perception (Jägerbrand & Sjöbergh, 2016). Studies show that well-designed street lighting improves drivers' ability to detect roadway hazards, interpret signage, and recognise vulnerable road users such as motorcyclists, pedestrians, and cyclists (Guerrieri et al., 2019). Accordingly, the iRAP model evaluates the presence, intensity, and uniformity of street lighting to support a safe nighttime driving environment (Satiennam et al., 2023). Insufficient or poorly designed lighting is linked to higher crash and pedestrian accident rates, underscoring its role in roadside safety performance.

2.5.8.2 Delineation

Delineation refers to the use of road markings, signage, and visual guidance devices that assist drivers in maintaining lane position and navigating complex traffic conditions (iRAP, 2021c). The iRAP model evaluates the quality, visibility, and consistency of delineation to determine its effectiveness in reducing off-road, single-vehicle crashes, and other roadway conflicts (Duddu et al., 2020; Rahimi et al., 2020; Rusli, 2017). Effective delineation is particularly critical under adverse weather conditions such as rain or fog, where reduced visibility limits drivers' ability to perceive road edges and lane boundaries (Rusli et al., 2017; Theofilatos & Yannis, 2014; Yu et al., 2015). Well-maintained markings enhance safety by providing continuous visual guidance, reinforcing intended traffic flow, and reducing driver error and collision risk in high-risk areas.

2.5.8.3 Centerline Rumble Strips

Centerline rumble strips are a proven road safety visual aid that the iRAP model considers vital for alerting road users who may be unintentionally drifting out of their driving lane (Shokat & Jameel, 2023). These centreline rumble strips will create a tactile and auditory warning when a vehicle's tires cross over them, prompting road users to correct their existing lanes and return to the appropriate lane. The effectiveness of centerline rumble strips in reducing head-on and opposite-direction sideswipe road crashes has been well-documented, especially on two-lane rural roads with high-speed limits (Cáceres et al., 2021). By incorporating centerline rumble strips into its risk assessment, the iRAP model aims to reduce the frequency of off-road or single-vehicle crash roadway conflicts, among the most severe types of traffic collisions.

2.5.8.4 Shoulder Rumble Strips

Shoulder rumble strips serve a similar safety function to centreline rumble strips but are installed along the road shoulder to prevent run-off-road crashes caused by driver inattention, fatigue, or adverse weather (Khan et al., 2015). The iRAP model evaluates their placement and design to ensure timely tactile and auditory warnings before vehicles depart the carriageway, enabling drivers to regain control and return safely to the travel lane (Gooch et al., 2016). These early warnings are effective in reducing severe crashes and rollover incidents (Shokat & Jameel, 2023). Within the iRAP star rating framework, shoulder rumble strips are assessed alongside other visual-aid elements, including street lighting, delineation, and centreline rumble strips, to capture their combined contribution to driver alertness and crash risk reduction, particularly under nighttime and adverse-weather conditions on mountainous roadways.

2.5.9 Facilities for Vulnerable Road Users (VRU)

Vulnerable Road Users (VRUs), including pedestrians, cyclists, and motorised two-wheeler riders, are significantly at higher risk of injury or death in road crashes due to their lack of physical protection compared to vehicle occupants of motor vehicles such as cars, buses, truck, van, Sport Utility Vehicle (SUV), Multi-Purpose Vehicle (MPV) and taxi passengers car (Mehar & Agarwal, 2013; Rogers & Hashim, 2011). The iRAP model strongly emphasizes the stage to assess and improve facilities for VRUs to enhance their safety level on road networks. By systematically evaluating various infrastructural elements for VRUs, the iRAP model identifies critical areas where targeted road safety interventions can reduce road crash risks and create safer road environments for these users. Each factor and sub-factor within the VRU category will be critically assessed within the model to understand its impact on road safety star rating and the opportunities it presents for reducing vulnerability issues related to road safety in road networks.

2.5.9.1 Pedestrian Crossing Facilities

Pedestrian crossing facilities are crucial for safeguarding individuals attempting to cross the road, especially in areas with heavy traffic flow (Colley et al., 2021; Logan et al., 2013). The iRAP model evaluates both the availability and quality of pedestrian crossing facilities on inspected and intersecting road networks. Strategically located and adequately designed pedestrian crossings facilities, such as refugees, marked crossings, raised marked crossings, marked crossing with refuges, signalised crossings, signalised crossings with refuges, and grade-separated facilities play a vital role in reducing pedestrian-vehicle conflicts by providing clear, designated areas for pedestrian crossing facilities (iRAP, 2014). Research has shown that well-designed pedestrian crossings can significantly decrease the number of pedestrian-involved road crashes cases by up to 50% (Logan et al., 2013). The iRAP model's analysis aims to identify deficiencies in pedestrian crossing facilities infrastructure and recommend best enhancements to improve pedestrian safety and mobility in high-risk areas, especially in tourist attraction cities.

2.5.9.2 School Zone Crossing Supervisor

Children and teenagers are among the most vulnerable road users due to their unpredictable actions and lack of awareness of traffic dangers while crossing the road. The iRAP model considers the presence of school zone crossing supervisors as a critical safety measure that directly influences the road safety of young pedestrians at school (iRAP, 2014). School zone crossing supervisors act as a protective measure, guiding children and teenagers safely across roads and managing vehicle flow to reduce the risk of road crashes during peak school hours (Yusoff et al., 2022). Studies indicate that school zone crossing supervisors can significantly lower the rate of child pedestrian death and injuries by creating a safer, more controlled environment around educational institutions (Logan et al., 2013). This focus section within the iRAP model highlights its commitment to safeguarding the most vulnerable members of society, particularly in sensitive areas like school zones.

2.5.9.3 Sidewalks

Sidewalks are fundamental to pedestrian safety, providing a dedicated walking space separate from vehicular traffic (Menini et al., 2021). The iRAP model evaluates the presence, continuity, and existing condition of sidewalks on the driver and passenger sides of the roadway. High-quality sidewalks with sufficient width and good maintenance will reduce the likelihood of pedestrian-vehicle traffic collisions by keeping pedestrians off the roadway. The lack of adequate sidewalks will increase pedestrian road crash rates, mainly in urban areas with high pedestrian activity traffic (Zavala-Reyes et al., 2019). By identifying gaps in pedestrian sidewalk infrastructure, the iRAP model seeks to promote safer pedestrian environments that encourage walking as an active mode of transport that involve physical activity while minimising pedestrian exposure to road traffic hazards and promoting health benefits, environmental sustainability, and means of reducing traffic congestion both urban dan rural areas.

2.5.9.4 Pedestrian Fencing

Pedestrian fencing is an essential control road safety measure to help direct pedestrian movements and prevent dangerous mid-block crossings (Saadeghvaziri et al., 2000). The iRAP model assesses the strategic placement and effectiveness of pedestrian fencing in guiding pedestrians to safe crossing points, thereby reducing the likelihood of unpredictable pedestrian behaviour that can lead to traffic collisions caused by human behaviour factors (Anik et al., 2021). Pedestrian fencing is effective, especially in high-speed or high-traffic roadway areas where pedestrian crossing at non-designated points poses significant risks of road crashes. Research findings support that pedestrian fencing, combined with clearly marked crossings, can reduce pedestrian-related road crashes by up to 30% (iRAP, 2021c). The iRAP model's evaluation of pedestrian fencing aims to ensure that these safety barriers are optimally located and do not mistakenly restrict pedestrian mobility or access while crossing the road.

2.5.9.5 Facilities for Bicycles and Motorised Two-Wheelers

Cyclists and motorised two-wheeler riders are highly vulnerable road users due to minimal physical protection and direct exposure to motor vehicle traffic. The iRAP model evaluates the availability, type, and quality of dedicated facilities for these users to reduce conflicts with higher-speed traffic. For motorcyclists, this includes assessing dedicated lanes and one-way or two-way paths with or without physical separation to enhance traffic segregation (Alvisyahri et al., 2020; McInerney & Smith, 2009). For cyclists, the model examines shared roadways, wide outer lanes (>4.2 m), on-road bicycle lanes, shared-use paths, and segregated bicycle facilities to mitigate collision risk (Ding et al., 2024; iRAP, 2013). Evidence indicates that well-designed VRU infrastructure significantly reduces crash risk and injury severity while encouraging safer, sustainable travel (Ding et al., 2024; Idris et al., 2019). By integrating VRU facilities into its risk assessment, the iRAP model supports an inclusive, infrastructure-led safety approach aligned with global road safety priorities enabling targeted interventions to reduce traffic-related injuries and fatalities (WHO, 2023).

2.5.10 Cross Section

The cross-section of a roadway is a fundamental aspect of road design that significantly influences road safety, traffic flow, and the overall operational performance of the road network (Rusli et al., 2017). The iRAP model systematically evaluates the various components of the road’s cross-section to identify potential risks and hazards for road safety improvement (iRAP, 2013). This comprehensive approach is critical to understanding how road design elements significantly impact road crash rates and advising best-targeted interventions to enhance road safety.

2.5.10.1 Carriageway Label

The classification and labeling of the road carriageway play a crucial role in determining road utilisation and road safety implications for road users (Choudhary et al., 2024; iRAP, 2014). The iRAP model examines the functional classification of the road carriageway, whether it is designated as an arterial, collector, or local road, as this type of road classification will determine the road's primary function, speed limits, and traffic volume (Maksid & Hamsa, 2014). Accurate road carriageway labeling will help to guide appropriate traffic behaviour and manage the mix of vehicles on the road. Misclassification or lack of clear road carriageway labeling can lead to inappropriate roadway use, such as high-speed traffic violence by road users, thereby increasing the likelihood of road crashes (Peng et al., 2021; Rahimi et al., 2020).

2.5.10.2 Median Type

Median types are critical road safety features that separate opposing traffic flows and reduce the risk of head-on collisions (Martinelli et al., 2023). The iRAP model evaluates the presence and design of roadway medians to classify centre lines, wide centre lines (0.3 to 1 meter), or central hatching (more than 1 meter). It further assesses configurations such as continuous central turning lanes, flexible posts, physical medians of varying widths (0 to 1 meter, 1 meter to less than 5 meters, 5 meters to less than 10 meters, 10 meters to less than 20 meters or more or equal to 20 meters), safety barriers (concrete, motorcycle friendly or wire rope) or one-way road only. By systematically assessing median type and configuration, the iRAP model highlights their importance in mitigating crash risk and improving the consistency of traffic flow for road users.

2.5.10.3 Number of Lanes

The number of lanes on a roadway directly influences its traffic capacity, congestion levels, and the potential for vehicle interactions (Anik et al., 2021; Rusli et al., 2018). The iRAP model evaluates whether the number of lanes is adequate for the roadway traffic volume, considering factors like peak hour traffic volume and lane distribution. Roadways with insufficient number of lanes may experience severe traffic congestion, leading to higher rates of rear-end crashes and side-swipe collisions due to sudden lane-changing maneuvers by drivers (Liang et al., 2023; Peng et al., 2018; Uddin & Huynh, 2018). Conversely, an excessive number of lanes on low-traffic roads can encourage speeding by road users, further increasing the road crash risk. Thus, the iRAP model aims to balance traffic capacity with road safety considerations of number of lanes.

2.5.10.4 Lane Width

Lane width is a critical factor in road safety, as it influences vehicle maneuverability and the likelihood of traffic collisions (Gooch et al., 2016; Jain et al., 2020). Lane width measures the distance from the edge line to the adjacent lane marking (Gooch et al., 2016). The iRAP model analyses lane width type, namely narrow (less than 2.75 meters), medium (between 2.75 meters to 3.25 meters), or wide (more or equal to 3.25 meters), to determine whether it can adequately accommodate the various types of vehicles. Narrow lane width can increase the risk of side-swipe crashes and reduce a driver's margin for error, especially in the presence of heavy vehicles or during adverse weather conditions (iRAP, 2014). Wider lane width generally provides a safer driving environment by allowing adequate space for road user vehicles to maneuver (Martinelli et al., 2023). However, wider lane width can also lead to higher vehicle travel speeds, which might increase road crash severity (Arévalo-Támara et al., 2020). The iRAP model’s assessment will reduce the likelihood of road crashes among road users by optimising the features of lane widths for better road safety and operational efficiency of a road network.

2.5.10.5 Paved Shoulders (Driver Side or Passenger Side)

Paved shoulders on both the driver and passenger sides of the roadway are essential cross-sectional features that contribute significantly to road safety by providing recovery space for errant vehicles and refuge areas for emergency stopping (iRAP, 2014). These shoulders form a critical buffer zone between the travelled way and roadside hazards, reducing the probability and severity of run-off-road crashes. Paved shoulders are typically defined as the usable, sealed portion of the roadway extending from the edge line to the outer edge of the paved surface, and their width and condition directly influence driver behaviour and vehicle stability (Olabarria et al., 2015). The iRAP model systematically evaluates paved shoulder width and surface condition on both sides of a road section, classifying them as narrow (0 to <1.0 m), medium (1.0 to <2.4 m), or wide (≥2.4 m), in recognition of their differing safety performance outcomes.

Narrow or deteriorated paved shoulders can significantly compromise road safety, particularly for vulnerable road users such as motorcyclists and cyclists, who rely on shoulder space to avoid conflicts, maintain lateral stability, or recover from minor trajectory deviations (Martinelli et al., 2023). In mountainous and high-speed road environments, insufficient shoulder width may also limit driver reaction time and increase the likelihood of vehicles leaving the carriageway and colliding with roadside hazards. Conversely, adequately wide and well-maintained paved shoulders improve lateral clearance, enhance vehicle stability for heavy vehicles, and provide operational flexibility during breakdowns, enforcement activities, or adverse weather conditions, thereby reducing crash risk (Kozmar et al., 2015).

Within the iRAP star rating framework, paved shoulder assessment is part of a broader cross-sectional analysis that evaluates how roadway design elements influence crash exposure and injury severity. By integrating carriageway classification, lane configuration, median type, and shoulder provision, the iRAP model provides a comprehensive evaluation of road infrastructure performance. This systematic approach enables engineers and authorities to identify infrastructure deficiencies and prioritise cost-effective safety interventions, particularly in high-risk corridors. As illustrated in Figure 2.3, the model supports evidence-based planning to enhance safety performance and reduce crash risk across road networks.

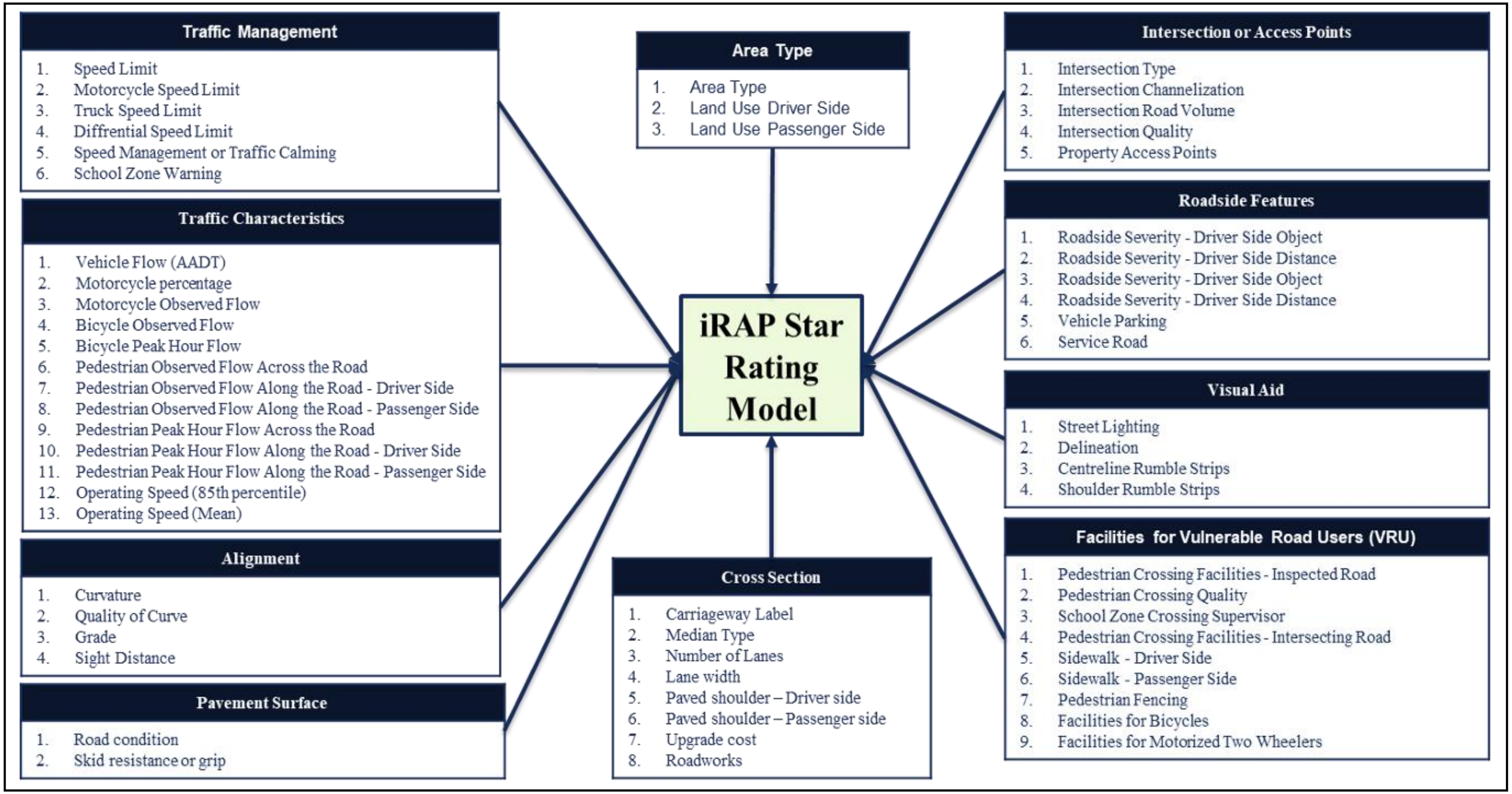

Figure 2.3 The iRAP Star Rating Model

2.6 Identification of Research Gaps

This literature review section aims to systematically analyze and synthesize existing studies conducted from 2014 to 2023 that focus on road crash forecasting tools in mountainous roadway areas, with an emphasis on research gaps in the Cameron Highlands. The review aims to identify key methodologies for evaluating strengths and research limitations and highlight the significant findings and trends within the field of road safety research. Through a comprehensive assessment of these studies, this review aims to understand the research landscape, identify critical areas that require further investigation, and propose targeted research solutions.

The scope of this review encompasses a wide array of research methodologies applied in road crash forecasting tools in mountainous roads. It includes 11 articles on modeling techniques, three (3) on land surveying tools, two (2) using secondary data analysis, three (3) case studies research, one (1) interview-based study, three (3) laboratory experiments, six (6) literature reviews on past studies, and one (1) questionnaire survey method. The researchers of these articles collectively provide a nuanced understanding of how different methods improve traffic management and road safety in high-risk areas, particularly by considering the geographic and environmental conditions of mountainous regions such as the Cameron Highlands, Malaysia.

To provide clarity, key terms such as "crash forecasting," "systematic literature review (SLR)," and "mountainous road networks" are defined in the context of this study. Crash forecasting involves predicting future road traffic incidents using statistical or machine learning models based on historical data. An SLR is a systematic approach to reviewing and synthesizing existing research findings to ensure a comprehensive overview of a particular field. Mountainous road networks refer to road systems located in areas with steep gradients, sharp curves, and varying elevations, which pose significant challenges for traffic management. This review employs the SLR methodology to ensure a rigorous analysis of studies on crash forecasting in mountainous areas, specifically focusing on the relevance to Cameron Highlands, Malaysia. By categorising past studies according to their thematic focus, the SLR approach enables a critical examination of methodologies, findings, and their contributions to advancing road safety research.

Mountainous road networks like Cameron Highland, Malaysia present unique challenges to road engineering and traffic safety due to complex topography, frequent adverse weather conditions, and limited visibility that will affect driver behaviour. These factors put road users in mountainous regions at higher risk of road crash incidents, making mountainous regions one of the most dangerous areas for drivers, especially during peak or festive seasons. Practical and effective road crash forecasting tools or risk assessment models in these regions are crucial for mitigating road crash risks and improving overall road safety. Over the years, researchers have focused on developing predictive tools and methodologies tailored to address these specific challenges, emphasizing the importance of customized solutions for these problematic terrains, steep gradients, sharp curves, hairpin bends, narrow lanes, limited sight distance, frequent change in elevation, variable weather conditions, lack of alternative routes, rockfall and debris, poor drainage system, and limited infrastructure (Andrade-Catano et al., 2020; Fitri & Wahyuni, 2022; He et al., 2012; Laliberté & St-Laurent, 2020; Rusli et al., 2018).

Interestingly, the Shaanxi Mountain Road Safety Project in China demonstrates key strategies for improving road safety in mountainous regions that can be applied similarly to Cameron Highlands, Malaysia (Rebecca et al., 2024). The mountainous roadways in Shaanxi Province, China, are renowned for their stunning landscapes and challenging terrains, particularly along routes like the Zhongnan Mountain Tunnel, Huanghe Road, and Qinling Mountains Highway. These roads offer breathtaking views of mountain ranges, valleys, and forests, making them popular for scenic drives. However, the same features, such as Cameron Highlands, Malaysia, make them visually appealing but also contribute to significant road safety challenges. To mitigate these problems, the Asian Development Bank (ADB), ChinaRAP, iRAP, and the Department of Transport of Shaanxi Province (DTSP) bring this project to focus on upgrading road infrastructure, including realigning roads, adding paved shoulders, installing safety barriers, and implementing rockfall protection and slope stability measures, all essential in reducing road crash risks in steep and winding terrains. Traffic management measures, such as lowering speed limits and creating pedestrian crossings, significantly reduced road accidents. This project won the prestigious International Road Federation (IRF) global award for the life-saving Shaanxi Mountain Road Safety Demonstration Project. Additionally, community engagement through this road safety education and professional training project has raised awareness of local hazards, such as weather-related risks, which has further contributed to a 50% reduction in fatalities and injuries. These findings underscore the importance of integrating infrastructure improvements with education and traffic management to enhance road safety in mountainous areas, such as the Cameron Highlands in Malaysia.

2.6.1 Limited Focus on Motorcyclists in Mountainous Roadways

The literature review conducted in this chapter highlights substantial progress in understanding road safety issues in mountainous regions; however, a critical synthesis of past studies reveals several significant research gaps that limit their applicability to the Cameron Highlands, particularly with respect to motorcyclist safety. Although numerous studies have adopted modelling techniques, GIS-based methods, secondary data analysis, case studies, laboratory experiments, and qualitative approaches by researchers such as Ingle and Gates, (2023), Joseph et al. (2023), Nhu et al. (2020), Diyaljee, (2008) and Heslop et al. (2010), these studies seldom offer a holistic assessment that integrates infrastructure, behavioural, and environmental factors within mountainous roadway conditions. Moreover, the majority of these studies are not designed to capture the specific crash risk dynamics experienced by motorcyclists, despite motorcycles being the dominant contributor to road fatalities in Malaysia (RMP, 2018; Shaadan et al., 2021).

Most existing studies on mountainous road safety concentrate on general traffic or vehicle-related analysis, such as slope stability (Matori et al., 2012), landslide susceptibility (Nhu et al., 2020), geotechnical design (Diyaljee, 2008), or roadway capacity (Jain et al., 2020). These studies do not explicitly examine motorcyclist-specific vulnerabilities, such as instability on curves, surface friction sensitivity, lack of roadside protection, and exposure to adverse weather. As a result, there is a clear research gap in establishing a dedicated assessment framework for motorcyclists navigating mountainous environments such as those in Cameron Highlands. This study develops a motorcyclist-specific modified iRAP model (iRAP@Highlands) tailored for highland road networks. Unlike previous studies that treat road users homogeneously, the proposed model explicitly accounts for the unique vulnerabilities of motorcyclists.

2.6.2 Absence of an Integrated, Multi-Factor Road Safety Risk Assessment Framework

A critical analysis of the reviewed literature shows that most studies focus on one or two dimensions of safety. For example, modelling studies emphasise operating speed or curvature research by Ingle and Gates, (2023) and Joseph et al. (2023), the GIS-based studies explore landslides without linking them to crash occurrence research by Nhu et al. (2020), and driver behaviour studies overlook terrain-specific interactions research by Heslop et al. (2010). This fragmentation demonstrates the absence of a comprehensive, integrated model combining infrastructure, rider behaviour, environmental exposure, and historical crash data for mountainous roads. This research employs an integrated approach that combines a Systematic Literature Review (SLR), detailed motorcyclist crash profiling (2015 to 2018), road surveys using RADIS, MiREV, and ViDA, and statistical modelling using Multiple Linear Regression (MLR). To the best of the researcher's knowledge, such a multi-level integration has not been documented in previous studies on mountainous road safety in Malaysia.

2.6.3 Limited Localisation of iRAP Tools for Mountainous Malaysian Conditions

The International Road Assessment Programme (iRAP) has been widely applied globally; however, its standard methodology is not calibrated for mountainous Malaysian road networks, nor does it explicitly address motorcyclist safety (iRAP, 2014; MIROS, 2017). The absence of customised risk scoring for steep gradients, sharp curvature, narrow shoulders, roadside hazards, and rapidly changing weather conditions limits the applicability of the existing iRAP model to highland corridors such as the research location. The iRAP@Highlands model modifies several iRAP variables to reflect local highland characteristics, including curvature severity, gradient-induced risks, pavement condition on slopes, roadside hazards, and weather-induced instability (iRAP, 2013; Murozi et al., 2022). This localisation creates a more realistic and sensitive assessment tool for Cameron Highlands.

2.6.4 Lack of a Detailed Motorcyclist Crash Data Profile for Cameron Highlands

Existing crash analyses do not provide a detailed, disaggregated profile of motorcycle-involved crashes, including their spatial distribution, severity trends, geometric correlations, and environmental influences (Dadlani, 2017; Varhelyi, 2016). This absence limits the ability to develop targeted countermeasures and to set road safety investment priorities for high-risk mountainous sections. This study produces the first star rating and risk map dedicated to motorcyclist safety along the Jalan Simpang Pulai to Blue Valley corridor, offering a powerful visualisation tool for identifying hazardous sections and prioritising road safety interventions.

2.6.5 Limited Use of Predictive Modelling for Crash Risk in Mountainous Areas

While several studies have adopted modelling techniques, most fail to incorporate local terrain characteristics, rider-specific behaviour variables, and real crash history (Hamednia et al., 2018; Shrestha, 2018b). As a result, predictive accuracy is low when applied to mountainous terrains. There is a methodological gap in developing a statistically validated model, such as Multiple Linear Regression (MLR), using real-world infrastructure attributes and crash outcomes specific to Cameron Highlands. The findings support decision-makers, including MIROS, JKR, and local authorities, in planning low-cost, high-impact interventions. The proposed model helps prioritise improvements based on measurable risk scores, greatly enhancing the practical value of the research. This research addresses major limitations in existing studies by proposing a motorcyclist-specific, localised, and comprehensive risk assessment model for mountainous road networks in Cameron Highlands. The novelty lies in its integrated methodological design, calibration of global iRAP principles to local topography, and its development of an actionable tool that aligns with Malaysia's road safety needs.

Table 2.1
Research Gap Analysis

No	Title	Author, Year	Issue	Result	Method	Gap
1	Crash Modification Functions for Rural Skewed Intersections	Ingle & Gates, (2023)	Evaluated the safety influence of intersection skew angle on rural two-lane, two-way facilities by calibrating crash modification factors.	Among four-leg intersections, a skew angle between 17° and 27° experienced 40% more crashes, whereas intersections with a skew angle greater than 45° did not have significantly different crash occurrence than perpendicular intersections.	Crash modification functions at three-leg and four-leg stop-controlled intersections.	The study evaluates skew angles at rural intersections but does not assess how skew-induced visibility issues interact with complex mountainous geometry. It also excludes motorcycle-dominant traffic typical of hilly regions. Thus, its findings are not directly transferable to mountainous road safety assessment.
2	Operating Speed Prediction of Vehicles at Combined Curves Using Mixed Effect Modeling Approach	Joseph et al., (2023)	Explores the relationship between radius, gradient, sight distance parameters, extra widening, and operating speeds at two-lane two-way non-urban roads in India.	Correlation analysis was done to find the significant geometric variable affecting the operating speed of vehicles.	Operating speed Models using correlation analysis.	The speed models exclude weather, elevation, and compound curvature effects found in mountainous terrain. The study also does not cover motorcycle behaviour. Therefore, its applicability to high-gradient mountain roads is limited.
3	Landslide Detection and Susceptibility Modeling on Cameron Highlands (Malaysia): A Comparison between Random Forest, Logistic Regression and Logistic Model Tree Algorithms	Nhu et al., (2020)	By using remote sensing techniques and machine learning to detect and map landslides, and landslide susceptibility in the Cameron Highlands, Malaysia	AUC was 92%, 90%, and 88% for the LMT, LR, and RF algorithms, respectively	Landslide Detection and Susceptibility Modeling	The study maps landslide susceptibility but does not evaluate the implications for traffic safety or crash exposure. Road geometry and driver behaviour are not incorporated. Hence, it cannot inform roadway risk modelling for mountain corridors.

No	Title	Author, Year	Issue	Result	Method	Gap
4	Modeling Traffic Noise in a Mountainous City using Artificial Neural Networks and Gradient Correction	Chen et al., (2020)	ANN-based noise prediction model achieved considerable accuracy improvement over the empirical predictive equations.	Modified HJ 2.4-2009 model incorporating the gradient correction coefficient achieved a significantly higher R^2 for mountainous cities than the original model.	Artificial Neural Network (ANN) model	The ANN model focuses on noise prediction accuracy but overlooks safety implications of terrain-related noise distraction. Road geometry and crash outcomes are not considered. Thus, its relevance to mountainous road safety is minimal.
5	Study on spatial tropism distribution of rural settlements in the Loess Hilly and Gully Region based on natural factors and traffic accessibility	Chen et., (2019)	Traffic accessibility to the townships had a greater impact on the spatial distribution of rural settlements than the traffic accessibility to the county	Density of rural settlements is significantly spatially different in Baota District	Logistic Regression Model, Kernel Density Estimation (KDE) and Minimum Cumulative Resistance (MCR)	The study analyses settlement distribution but ignores how terrain, road geometry, and access paths influence safety risk. No crash-related variables are included. Therefore, it offers limited insight for transportation safety in hilly regions.
6	Rural Road Network Decision Model for Hilly Regions of Nepal	Shrestha, (2018b)	Transportation cost is one of the major costs for public and private sectors in rural areas of developing countries (in order to deliver goods and services)	Careful decision about which links should be improved or constructed to achieve the minimum transportation cost is needed	Decision Support Model	The model minimises transportation cost but does not incorporate road safety factors such as slope hazards, curvature, or surface condition. Crash risk is not analysed. This limits its suitability for safety-focused planning in mountainous areas.

No	Title	Author, Year	Issue	Result	Method	Gap
7	Predictive velocity control in a hilly terrain over a long look ahead horizon	Hamednia et al., (2018)	Computationally efficient velocity control of vehicles driving in a possibly hilly terrain and over long look-ahead horizons that may stretch to hundreds of kilometres	Efficiency of the proposed controller is shown for different horizon lengths	Powertrain Modelling	The model focuses on powertrain optimisation but does not assess safety issues such as speed variability on sharp curves or steep gradients. Driver behaviour and pavement risk factors are excluded. Thus, it lacks value for crash risk modelling.
8	Rural Road Construction in Hilly Regions of Nepal	Shrestha, (2018a)	Review of geological and engineering aspects of rural road construction in hilly regions of Nepal	The width of cut is a key geometrical design parameter that has significant impact to slope vulnerability and volume of excavation	Mountain model for slope stability	The paper emphasises slope vulnerability and cut-width design but does not examine how these factors affect crash likelihood. It excludes traffic characteristics and user behaviour. As a result, safety risk implications remain unclear.
9	Probability of Road Interruption due to Landslides under Different Rainfall-Return Periods Using Remote Sensing Techniques	Yang, (2016)	The landslide prediction model can be used in predicting road interruption due to rainfall-induced landslides.	Proposed landslide prediction model, the probability of road interruption due to rainfall-induced landslides was evaluated under different rainfall-return periods	Validation of the Landslide Prediction Model	The model predicts road interruptions but does not evaluate safety impacts on drivers or crash risk during landslide events. It also ignores geometric and speed-related factors. Hence, it does not provide a complete safety assessment framework.

No	Title	Author, Year	Issue	Result	Method	Gap
10	Transport energy consumption in mountainous roads. A comparative case study for internal combustion engines and electric vehicles in Andorra	Travesset-Baro et al., (2015)	Traffic accessibility to the townships had a greater impact on the spatial distribution of rural settlements than the traffic accessibility to the county.	Road grade has a major impact on fuel economy, although it affects consumption in different levels depending on the technology analysed	Energy consumption model	The study compares fuel consumption but does not address how steep gradients and curvature affect driving safety. Crash-related variables are not analysed. Thus, the findings do not contribute to safety assessment on mountainous roads.
11	A multi-objective analysis of a rural road network problem in the hilly regions of Nepal	Jagat et al., (2014)	Choice of roads to upgrade in the hilly regions of Nepal	The problem was solved for a real-world rural road network in the Gorkha district of Nepal	Multi-objective optimization model	The optimisation model selects links for upgrading but excludes safety criteria such as crash hotspots or hazardous geometry. Environmental and behavioural risks are not integrated. Therefore, safety considerations are absent.
12	Integrating biodiversity conservation into land consolidation in hilly areas – A case study in southwest China	Zhang et al., (2012)	Integrating biodiversity conservation into traditional land consolidation projects and integration biodiversity conservation measures into land consolidation engineering from the overall planning.	Land leveling engineering, farmland water conservancy engineering, roads and landscape construction engineering respectively	Geographic Information System (GIS) and Land surface temperature (LST)	The paper focuses on land consolidation and ecology but does not analyse the consequences for road safety or slope stability near roadways. Transportation hazards are not considered. Thus, it has limited relevance to roadway risk.

No	Title	Author, Year	Issue	Result	Method	Gap
13	Study of regional monsoonal effects on landslide hazard zonation in Cameron Highlands, Malaysia	Matori et al., (2012)	Effect of monsoonal-related geospatial data in landslide hazard modeling in Cameron Highlands, Malaysia	Landslide factors chosen from topography map were slope, slope aspect, curvature, elevation, land use, proximity to road, and river/lake; while from geology map were lithology and proximity to lineament.	Geographic Information System (GIS) and Land surface temperature (LST)	The study maps landslide risks but does not evaluate their impact on road crashes or traffic safety. Road geometric features are not included. Hence, it does not support integrated road safety analysis.
14	Covering-Based Rural Road Network Methodology for Hilly Regions of Developing Countries: Application in Nepal	Jagat e al., (2017)	Geographic information system (GIS), takes into account the regions' main characteristics (i.e., trails slope and availability).	Determination of obligatory points for the road network, which provides basic accessibility to settlements within a specified maximum walking time.	Geographic Information System (GIS)	The methodology improves accessibility but does not incorporate geometric safety factors such as sharp curves or gradients. Crash data are absent. As a result, safety implications for mountainous roads remain unassessed.
15	Capacity estimation on two lane hilly roads under heterogeneous traffic condition in India	Jain et al., (2020)	Four different study sections with varying magnitude of gradient (2% to 7%) are selected between Saputara and Waghai town, area in the State of Gujarat, India	Capacity values developed are realistic and consistent with the values given in Highway Capacity manual (HCM) of developing countries like Indonesia and China	Secondary Data of traffic data analysis	The study determines capacity under gradients but does not examine safety outcomes like speed-risk relationships or overtaking hazards. Crash involvement is not modelled. Therefore, safety insights are limited.

No	Title	Author, Year	Issue	Result	Method	Gap
16	A Comparative Analysis of Heterogeneity in Road Accident Data Using Data Mining Techniques	Kumar et al., (2017)	The heterogeneity of road accident data is a big challenge in road safety analysis.	Road accident data analysis is a very important means to identify various factors associated with road accidents and can help in reducing the accident rate.	Secondary data using road accident data mining techniques.	While analysing data heterogeneity, the study does not model geometric or environmental predictors specific to mountainous terrain. It also lacks terrain-segregated crash patterns. Hence, its findings cannot inform mountain road safety.
17	Geotechnical and Geometric Considerations in Highway Design and Construction in Hilly Terrain	Diyaljee, (2008)	Primary geotechnical and geometric issues considered in the upgrading of a 12 km section of Hwy 40:34 situated in hilly terrain.	Steep grades, erosion, substandard curves, sharp shoulders, rock slopes, soft ground, wetlands, and the proximity of natural lakes to the highway were some of the features addressed	Case Study	The study describes engineering issues but does not quantify associated crash risks. Behavioural and traffic flow variables are not analysed. Thus, safety consequences of design limitations remain undefined.
18	Defining Rural Road Networks in Hilly Areas of Nepal	Shrestha & Kumar (2018)	Suitable road network in the hilly regions of Nepal utilizing maximal covering location problem (MCLP) to identify nodal (obligatory) points.	Linking the nodal points by the road links which cover the settlements and public facilities forms a basic road network.	Case Study	The model identifies nodes and connections but ignores geometric safety characteristics such as curvature severity or slope hazards. It also lacks crash data integration. Therefore, safety-rich network optimisation remains unaddressed.

No	Title	Author, Year	Issue	Result	Method	Gap
19	Low Cost Mountain Road Maintenance	Singh et al., (2014)	Social satisfaction, by either finding a solution to road maintenance or replacing the raw material involved in construction purposes.	Low cost road maintenance is that maintenance has always been considered as a third-grade project.	Case Study	The study proposes maintenance solutions but does not link maintenance deficiencies to crash risk or operational safety. It also omits geometric and environmental risk evaluation. Thus, safety implications are not explored.
20	Environmental Laws and Their Compliance in Road Projects	Sinha & Neeraj, (2020)	Identify the inactions that result in noncompliance with environmental laws and the reasons behind them	Reduction of time for granting EC from around 600 to 700 days to an average of 140 days	Semi-structured interviews	The study focuses on legal compliance but does not address how poor environmental practices contribute to road safety hazards in mountainous regions. Crash implications are not assessed. Hence, it does not inform safety risk management.
21	Downslope Gusty Wind Loading of Vehicles on Bridges	Kozmar et al., (2015)	Difficulties associated with vehicle maneuvering and stability in the upwind traffic lane in terms of unsteady aerodynamic loading	The higher risk for vehicles exists at lower vertical wind incidence angles up to 30° and closer to the upwind edge of the bridge deck with respect to steady aerodynamic loads.	Laboratory Experiment	The study analyses wind effects on vehicles but does not integrate road geometry, visibility issues, or driver behaviour on mountain bridges. Crash risk modelling is absent. Therefore, its safety applicability is limited.
22	Prevention Measures on Blind Curve of Hilly Area	Chauhan et al., (2020)	Keeping an ultrasonic sensor in one side of the road before the curve and keeping a LED light after the curve.	Top 10 dangerous roads in the world, we can see that all of them are mountain roads and curve roads.	Laboratory Experiment	The system addresses visibility but does not evaluate performance under steep gradients, wet surfaces, or adverse mountain weather. It also lacks behavioural compliance analysis. Thus, real-world safety impact remains uncertain.

No	Title	Author, Year	Issue	Result	Method	Gap
23	Road Traffic Management System for Hilly Terrain Areas	Manikandan et al., (2019)	Percentage of accident in hilly areas is increasing rapidly because of falling trees and other obstacles in the road.	Technologies that are available in the market like sensors GSM are used and the design is implemented for the road traffic management in hilly terrain areas using IOT.	Laboratory Experiment	The prototype system detects obstacles but does not consider geometric risk factors or incorporate crash data. User acceptance and behavioural responses are not studied. Therefore, safety benefits are unverified.
24	Analysis of active school transportation in hilly urban environments: A case study of Dresden	Müller et al., (2020)	The way students travel to school and examines the influence of environmental conditions on travel patterns.	Models perform better when they account for the topographic conditions of the urban environment.	Literature Review	The study examines mode choice but does not evaluate roadway safety risk for vulnerable users on steep gradients or curved streets. Crash risk aspects are omitted. Hence, its implications for safety planning are limited.
25	Road Construction, Maintenance Challenges and their Solutions in Kashmir	Rashid et al., (2017)	The carving of roads and their maintenance through the continuous mountainous ranges has become a challenge for the engineers and constructors.	The materials and some of the improved methods	Literature Review	The study identifies engineering challenges but does not analyse how these deficiencies translate into crash risks. Road user behaviour and geometric safety variables are not included. Thus, it lacks a safety perspective.
26	Review on Road Safety in Hilly Area using WSN and IoT	Jane & Jirapure, (2019)	Designing a system with some innovative idea like minimizing accident, landslide, bridge break, sharp turn mainly in hilly area and showing direction to driver.	The circuit will be designed in such manner that driver will be informed about the natural calamities before arrival of the spot.	Literature Review	The concept proposes safety alerts but does not validate effectiveness in real mountain traffic conditions. Geometric design and crash severity factors are not integrated. Therefore, practical safety impacts remain unknown.

No	Title	Author, Year	Issue	Result	Method	Gap
27	Road Construction in Hilly Region and Their Problem and Solution	Scholar et al., (2019)	Road construction mode in the hilly region as well as their problem and solution with reference to the segment of NH-13 from Sagalee to Midpu (Doimukh).	Condition of the road in hills region is in dilapidate condition throughout the year after the completion of road construction.	Literature Review	The review highlights construction issues but does not assess how these influence road safety or crash probability. Traffic and behavioural risks are not addressed. Thus, safety modelling remains outside its scope.
28	Critical Problems and Their Solution for Hilly Road Pavement with Particular Reference to NH-52(A) – A New Avenue	Bayan, (2013)	To emphasis problems that encounter in a national highway NH-52(A) within hilly terrains of Himalayan subsoil origin since its inception.	A new innovative Research and Development activity carried out recently, which generates a system comprising road foundation concept to solve the problems.	Literature Review	The study discusses pavement failures but does not evaluate how defects affect skid risk, vehicle stability, or crash likelihood. Interactions with gradient and curvature are missing. Therefore, safety outcomes are not quantified.
29	Slope Failure and Highway Management in Hilly Areas	Jangpangi et al., (2019)	Slope failures in the form of variety of mass wasting processes including landslides on/along the highways are usual phenomena.	Management strategy of the highway and its slopes beyond construction.	Literature Review	The paper reviews slope failures but does not link them to crash risk or operational safety impacts. Traffic exposure and driver reactions are not examined. Thus, safety implications of slope events remain unassessed.
30	Factors that comprise driver boredom and their relationships to preferred driving speed and demographic variables	Heslop et al., (2010)	Explores the factor structure underlying driver boredom and investigates age and gender differences in the experience of driver boredom, and preferred driving speeds using a self-report questionnaire.	In terms of cognitive capacity required for driving, self-reporting of cognitive failure and error-proneness and the implications for drivers maintaining safety margins when bored.	Questionnaire Survey	The study explores boredom factors but does not consider how monotony interacts with hazardous mountain features such as sharp curves and steep descents. Terrain-specific safety risks are absent. Therefore, its applicability to mountainous road safety is limited.

2.7 Chapter Summary

This chapter critically reviewed the literature on road safety in mountainous environments and established the conceptual foundation for this study, with a specific focus on motorcyclist safety. The review synthesised prior research covering the (i) characteristics of mountainous road environments, with Cameron Highlands as the study context; (ii) the development and application of the International Road Assessment Programme (iRAP) and MyRAP; (iii) the major contributing factors to road crashes in mountainous regions; (iv) the structure of the iRAP Star Rating model; and (v) existing modelling approaches used to assess roadway safety risk.

The literature consistently identifies road engineering and geometric design as dominant contributors to crash occurrence in mountainous settings, particularly for motorcyclists. Sharp horizontal curvature, steep gradients, limited sight distance, deteriorated pavement condition, inadequate skid resistance, and friction loss under wet conditions disproportionately affect motorcyclists, given their reduced stability and limited physical protection. While other iRAP domains, such as traffic exposure, roadside hazards, intersections, visual aids, and facilities for vulnerable road users, are recognised as important, their influence is often reported as secondary or highly site-specific compared with geometric and surface-related deficiencies.

A key gap identified in the literature is that most studies have applied the iRAP Star Rating model primarily as a descriptive or screening-based assessment tool, with limited statistical validation of relationships between individual iRAP domains and observed crash risk, particularly in mountainous and motorcyclist-dominated contexts. Few studies have recalibrated iRAP-based models to account for local terrain characteristics, mixed traffic conditions, and the high motorcycle exposure typical of Malaysian highland corridors. In response, this research proposes a modified, motorcyclist-focused framework that integrates iRAP with Multiple Linear Regression (MLR) to validate and refine key explanatory domains. The next chapter details the research methodology, including RADIS data acquisition, domain classification, MLR variable screening, and final model development.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides a roadmap of the research methodology and the rationale behind selecting the suitable method to accomplish the aims and objectives set for this research, the strengths and weaknesses of the method used, and the research limitations using selected methods in every stage of conducting the overall research. Clarification and justification are also proposed and discussed in this chapter to overcome research limitations in this research. A methodological research framework is provided in this chapter to give a brief idea of the research methodology workflow process involved in this research.

The previous iRAP and MyRAP models, which used a similar approach, were carried out on four (4) major expressways across the main states, from the Northern to Southern regions and the West Coast and East Coast of Peninsular Malaysia. This research considers the road network of the mountainous areas of Jalan Simpang Pulai to Blue Valley, Cameron Highlands, as a study location. A series of research phases at the said location is crucial to better understanding the mountainous region's road safety management systems and scenarios. The initial stage involves the qualitative method using a Systematic Literature Review (SLR). The next stage incorporates the primary and secondary data using quantitative methods to develop road crash data profiles and establish detailed road condition reports for the main road that captured the highest fatal crash frequency in Cameron Highlands using Tableau software. After that, the researcher used the iRAP methodology to establish a detailed condition report that captured the highest fatal crash frequency in Cameron Highlands. Finally, the researcher uses quantitative and analytical methods, using the Multiple Linear Regression model, to clearly show how the modified model for motorcyclists was developed in this research. Several phases are required to develop and evaluate the modified model. Thus, a detailed explanation of this research methodological framework, comprising four (4) main stages, is presented in this chapter. The following section will describe the phases mentioned within the methodological research framework.

3.2 Research Framework

A research framework is essential in helping researchers, as it provides structure and coherence, guiding the researcher and reader through the whole process of a study (Fellow & Liu, 2008; Noor, 2012). This section defines the theoretical foundation, research concepts, and the relationships among research variables, ensuring alignment among research objectives, methodology, analysis, and findings. A solid research framework demonstrates academic rigor and enhances the overall research's credibility by grounding it in existing literature (Qu & Dumay, 2011). The research scope and limitations, aiding in the interpretation of findings, can also be clarified in a research framework (Svinicki, 2010; Williams, 2007). Without a clear framework, a thesis risks becoming unfocused and difficult to assess for its relevance and contribution to the field study.

This research aims to propose a modified road safety risk assessment model for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands, using the iRAP@Highlands model. To accomplish the research aim, it is crucial to understand the contributing factors to road crashes in mountainous road networks, as a groundwork analysis based on previous research. The researcher illustrated the research framework for this study in Figure 3.1. Based on Figure 3.1, Stage 1 of the study was selected to identify the thematic structure and key factors contributing to road crashes in mountainous road networks through a Systematic Literature Review (SLR). In the next phase, stage 2 of the study focused on developing a road crash data profile of the Cameron Highlands mountainous road network using Tableau software. Meanwhile, stage 3 of the study synthesized the qualitative data from the SLR findings in stage 1 and the quantitative data insights from road crash data profiling in stage 2 to establish detailed road condition reports for the main road with the highest fatal crash frequency in Cameron Highlands. Finally, stage 4 of the study assembles a set of quantitative data comprising star ratings and risk maps (before and after road safety intervention countermeasures) generated by the iRAP model to propose a modified road safety risk assessment model for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands. This research focuses only on motorcyclists' road-safety intervention countermeasures, based on road crash data profiles for the location, which reveal that motorcyclists are the most frequently involved vehicle type in fatal crashes in Cameron Highlands *(Refer to Figure 4.1)*.

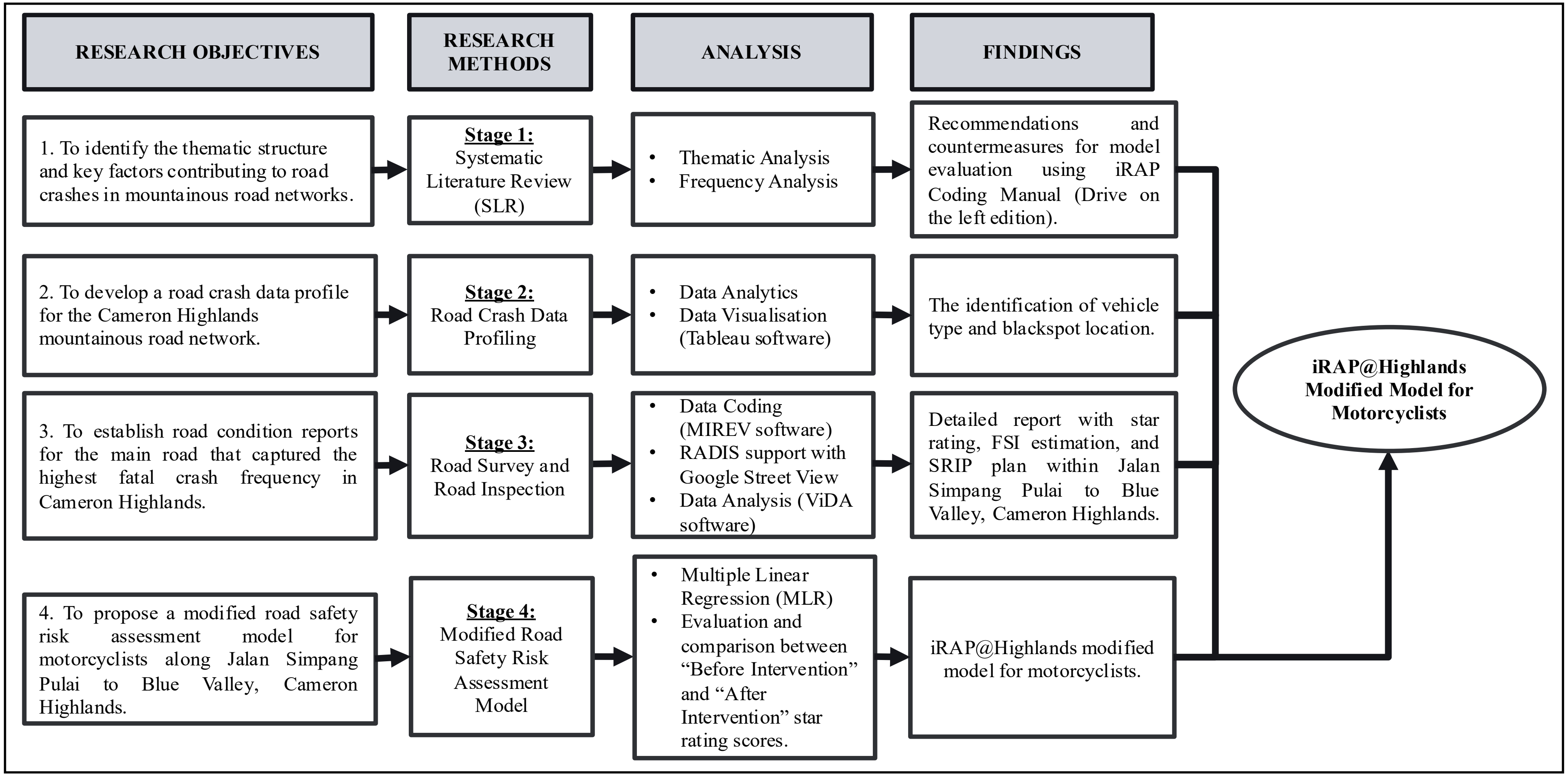

Figure 3.1 Research Framework

The research development is organised into four systematic stages, as shown in Figure 3.1. Each stage is aligned with one research objective, each targeting specific goals to ensure a focused, data-driven approach and meaningful insight findings. The researcher chose the best and most applicable research method to suit each research objective, describing the methodological approach employed in this research. The framework integrates established methodologies such as thematic analysis, road crash profiling, and star rating evaluations, culminating in the development of a practical, evidence-based road safety intervention model using a Multiple Linear Regression (MLR) model. The first stage involves conducting a Systematic Literature Review (SLR) to identify the thematic structure and key factors contributing to motorcycle crashes in mountainous areas. This phase adopts thematic and frequency analysis to synthesize existing research, focusing on road crash causation variables such as road engineering, geometric design, environment, vehicle, and driver behaviour factors. This stage is crucial in gathering information from past research to fill in the research gap due to the high frequency of fatal road crash incidents in the complexity of mountainous roadways, where factors such as sharp curves, steep gradients, and weather conditions significantly amplify risks. The output includes recommendations and countermeasures derived from the iRAP Coding Manual: Drive on the Left Edition (iRAP, 2013), which forms the theoretical basis for the next phase of this study. By synthesizing knowledge, this stage ensures that road safety interventions are grounded in evidence and align with Haddon's Matrix principles.

In the second phase, the researcher developed a road crash data profiling dashboard to understand the crash landscape in Cameron Highlands. This stage involves advanced data analytics and visualisation techniques using Tableau software as a tool to create interactive data profile insights. Road crash data profiling enables the identification of critical blackspots along all four main roadways to reach the Cameron Highlands road network, revealing the spatial map distribution pattern of all vehicle types. This stage justifies the need for focus and localised road safety interventions by integrating crash data with road design attributes, helping to pinpoint specific areas where risk factors are concentrated. Such profiling ensures that resources for road safety interventions are strategically allocated, providing a quantitative basis for targeting high-risk road segments. The insights from this phase also guide the detailed report of star rating analysis conducted in Phase 3.

The third stage evaluates existing road infrastructure conditions using road surveys and road inspection methods. By utilising tools like MIREV software, RADIS, and Google street view applications, this stage is crucial to ensure precise and detailed road condition reports, including the star rating, Fatality and Serious Injury (FSI) estimations, and SRIP plan. This phase uses the web-based ViDA software to evaluate road conditions data coding obtained from the road survey observed. By determining the star rating score for specific road segments, the findings provide a granular understanding of how infrastructure elements contribute to crash risks. This approach allows the researcher to quantify infrastructure deficiencies and prioritise appropriate road safety interventions according to the star rating score. For instance, low-star-rated road segments highlight the urgent need for road safety enhancements like clearing roadside hazards, improving delineation, or sealing paved shoulders. This stage aligns with iRAP's methodology of translating road infrastructure assessments into actionable road safety improvements.

The final stage involves the development of a modified road safety risk assessment model focusing on motorcyclist users by integrating Multiple Linear Regression (MLR) model and comparative evaluations of "before intervention" and "after intervention" star rating scores at required high-risk road segments. At this point, the researcher is focusing on the potential road segment that can increase the star rating score at the safest level (i.e, from black zone (1 star) to red zone (2 star) or orange zone (3 star) to yellow zone (4 star)). This stage validates the effectiveness of proposed countermeasures using the iRAP methodology by simulating their impact on road safety outcomes by monitoring the star rating output. The modified model emphasizes the quick win road safety countermeasures on motorcyclist-specific considerations, including motorcycle-friendly barriers, eliminating roadside hazards, anti-skid surfaces, and enhanced visibility measures in foggy conditions. The evaluation process ensures that the model is both practical and adaptable to the unique challenges of mountainous roadways. This stage is critical for advancing the theoretical framework into a functional risk assessment tool, addressing gaps in conventional models that often overlook motorcyclist-specific risks. By incorporating accurate and localised data, this stage ensures that the modified model delivers tailored solutions for improving motorcycle safety at mountainous road networks.

The research methods outlined in Figure 3.1 provide a systematic and evidence-based roadmap to achieve the research objectives. Each phase builds on the preceding one, ensuring a holistic approach to understanding and mitigating road crashes in mountainous roadways. The integration of advanced data analytics, road safety theories, and innovative modeling tools, such as the iRAP methodology, highlights this research's academic rigor and practical relevance. Focusing on motorcycle riders and high-risk road segments like Jalan Simpang Pulai to Blue Valley, Cameron Highlands, this research addresses an urgent need for targeted road safety interventions, contributing to Malaysia's broader road safety goals and aligning with the United Nations' Decade of Action for Road Safety. This framework advances road safety research methodologies and provides a replicable model for addressing similar challenges in other high-risk, mountainous regions. Through the modified iRAP@Highlands model, this study paves the alternative way for transformative changes in motorcycle road safety, ensuring that interventions are effective, scalable, and sustainable. Details of the following stages are elaborated in the next section in this chapter, and the research findings are presented in chapters 4 and 5.

3.3 Research Nature

This research proposes a modified road safety risk assessment model for motorcyclists on a mountainous road network, specifically from Jalan Simpang Pulai to Blue Valley, Cameron Highlands. The prestigious International Road Federation (IRF) global award for the life-saving road safety project confirms that only the Shaanxi Mountain Road Safety Demonstration Project has so far been conducted road safety risk assessment using ChinaRAP, which represents the mountainous areas road network for Asian countries (Rebecca et al., 2024). However, other studies used other methods in assessing road safety for mountainous road networks, such as operating speed model, crash modification model, Artificial Neural Network (ANN) model, logistics regression model, decision support model, slope stability model, powertrain model, landslide prediction model, energy consumption model, and multi-objective optimisation model (Chen et al., 2020; Chen & Pai, 2019; Ingle & Gates, 2023; Joseph et al., 2023; Nhu et al., 2020; Shrestha et al., 2014; Shrestha, 2018; Shrestha et al., 2017; Travesset-Baro et al., 2015; Yang, 2016; Zhang et al., 2020). A similar model for mountainous areas' road networks in Peninsular Malaysia is the main purpose for why the researcher conducted this research. By utilising the iRAP methodology, the researcher can generate a road safety risk assessment model for all transport modes: car occupants, motorcyclists, bicyclists, and pedestrians. However, this research has time constraints to proceed with the data coding and data analysis stage for all transport modes and only focuses on the high-frequency type of vehicle involved in fatal accidents.

Thus, this research can be classified as applied research due to its potential to solve road safety issues for motorcyclist users riding in the mountainous road network environment in Peninsular Malaysia. It seeks to address specific real-world challenges by applying existing knowledge to develop practical solutions for society, academicians, researchers, government, industry, and environmental sustainability. This research also involved working closely with researchers and iRAP experts in MIROS to consolidate data, data interpretation, data analysis, data validation, and identify problems and relevant road safety recommendations and countermeasures related to the scope of study.

3.4 Research Design

Research design refers to selecting suitable empirical research methods to integrate with the research questions and data collection (Creswell & Creswell, 2018; Fellows & Liu, 2015). Combining qualitative and quantitative methods with multiple data sources, namely secondary and primary data, in an investigation to produce research outcomes is defined as a triangulation research approach (Creswell & Creswell, 2018). The triangulation method was popular among researchers for testing the validity of results to ensure the data collection is rich, robust, comprehensive, and well-developed (Golfshani, 2003). By implementing triangulation, one research method will be compensated by another research method, giving a richer research output and deeper understanding instead of using a single research method alone (Sekaran & Bougie, 2016; Williams, 2007).

This research design reflects a rigorous and multidimensional approach to road safety for motorcyclists in mountainous regions, specifically targeting the unique and challenging route along Jalan Simpang Pulai to Blue Valley, Cameron Highlands. By introducing the International Road Assessment Programme (iRAP) as the primary modeling tool, the study aims to create a modified road safety risk assessment model, namely the iRAP@Highlands model. Table 3.1 summarises the research objectives, methods, and contribution to the overall research:

Table 3.1
The Objectives, Methods, and Contributions to the Overall Research

No	Objectives	Research Methods	Contribution to the overall research
1	To identify the thematic structure and key factors contributing to road crashes in mountainous road networks.	• Systematic Literature Review (SLR) • Modified Road Safety Risk Assessment Model	Provide groundwork and benchmark for possible road safety recommendations and countermeasures for the modified iRAP@Highlands model development.
2	To develop a road crash data profile for the Cameron Highlands mountainous road network.	• Systematic Literature Review (SLR) • Road Crash Data Profiling	The type of vehicle involved in a fatal crash and identification of the impacted main road are the focus of the road safety intervention required in the Cameron Highlands mountainous road network.
3	To establish road condition reports for the main road that captured the highest fatal crash frequency in Cameron Highlands.	• Road Crash Data Profiling • Road Survey and Road Inspection	Uncovers detailed condition report with star rating, FSI estimation, and SRIP plan within Jalan Simpang Pulai to Blue Valley, Cameron Highlands, Malaysia.
4	To propose a modified road safety risk assessment model for motorcyclists along Jalan Simpang Pulai to Blue Valley, Cameron Highlands.	• Systematic Literature Review (SLR) • Road Crash Data Profiling • Road Survey and Road Inspection • Modified Road Safety Risk Assessment Model	Provide possible road safety countermeasure recommendations focusing on motorcyclists at the targeted location using the iRAP@Highlands model.

This research adopted both exploratory and explanatory research designs to investigate and explain road safety risks in mountainous environments. Exploratory research was applied to identify key contributing factors to road crashes in mountainous areas, which remain underexplored in road safety and transport research. Explanatory research was then employed to examine how these factors can be quantitatively modelled and integrated into a predictive framework to improve road safety outcomes on high-risk mountainous road networks.

This research employed a triangulated research approach that combined a Systematic Literature Review (SLR), road crash data profiling, the iRAP Star Rating research model, and Multiple Linear Regression (MLR) analysis. This triangulation enhanced the robustness and validity of the findings by cross-verifying results across qualitative and quantitative methods. Integrating theoretical insights with empirical data provided a comprehensive understanding of mountainous road safety risks and ensured that the proposed model is grounded in both evidence and established frameworks.

The SLR formed the qualitative foundation of the research by systematically identifying key variables, conceptual structures, and research gaps related to mountainous road safety. Using a structured and transparent review process, the SLR synthesised prior studies on road geometry, environmental exposure, traffic conditions, and driver behaviour. The resulting thematic structure enabled the identification of critical risk factors relevant to complex mountainous contexts such as Cameron Highlands, where road and weather conditions vary significantly over time.

Building on the qualitative findings, the research progressed to quantitative analysis, profiling descriptive and frequency-based road crash data using Tableau. Historical crash data were analysed to identify spatial and temporal patterns, crash severity, vehicle types, collision characteristics, environmental conditions, and blackspot locations. This profiling was essential for understanding crash dynamics in mountainous terrain, where steep gradients, sharp curves, and unpredictable weather contribute to higher crash frequency and severity.

Subsequently, the iRAP Star Rating research model was applied to translate roadway and traffic characteristics into standardised safety performance scores. Factors such as traffic flow, speed limits, mid-block features, roadside conditions, intersections, and vulnerable road user facilities were quantified to identify high-risk road sections. Given the dominance of motorcyclists along the Jalan Simpang Pulai–Blue Valley corridor, the analysis placed particular emphasis on motorcyclist star ratings to support targeted safety interventions.

The final stage involved developing a modified motorcyclist-focused road safety risk assessment model using Multiple Linear Regression (MLR). This predictive modelling approach integrated insights from the SLR, crash data profiling, and iRAP star ratings to quantify the relationship between key road safety factors and crash risk. The resulting model provides a practical, data-driven tool to support decision-making by road authorities and policymakers, enabling prioritisation of cost-effective safety interventions. The overall methodological integration and analysis process is summarised in the research methodology flowchart presented in Figure 3.2.

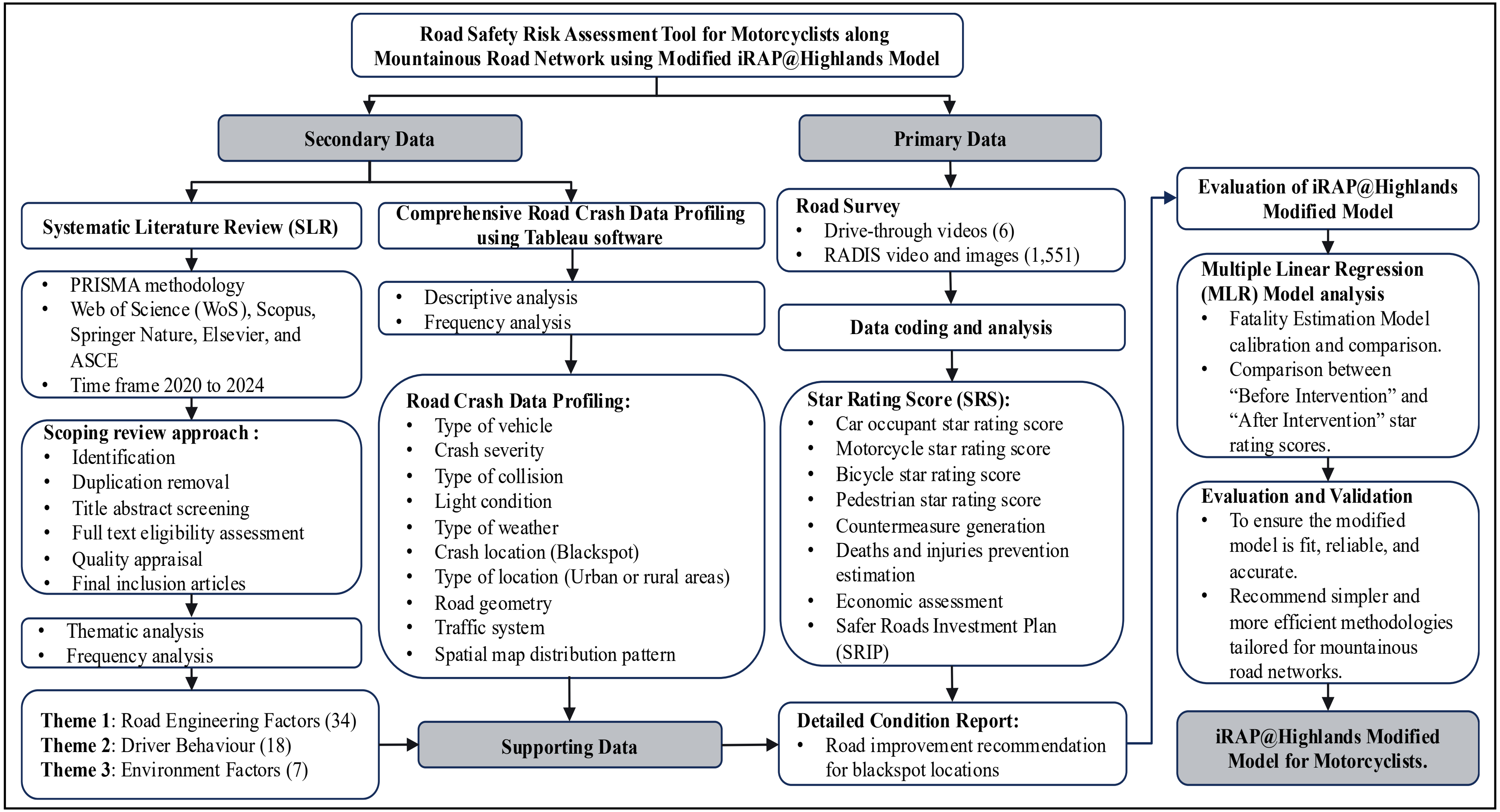

Figure 3.2 Research Methodology

3.5 Stage 1: Systematic Literature Review (SLR)

This research stage refers to the Systematic Literature Review (SLR) procedures used to identify the thematic structure and key factors contributing to road crashes in mountainous areas of road networks. The systematic literature review (SLR) in this study was conducted using a structured and predefined procedure to ensure rigour, transparency, and reproducibility. A clear search strategy, screening process, and set of inclusion and exclusion criteria were applied to identify all relevant studies and minimise selection bias. The procedure also included a consistent approach for data extraction and appraisal to ensure that only relevant and reliable evidence informed the review. This structured method enables the synthesis of findings in a way that highlights key themes and research gaps, forming a solid foundation for the present research.

This study utilised SLR to explore the factors contributing to road crashes in mountainous road networks and identify thematic structures and key factors influencing crash risks. The updated PRISMA 2020 guidelines informed the approach, which emphasizes transparent reporting and methodological robustness in reviewing documents (Shaffril et al., 2021). The objectives of this section are (i) to discuss insight knowledge associated with factors contributing to road crashes along mountainous road networks, and (ii) to identify the thematic structure and key factors contributing to road crashes along mountainous regions by exploring proactive road engineering strategies, concepts, and approaches shaping the road safety discourse. The findings from this section identified suitable roadway design countermeasures and offered theoretical support for roadway design, especially within mountainous environments.

Figure 3.3 illustrates the flow diagram for the article screening procedures using the scoping review approach as follows:

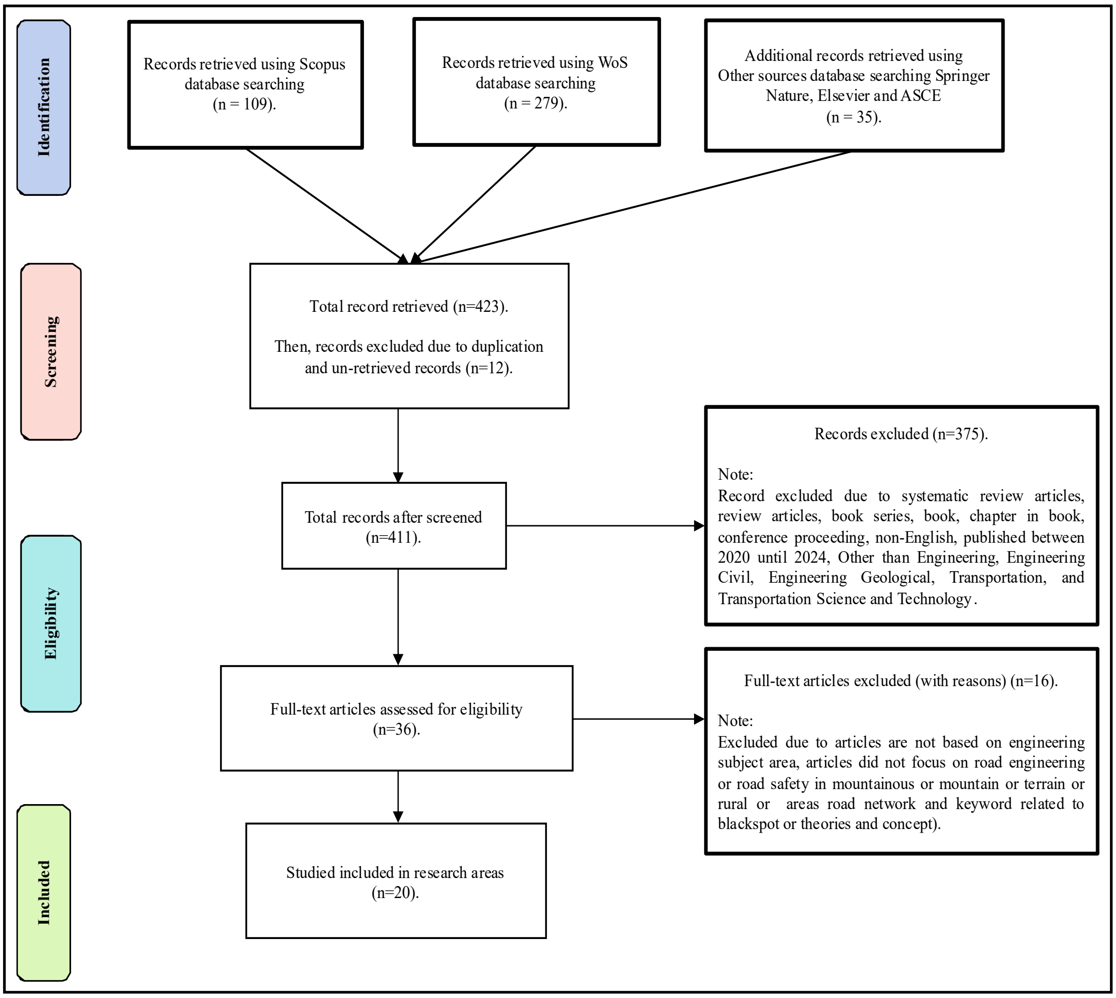

Figure 3.3 Flow Diagram for Article Screening Procedures Using the Scoping Review Approach

3.5.1 Define Research Question for SLR

A well-defined research question guides the systematic review process, ensuring relevance and focus on the specific objectives of the study (Shaffril et al., 2019; Shaffril et al., 2021). A clearly articulated research question is a strong foundation for the SLR process. This section aimed to answer the following research question: What are the primary factors contributing to road crashes in mountainous regions, and how can proactive engineering strategies mitigate these risks? The researcher framed this question to address the unique challenges of mountainous terrains, including their geomorphological and environmental characteristics affecting road safety for users.

3.5.2 Specify Objectives for SLR

The objectives of the SLR were to: (i) identify thematic structures and engineering strategies shaping the road safety discourse and (ii) understand the factors contributing to road crashes in mountainous road networks. This research also aimed to provide evidence-based recommendations for improving roadway design and theoretical guidance for safer infrastructure planning in mountainous regions. These objectives ensured the review was not only descriptive but also analytical and solution-oriented (Shaffril et al., 2019; Shaffril et al., 2021).

3.5.3 Conduct a Comprehensive Literature Review Search for SLR

The literature search was systematic and exhaustive, encompassing databases such as Scopus, Web of Science, and Google Scholar, supplemented by manual searches in high-impact journals and technical reports. Search strategies incorporated Boolean operators, phrase searching, truncation, and wildcard functions to enhance comprehensiveness. Predefined inclusion and exclusion criteria focused on high-quality studies addressing road crashes, mountainous terrains, and engineering countermeasures. This methodological rigor ensured a broad yet relevant selection of studies (Shaffril et al., 2019; Shaffril et al., 2021).

This research adopted a systematic literature review (SLR) approach using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (Page et al., 2021). PRISMA aims to enhance transparency and rigor in identifying the most significant themes and factors contributing to road crashes along mountainous road networks, particularly within the domains of road engineering, driver behaviour, and weather conditions (Shaffril et al., 2019; Safarpour et al., 2020).

The process began with a comprehensive search across electronic databases including Web of Science (WoS), Scopus, Springer Nature, Elsevier and ASCE, restricted to a five-year timeframe 2020 to 2024. This period was deliberately selected in line with SLR best practices, which recommend defining the search window based on the pace of methodological and technological developments within a research field (Kitchenham & Charters, 2007). Given the rapid advancements since 2020 in road safety engineering, geospatial modelling, remote sensing, machine-learning applications, and iRAP-based risk assessment, limiting the search to the most recent five years ensures that only contemporary, policy-relevant, and methodologically robust studies are included, consistent with PRISMA guidance on the timeliness of evidence (Page et al., 2021). The database search strings were carefully constructed to capture key concepts related to road safety in mountainous areas. Table 3.2 presents the record of the database search string with the keyword chosen during the SLR process.

Table 3.2
The Database Research String

Type of database	Database search string
Web of Science (WoS)	Topic. (("road engineering" OR "highway engineering" OR "geometric design" OR "infrastructure design") AND ("road safety" OR "traffic safety" OR "accident prevention" OR "crash reduc-tion") AND ("mountainous" OR "terrain" OR "mountain" OR "hilly" OR "slope" OR "roadway" OR "highway")) AND (("driver behavior" OR "driver characteristics" OR "human factors" OR "driver error" OR "distracted driving" OR "fa-tigued driving" OR "risky driving") OR ("crash blackspot" OR "accident blackspot" OR "high-risk location"))
Scopus	Article title, abstract, keyword. (("road engineering" OR "highway engineering" OR "geometric design" OR "infrastructure design") AND ("road safety" OR "traffic safety" OR "accident prevention" OR "crash reduc-tion") AND ("mountainous" OR "terrain" OR "mountain" OR "hilly" OR "slope" OR "roadway" OR "highway")) AND (("driver behavior" OR "driver characteristics" OR "human factors" OR "driver error" OR "distracted driving" OR "fa-tigued driving" OR "risky driving") OR ("crash blackspot" OR "accident blackspot" OR "high-risk location"))

3.5.4 Screen the Literature Review for SLR

The screening process followed a multi-stage approach, starting with title and abstract reviews to eliminate irrelevant studies. The researcher then conducted full-text evaluations to ensure the best alignment with the inclusion criteria. The PRISMA 2020 flow diagram was employed to document the screening process, promoting transparency and replicability. The researcher resolved conflicts in study selection through the scoping review approach, ensuring the final article dataset was robust and relevant (Bobermin et al., 2021; Page et al., 2021; Shaffril et al., 2021).

Following the initial database search process, the identified articles were systematically screened using predefined inclusion and exclusion criteria. The selected research articles underwent a detailed data extraction process, during which relevant information, including document type, language, publication year, and country of study, was systematically extracted. The researcher also screened information from the research articles, such as research objectives, type of methodologies, key findings, results, and implications, to determine whether it was suitable to form a thematic synthesis analysis from the information.

The researcher conducted a quality assessment for each of the selected research articles to ensure the reliability and validity of the gathered information. The findings were then extracted systematically, providing a comprehensive overview of existing knowledge on the topic, focusing on road safety in mountainous areas. Employing the methodological rigor ensures a rigorous and transparent approach, contributing to the credibility and reliability of the research findings and themes that can be identified for a research topic (Beaulieu-Thibodeau et al., 2023; Shaffril et al., 2019). Table 3.3 records the inclusion and exclusion criteria procedure for this research.

Table 3.3
The Inclusion and Exclusion Criteria

Criteria	Eligibility	Exclusion
Document Type	Journal, Article, and Review Article	Book Series
Language	English	Non-English
Publication Years	2020 to 2024	< 2020
Countries	Countries with mountainous areas road network	Countries with non-mountainous areas road network
Subject Area	Engineering, Engineering Civil, Engineering Geological, Transportation, and Transportation Science and Technology.	Other than Engineering, Engineering Civil, Engineering Geological, Transportation, and Transportation Science and Technology.

The data analysis was employed using thematic synthesis analysis and frequency analysis. At this stage, the data analysis involved a systematic review of extracting information and keywords from 423 articles from the first level of the identification stage in SLR (Please refer to Figure 3.3). The next stage involved the screening process, where 12 articles were excluded due to duplication and unretrieved records from the database chosen. Then, the process continued with the eligibility stage, where 375 articles were excluded due to the type of articles, language provided, and other concerns, such as the area of research. Finally, the last part of the included stage indicated 20 articles retained as the selected articles obtained from the SLR filtering process using the scoping review approach. A total of 20 peer-reviewed articles were retained through the SLR filtering process using the scoping review approach, based on their direct relevance to the research objectives and methodological rigor. This number is considered sufficient, as scoping reviews prioritize thematic saturation and conceptual relevance over quantity, aligning with established review guidelines (Arksey & O'Malley, 2007; Levac et al., 2010). These proper guidelines are essential to maintain transparency in research, academic integrity, and ensure that all information considered for the subject matter is robust and credible (Beaulieu-Thibodeau et al., 2023; Safarpour et al., 2020).

3.5.5 Extract and Synthesize the Data for SLR

Data extraction involved systematic documentation of key information, including study objectives, methodologies, findings, and proposed countermeasures (Shaffril et al., 2021). The research findings should reflect the identified themes, patterns, contradictions, and gaps in the existing knowledge on the research topic. Thematic synthesis analysis was used to identify recurring patterns and themes, such as the influence of road geometry, weather conditions, and vehicle types on crash risks. This process enabled the integration of diverse findings into a coherent framework, highlighting critical factors influencing road safety in mountainous areas (Shaffril et al., 2019; Shaffril et al., 2021). The researcher detailed results and findings for thematic synthesis and frequency analysis from the SLR in Chapter 4, Section 4.2.

3.5.6 Analyse and Interpret the Results for SLR

The analysis stage involved synthesising the findings from all studies that met the inclusion criteria, with a focus on identifying the prevalence, patterns, and interrelationships of risk factors associated with road crashes in mountainous environments. The reviewed literature consistently highlighted three dominant thematic domains road engineering, driver behaviour, and weather-related influences as the primary contributors to crash occurrence and severity.

As part of the synthesis, attention was given to the proactive engineering countermeasures reported in the reviewed studies. Several authors evaluated interventions such as realigning hazardous curves, installing guardrails and roadside barriers, stabilising slopes, improving drainage systems, and providing advanced warning devices. These studies examined the extent to which such treatments reduced crash frequency, improved vehicle stability, or mitigated exposure to hazardous terrain. In this research, these findings were critically reviewed and compared to determine the effectiveness of engineering-based strategies within the context of mountainous road networks; however, the researcher did not conduct a direct engineering evaluation.

The synthesis also revealed persistent gaps in existing research, particularly in integrating geometric design parameters, human behavioural factors, and environmental conditions within a single analytical framework. Many studies examined these elements in isolation, which limits the ability to develop holistic, terrain-specific safety models for mountainous roads. These limitations reinforce the need for a comprehensive, data-driven approach that accounts for the combined influence of engineering geometry, driver characteristics, and weather conditions (Martinelli et al., 2023; Varhelyi, 2016). The researcher detailed the result analysis and interpretation from the SLR in Chapter 4, Section 4.2.

3.5.7 Draw a Conclusion and Make Recommendations for SLR

The researcher synthesized the findings to conclude the primary factors contributing to road crashes and the most effective road safety risk mitigation engineering strategies for a mountainous road network. The researcher recommended integrating evidence-based countermeasures into roadway design, including enhanced road alignment regarding curvature and curve quality, and repaved road surface to improve road condition. These conclusions provide actionable insights for policymakers and engineers while offering a theoretical framework for future research (Shaffril et al., 2021). Detailed conclusions and recommendations for the SLR findings are in Chapter 4, Section 4.2.

3.5.8 Report and Disseminate the Review Findings for SLR

The results were reported in compliance with PRISMA 2020 standards and procedures, ensuring comprehensive and transparent documentation (Shaffril et al., 2021; Page et al., 2021). The SLR findings were disseminated through a conference presentation, including the presentation titled 'A Systematic Literature Review of Factors Contributing to Road Crashes in Mountainous Areas Road Network Through

Comprehensive Road Engineering Strategies' at the 5th MITRANS International Logistics and Transport Conference (MILTC), 2023. This ensured that the outcomes were shared with relevant academic and professional audiences. This multi-channel dissemination strategy fosters collaboration and promotes the adoption of best practices in road safety, especially in challenging terrains like mountainous regions. This research contributes to a deeper understanding of crash factors and engineering proactive solutions by adhering to the SLR methodology, offering a robust foundation for safer road infrastructure and road networks in mountainous areas. The researcher detailed results and findings for thematic synthesis and frequency analysis from the SLR in Chapter 4, Section 4.2.

3.6 Stage 2: Road Crash Data Profiling

This research stage involves applying data profiling techniques to develop a detailed crash data profile of the Cameron Highlands mountainous road network. In this context, data profiling refers to systematically examining, cleaning, and summarising crash datasets to extract meaningful insights concerning crash characteristics, frequencies, spatial-temporal distributions, and contributing risk factors. The aim is to transform raw, unstructured road crash data into analytically useful information to support more profound understanding and informed decision-making in road safety risk assessment.

Studies have revealed multiple factors contributing to frequent road crashes in mountainous roadway areas. Jain et al. (2020) and Shrestha and Kumar (2018) highlighted how increasing transport demand and unsafe vehicle operation during unpredictable weather conditions significantly influence crash occurrence. Similarly, Jawi et al. (2009), emphasized that mountainous road networks are particularly susceptible to environmental and operational risks due to steep gradients, limited visibility, and unstable terrain. Zhang et al. (2020) also highlighted the logistical difficulties and high costs associated with upgrading and maintaining road infrastructure in mountainous environments. While past studies by Shaadan et al. (2021) and Sunkpho and Wipulanusat, (2020), have examined qualitative factors, predictive modeling, and socio-economic impacts of road crashes, limited research has conducted data-driven investigations focusing specifically on mountainous regions using secondary crash data. A study by Rusli et al. (2017) comparing crash characteristics in mountainous and non-mountainous roads in Sabah, Malaysia, found that horizontal curves, single-vehicle crashes, and weekend incidents were significantly more common in mountainous settings. These findings reinforce the need for user-friendly and efficient analytical tools to process large datasets and uncover trends, root causes, and behavioural or environmental patterns linked to crash occurrences. Therefore, this research incorporates data analytics and visualisation tools to profile road crash data in the Cameron Highlands and to facilitate comparative analyses between rural zones, as well as mountainous and non-mountainous areas. Analytical techniques, such as statistical classification, trend analysis, and spatial visualisation (e.g., using SPSS, Excel, and GIS tools), are used to structure and interpret the crash data, laying the groundwork for later stages, including star rating evaluation and risk mapping, under the modified model.

Past studies have typically discussed qualitative factors, forecasting models, predictive models, causes, impacts, and social influences of road crashes. However, limited studies have examined specific road crashes in specific areas and crash characteristics. Therefore, user-friendly and efficient analysis techniques are crucial for comprehending big data and deriving meaningful insights into data structure, trends, causes, impact, and patterns (Sunkpho & Wipulanusat, 2020). Thus, this research uses data analytics and visualisation techniques to explore road crash data in Cameron Highlands compared to non-mountainous areas to increase knowledge and understanding about road crash scenarios and patterns, particularly in rural areas.

3.6.1 Source of Secondary Data for Road Crash Data Profiling

Cameron Highlands, located in the district of Pahang, Malaysia, has been selected as the study area for this research. Occupying a land area of 712.18 square kilometres, the region is a prominent highland destination bordering Kelantan to the north and Perak to the west. Cameron Highlands is one of the tourist cities in the north of Pahang, and its boundaries touch Kelantan. To the West, Cameron Highlands shares a part of its border with Perak in Peninsular Malaysia. The mountainous terrain, tourism activity, and limited infrastructure upgrades make it a critical area for road safety analysis. This research utilises four years of road crash data (2015 to 2018) obtained from two authoritative sources: the Royal Malaysian Police (RMP) and the Malaysian Institute of Road Safety Research (MIROS). The researcher accessed the data via the

M-ROADS (Malaysian Road Accident Database System) platform, which archives detailed records of road crashes nationwide with the support and help of the Data Intelligence and Traffic Exposure Unit (DTE), MIROS. The selected data focus on four key roads within Cameron Highlands, strategically chosen for their crash prevalence and varying geographic features:

(i) Jalan Gua Musang – Lojing (rural and urban areas)
(ii) Jalan Keramat Pulai (rural areas)
(iii) Jalan Ringlet – Kampung Raja – Blue Valley (rural and urban areas)
(iv) Jalan Tapah (rural areas)

The researcher identified these segments based on topographical complexity, traffic volume, and historical crash trends, making them suitable for data profiling and comparative analysis.

3.6.2 The Framework for Road Crash Data Profiling and Data Analytics Procedures

This study adopts the data analytics framework proposed by Shaadan et al. (2021) to ensure methodological rigor and alignment with past research practices. The researcher illustrated the overall data analytics process, as shown in Figure 3.4, outlining the stages from raw data extraction to the generation of insights that informed the later phases of risk assessment and model development.

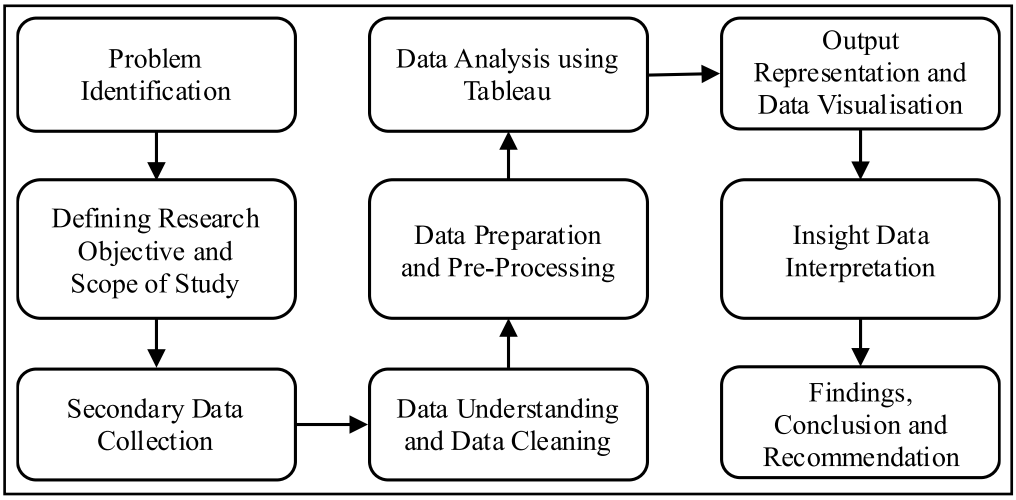

Figure 3.4 The Framework for Road Crash Data Profiling and Data Analytics Procedures Adopted from Shaadan et al., (2021)

This framework facilitates a structured flow of analysis that includes data acquisition, preprocessing (data cleaning and classification), profiling (descriptive statistics and trend exploration), and visualization (mapping crash hotspots and patterns). The analytical process supports the research objective of identifying high-risk segments and underlying crash factors within the Cameron Highlands region.

The researcher initiates the data analysis by identifying the problem, subsequently defines the research objectives, and proceeds to execute the defined scope of the research in the following stage. Next, the secondary data or raw road crash data gathered in this research was filtered and arranged according to research categories in Table 3.4 using Microsoft Excel.

Table 3.4
Variable Names and Level of Measurements for Raw Data

No	Variable Name	Description	Level of Measurement
1	Crash Severity	The four types of crashes are fatal injury, serious injury, slight injury, and property damage only.	Nominal (category)
2	Crash Location	Road Type: The road type is divided into five categories: expressway, federal road, state road, municipal road, and others. Route No.: Each of the gazette roads in Malaysia has its unique route number.	Nominal (category)
3	Type of Collision by Year	There are thirteen collision types: head-on, rear-end, right angle side, angular, sideswipe, forced, hitting the animal, hitting an object off-road, hitting an object on the road, hitting pedestrian, overturned, out-of-control, and others.	Nominal (category)
4	Type of Collision (Urban or Rural Areas)	There are four categories of location types: city, urban, built-up area, and rural area.	Nominal (category)
5	Traffic System by year	Four traffic systems categories are one-way, two-way, three-lane, and dual carriageways.	Nominal (category)
6	Road Geometry	There are seven categories of road geometry, including straight, bend, roundabout, cross-section, T or Y junction, staggered junction, and interchange.	Nominal (category)
7	Light Condition	There are four categories of lighting conditions: day, dawn or dusk, dark with street lighting, and dark without street lighting.	Nominal (category)
8	Type of Weather	Three categories of weather conditions are available: clear, foggy, and rain.	Nominal (category)

Note: Information variables filtered from secondary data may depend on the raw data available. Some data is missing and incomplete. Therefore, the researcher used Tableau software to analyse only consistent data for selected years.

The researcher compares the research categories and variable names to the standard POL27, a road traffic crash form utilized by the Royal Malaysia Police. Generally, POL27 form contains more than 63 variables of information, including a detailed road traffic crash report such as time of the crash, road information, environmental information, crash location, vehicle information, driver information, comments from the police officer in charge, the sketch of the crash incident with its location (Rusli et al., 2017). However, the variables of information filtered from the M-ROADS system may be subject to the records and raw data available in the system at that particular time.

The researcher employs frequency and descriptive analyses using a data analytics methodology that incorporates a data visualization tool, specifically Tableau software. In total, the researcher identifies eight (8) variables for the selected study locations in this research, namely:

(i) crash severity
(ii) crash location
(iii) type of collision by year
(iv) type of collision (urban or rural areas)
(v) traffic system by year
(vi) road geometry
(vii) light condition
(viii) type of weather

The researcher then transferred the data into Tableau software and arranged it into the desired sequence and suitable visuals and figures. Tableau software allows the researcher to explore data preparation and to pre-process using limitless visuals such as spatial distribution patterns, graphical visuals, tables, bar charts, interactive histograms, and summary statistics. Subsequently, the researcher conducts data understanding and data cleaning simultaneously using Tableau software to produce a quick and interactive data visualisation for research purposes. In addition, integrating Tableau into the analysis strengthens data visualisation and facilitates clearer interpretation, allowing readers to better understand the underlying patterns and insights. Finally, the researcher discussed the research findings for each data presented in the conclusion and recommendation section. The researcher detailed results, findings, and recommendations for road crash data profiling from the Tableau software in Chapter 4, Section 4.3. From the result, the main road of the research location captured the highest fatal crash frequency in Cameron Highlands, leading to the need to conduct a road survey and road safety inspection, as explained in the next stage 3.

3.7 Stage 3: Road Survey and Road Safety Inspection Using the iRAP Methodology along the Research Location

This stage focuses on the systematic collection of empirical (primary) data through a detailed road survey and safety inspection along the mountainous road network stretching from Jalan Simpang Pulai to Blue Valley, Cameron Highlands. The primary objective is to assess road infrastructure conditions, safety-related risks, and attributes critical to the iRAP star rating assessment and subsequent risk modelling. The following Figure 3.5 illustrates the iRAP methodology of conducting the road network assessment guided by the iRAP road safety risk assessment.

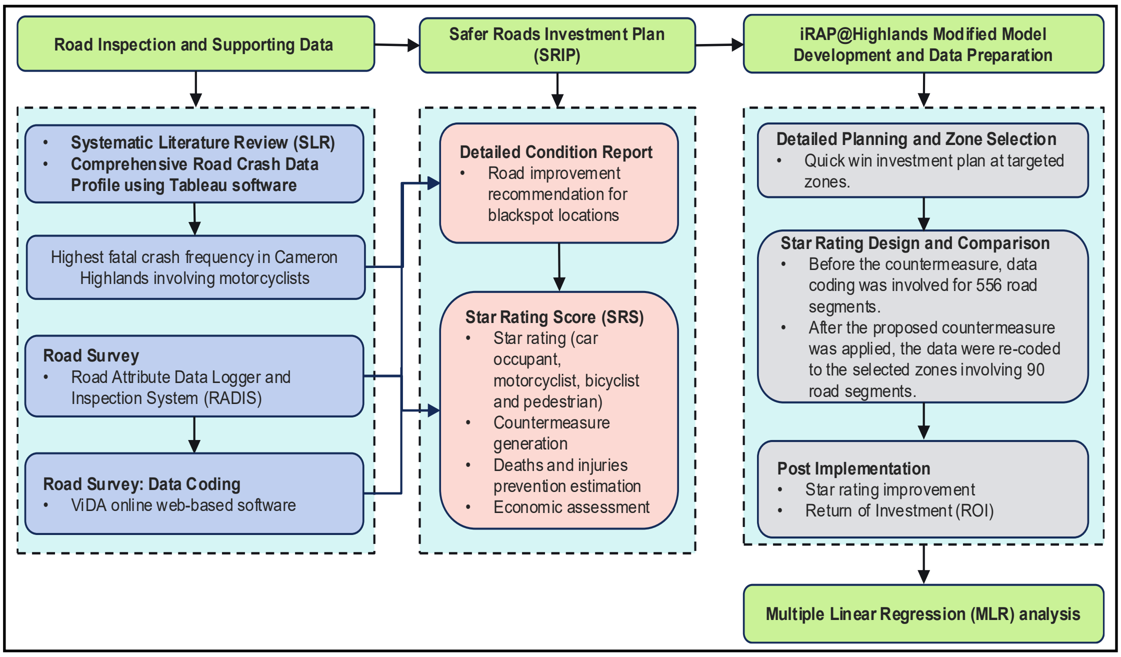

Figure 3.5 Protocols and Procedures Workflow of Data Collection and Modelling Process Using the iRAP Methodology

Guided by insights from the Systematic Literature Review (SLR) and a crash data profile developed using Tableau software, the research identifies motorcyclists as vulnerable road users who account for the region's highest fatal crashes. To address this, the researcher conducted a field-based road survey using a vehicle equipped with the Road Attribute Data Logger and Inspection System (RADIS), which captures high-resolution 360 degree camera, video footage and GPS-logged observations of road geometry, roadside hazards, traffic signage, intersections, and other key safety features in both travel directions. These observations are spatially referenced and systematically coded according to the iRAP Road Attribute Coding Manual (iRAP, 2019) using the ViDA online web-based software. These protocols and procedures ensured that the data collected were standardised and aligned with international benchmarks, thereby supporting objective infrastructure risk evaluation.

The coded road attribute data serve as the foundation for the development of the Safer Roads Investment Plan (SRIP). The researcher includes the generation of Star Rating Scores (SRS) for multiple road user groups, namely car occupants, motorcyclists, bicyclists, and pedestrians. The researcher produced a detailed condition report highlighting high-risk road segments and proposing cost-effective engineering countermeasures. These are supported by economic assessments and injury prevention estimations, allowing the prioritisation of interventions based on cost-benefit criteria. The researcher embedded all the analyses in the ViDA online web-based software and used the platform to generate the results. A before-and-after star rating comparison is then performed within the ViDA platform to assess the impact of the proposed countermeasures. The researcher conducts a post-implementation evaluation to measure Star Ratings and the Return on Investment (ROI) improvements.

Finally, the output of this process supports the preparation of the modified model, which integrates the observed data into a quantitative framework using Multiple Linear Regression (MLR) analysis. This model statistically examined the relationship between individual road safety attributes and the resulting star rating scores. The application of the iRAP methodology, including star ratings and SRIP, offers a structured, proactive, and evidence-based approach to identifying and mitigating road infrastructure risks. The researcher emphasizes the importance of this study in mountainous, high-risk road environments, such as those in Malaysia, where challenging terrain, adverse weather conditions, and sub-optimal road design often exacerbate crash severity.

3.7.1 Sampling Strategy for Road Survey and Inspection

The researcher designs the road survey and inspection sampling strategy to ensure a comprehensive and representative evaluation of infrastructure-related safety risks along the research location. Given the research objective to propose a modified iRAP-based road safety risk assessment model, the researcher's sampling approach was structured around the selected route's spatial and risk-based characteristics. The mountainous nature of this road network, coupled with its historically high incidence of fatal crashes (result of crash data profiling), particularly among motorcyclists, necessitates a focused and context-sensitive sampling framework (iRAP, 2019; Murozi et al., 2024; WHO, 2024).

Rather than relying on random or statistical sampling of discrete points, this research adopts a census-based and purposive sampling strategy, surveying the entire length of the selected highest fatal crash frequency route in both travel directions. This approach aligns with the iRAP methodology, which treats roads as a series of continuous segments typically in 100-meter intervals that serve as the unit of analysis for infrastructure attribute data coding and star rating assessment (iRAP, 2019). The researcher stratifies the selected route based on key roadway features (e.g., sharp curves, steep gradients, limited visibility zones) and crash-prone locations identified through earlier crash data profiling using Tableau software. This approach will enable targeted data collection on high-risk segments and be representative of typical road safety conditions in Malaysia's highland road networks. The researcher ensures that all relevant geometric, environmental, and roadside safety characteristics are adequately captured to support accurate and evidence-based road safety modelling (iRAP, 2014; MIROS, 2017).

3.7.2 Research Location

The researcher conducted this research in one of Malaysia's most significant highland tourism regions, the Cameron Highlands, located in Peninsular Malaysia. Specifically, the selected study route is a mountainous road network segment extending from Jalan Simpang Pulai to Blue Valley, encompassing a portion of the Federal Route F185. This route covers a total distance of approximately 55.6 kilometres, beginning at latitude and longitude 4°34'58.4"N, 101°24'28.5"E and ending near 4.530079607°N, 101.1313696°E. The corridor spans the border between the state of Perak and Pahang, serving as a vital arterial link between the lowlands and the Cameron Highlands plateau. Traveling this route typically takes about 1 hour and 36 minutes under normal traffic conditions.

The selected road segment presents a complex array of topographical, environmental, and operational challenges. It features numerous steep gradients, sharp curves, narrow shoulders, unprotected embankments, and sections with limited sight distance. These physical characteristics are often worsened by adverse weather conditions, including heavy rainfall and persistent fog, making the route particularly hazardous, especially for motorcyclists, the main road users who have been identified through crash profiling as the most vulnerable road user group in this area (Jawi et al., 2009; McInerney & Smith, 2009). Visual analytics performed using Tableau software, combined with crash data from the POL27 Malaysian police crash form, confirmed that this route contains multiple high-risk road segments, justifying it is selection for field-based road survey inspection and infrastructure risk modelling.

In alignment with the iRAP methodology protocols, this location offers an ideal case study for applying star rating assessments and developing a Safer Roads Investment Plan (SRIP) tailored to mountainous, high-risk, and ecologically sensitive regions. As a heavily trafficked tourism and agricultural route, the research location provides a representative and policy-relevant environment to support the development of the modified model. The study's location enables the empirical assessment of infrastructure-related risk using 100-meter road segments, as outlined in iRAP's global methodology (iRAP, 2021a; Murozi et al., 2024). While reinforcing the broader objective of improving road safety for all road users in low- and middle-income countries, the burden of road traffic deaths remains disproportionately high (WHO, 2024). Figure 3.6 shows the topography and elevation of the mountainous terrain view of Simpang Pulai to Cameron Highlands main roadway, and Figure 3.7 shows the map of Cameron Highlands showing main towns and villages in Peninsular Malaysia.

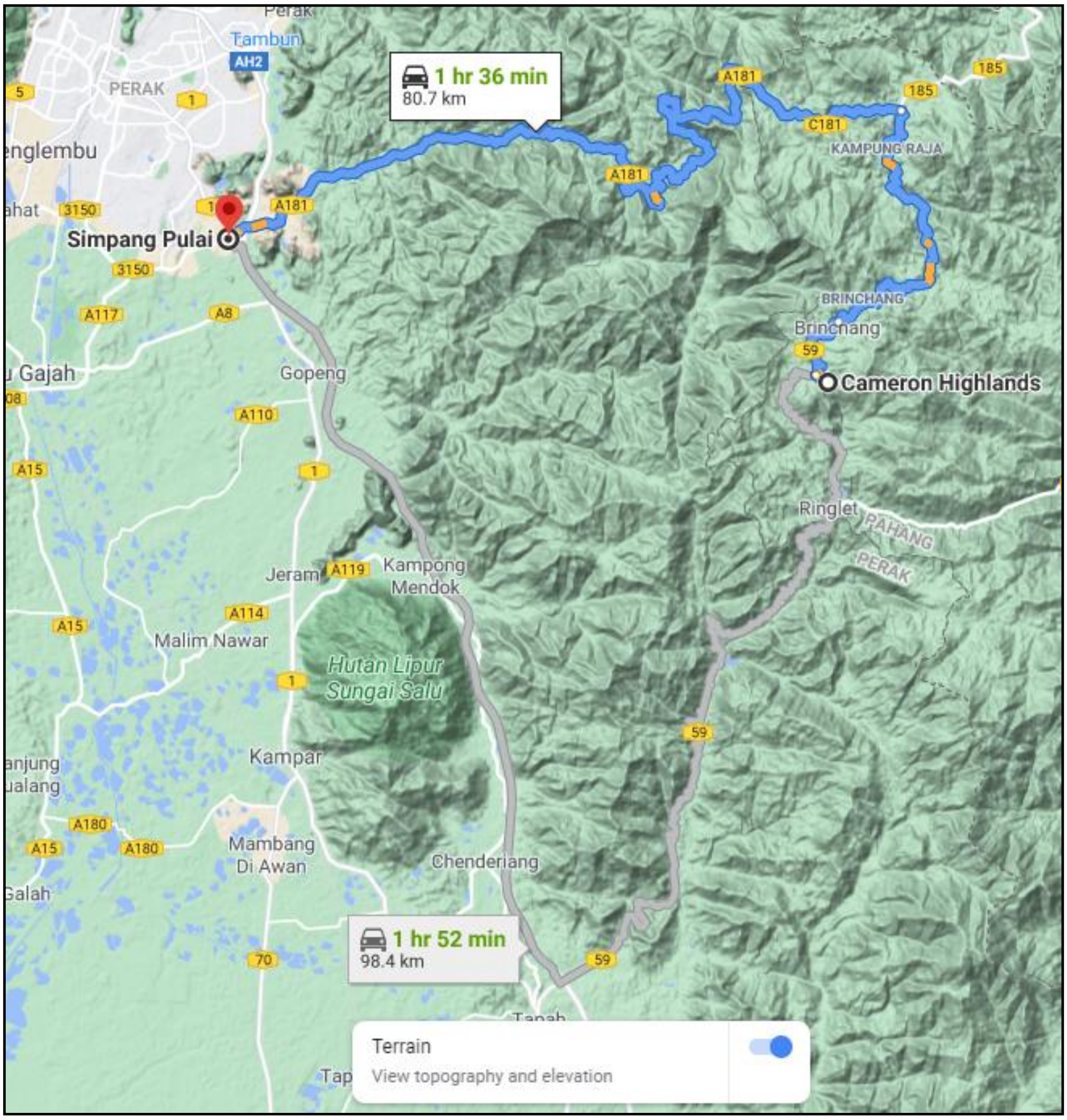

Figure 3.6 Topography and Elevation of the Mountainous Terrain View from Simpang Pulai to the Cameron Highlands Main Roadway

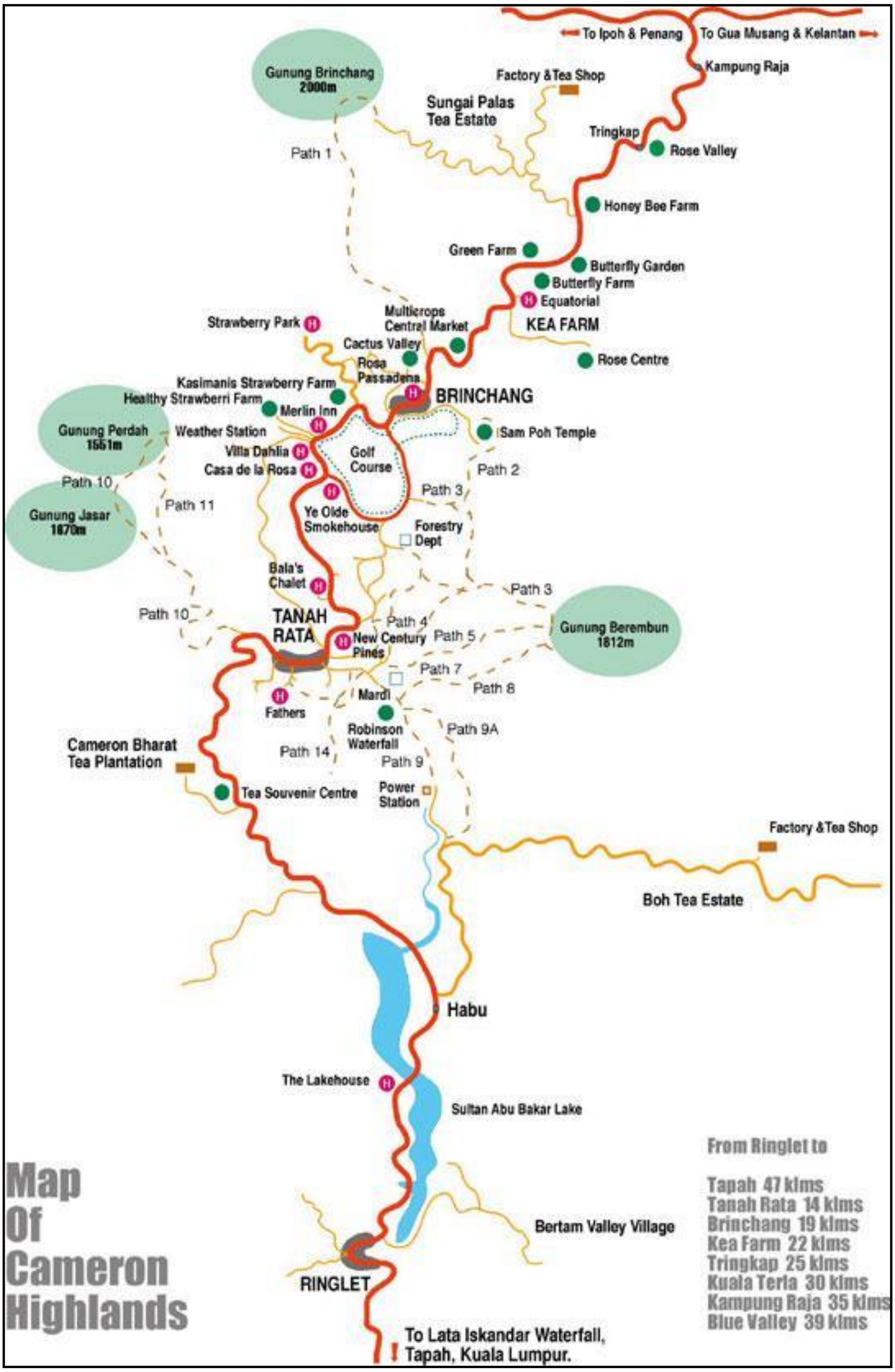

Figure 3.7 Map of Cameron Highlands Showing Main Towns and Villages in Peninsular Malaysia

3.7.3 Data Collection Method Using the iRAP Methodology: Protocol and Procedures

This research adopts the global International Road Assessment Programme (iRAP) methodology protocol and procedures to systematically collect, code, and analyse road infrastructure data along the high-risk mountainous road segment at the research location. The process is designed to support the development of a modified model that quantifies road safety risk through infrastructure-based assessment protocols. The data collection framework follows the structured phases outlined in Figure 3.4 in section 3.7, integrating road inspection techniques, star rating evaluation, investment planning, and risk modelling.

According to Figure 3.4, the study began with data collection through a road survey, followed by data coding and data input analysis via ViDA online web-based software. The road attribute data coding intends to record road attributes for each 100-meter road section using geo-referenced pictures gathered during the on-site road survey activities. This coded data is then integrated with other supporting data, such as Annual Average Daily Traffic (AADT) from the traffic volume study and operating speed from the spot speed study, and submitted in ViDA online web-based software to generate star ratings for each of the road networks and eventually stimulate the deployment of life-saving road safety countermeasures. In this research, the researcher retrieved the traffic volume study and vehicle spot speed study data from the repository advised by MIROS. Therefore, traffic volume and vehicle spot speed studies have not been conducted on-site for this research due to time constraints, and the updated data is available for the current year. The following process is in its implementation. The iRAP methodology recommends revisiting the on-site location every three (3) years to understand ROI investment applied to the selected road network and compare the star ratings between the years. However, in this case, the researcher should do no action because it is up to the government and local authorities' decision to implement the road safety countermeasure at the said location. This research continues with MLR modelling to validate risk factors and propose the best-fit model for iRAP@Highlands for future reference.

3.7.4 Road Survey

This research employs an inclusive road survey methodology grounded in the globally recognised protocols and procedures of the International Road Assessment Programme (iRAP) (iRAP, 2014; MIROS, 2017). The road survey serves as a critical step in evaluating the physical and safety-related characteristics of the selected road network of the research location. This road network is a mountainous federal route identified for its high crash risk, particularly involving motorcyclist road users.

3.7.4.1 Video and Images-Based Road Survey Method

With help from the experienced MIROS iRAP team, the researcher performed the road survey using a forward-facing, high-resolution 360-degree video camera mounted on a dedicated survey vehicle, as illustrated in Figure 3.8. This configuration enables the continuous and consistent capture of the roadway environment in both directions of travel directions, providing panoramic views that include forward, left, right, and rear angles. The video system captures imagery at 100 metres intervals, enabling data coders to examine road features more precisely and objectively. A specific tool known as RADIS is attached to the vehicle (shown in Figure 3.9) to facilitate the video and image capture process, allowing for calibrated measurement of key road design elements such as lane and shoulder widths, delineation, and proximity to fixed roadside hazards.

Figure 3.8 The Road Survey Vehicle

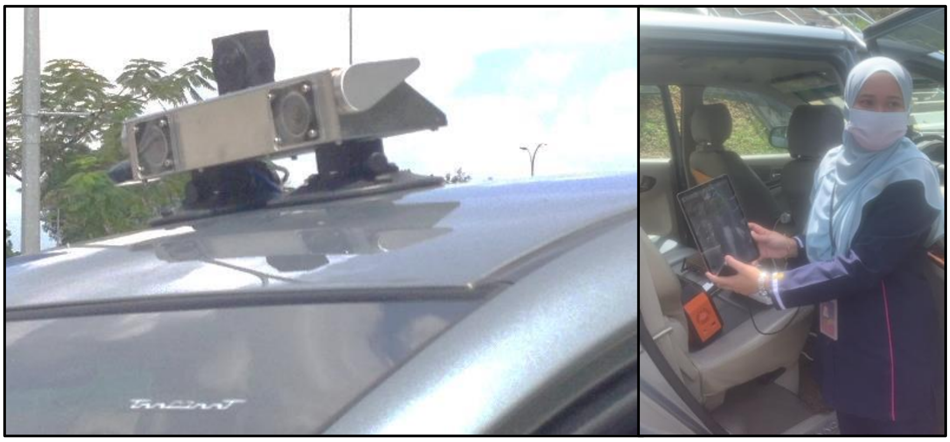

Figure 3.9 The RADIS Tool Attached to the Survey Vehicle

The iRAP methodology supports two primary modes of road inspection, namely drive-through and video and image-based road inspections. Video and image-based inspections are commonly employed in the Asia Pacific region, including Malaysia, for road safety assessments due to their efficiency and effectiveness in capturing comprehensive roadway data (MIROS, 2017). This method was conducted in two stages: first, a specially equipped survey vehicle traverses the road network to record video footage; second, trained analysts assess and code the footage using the iRAP Road Attribute Coding Manual (Drive on the Left Edition for Malaysia) (iRAP, 2019). Analysts perform desktop assessments at 100-meter intervals, virtually inspecting the road segment using ViDA web-based software, iRAP's web-based coding and analysis platform. This process ensures international consistency in infrastructure-based risk assessment (McInerney & Smith, 2009). The survey vehicle operates at average road speeds, minimising disruption to regular traffic and simulating typical driving conditions. This methodological approach enhanced operational efficiency and ensured that the collected data reflected realistic road-user perspectives and behaviours (Rogers & Hashim, 2011). However, researchers sometimes encounter problems such as lost internet connections and the telco provider's non-coverage of the internet signal during bad weather and high plateaus. The researcher verified and supplemented missing data through the Google Street View application. This situation is a normal technical issue since the research location are rural areas with limited internet connectivity.

3.7.4.2 GPS Logging and GIS Mapping

The survey vehicle has a Global Positioning System (GPS) data logging system that geotags each recorded segment with spatial coordinates to complement the video data. This geo-referencing capability enables seamless integration with Geographic Information System (GIS) platforms such as ArcGIS Pro, which supports advanced spatial analysis and thematic mapping. Through this process, the researcher maps critical road segments, overlays crash data, and identifies spatial correlations between road design features and crash occurrences. The following Table 3.5 shows the surveyed road network of the research location, and Figure 3.10 shows the surveyed route map of the research location from ViDA web-based software provided by iRAP.

Table 3.5
Surveyed Road Network of the Research Location

Road Network	**Road Name**	**Length (km)**	**Road Survey Date**	**Coding Dat**
Jalan Simpang Pulai to Blue Valley, Cameron Highlands	F185	55.6	10/8/2022	17/8/2022

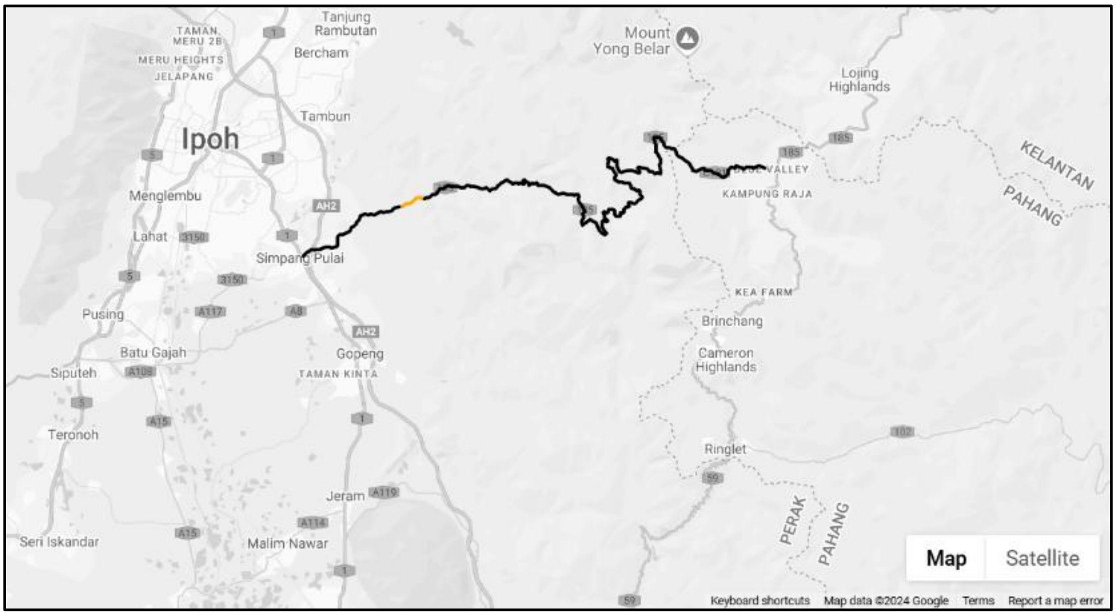

Figure 3.10 Surveyed Route Map of the Research Location from ViDA

3.7.4.3 Ensuring Data Accuracy through the Triangulation Technique during Road Survey

This research applies the triangulation technique to enhance the validity and reliability of the data collection process by combining multiple sources and technologies, namely video imagery, GPS logging, and GIS-based spatial analysis. This methodological triangulation ensures that each road attribute is consistently recorded, systematically stored, and available for long-term analysis, experimentation, and model development (Fellow & Liu, 2008). By rigorously adhering to iRAP's data coding procedures and integrating spatial tools, the researcher increases the chance that collected data are accurate, unbiased, and suitable for infrastructure risk modelling.

3.7.4.4 Data Integration into the iRAP ViDA Web-based Software

The researcher analysed all coded video, images, and spatial data attributes and uploaded them into the iRAP ViDA web-based software platform at this website link: https://vida.irap.org/en-gb/home. In this phase, the researcher generated the star rating scores and identified the corresponding blackspot locations. ViDA can also facilitate the estimation of fatal and serious injury risk for each 100-meter road segment and supports the development of cost-effective countermeasure plans through the SRIP module. The road survey results serve as the foundation for developing the modified model, enabling a data-driven evaluation of infrastructure-based risk along the surveyed mountainous road network.

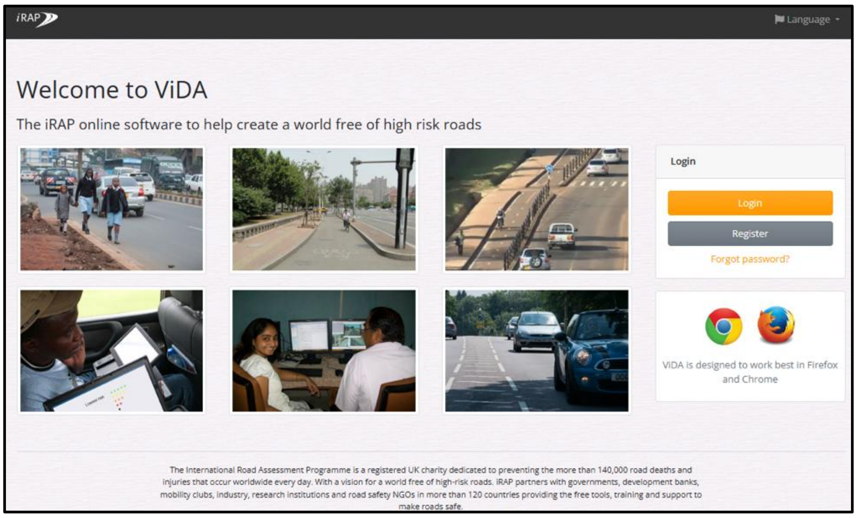

Figure 3.11 ViDA Web-Based Software Website

3.7.5 Data Coding

The data coding phase in this research serves as a foundational process for translating observed road infrastructure attributes into structured, analysable datasets and systematic documentation (iRAP, 2019). According to Table 3.5, the road survey date was on 10th August 2022 and the data coding started on 17th August 2022. This process is conducted in accordance with the globally recognised standards established by the iRAP, using the Road Attribute Coding Manual (Drive on the Left Edition for Malaysia) and transferred into the ViDA web-based platform, iRAP's cloud-based coding and analysis tool (iRAP, 2019). Data coding is a critical intermediary step in the broader iRAP methodology, directly informing the generation of Star Rating Scores (SRS) and the development of Safer Roads Investment Plans (SRIPs). Figure 3.12 illustrates the structured process of road inspection, attribute coding, star rating generation, countermeasure planning, and post-implementation evaluation as defined by the iRAP methodology as follows:

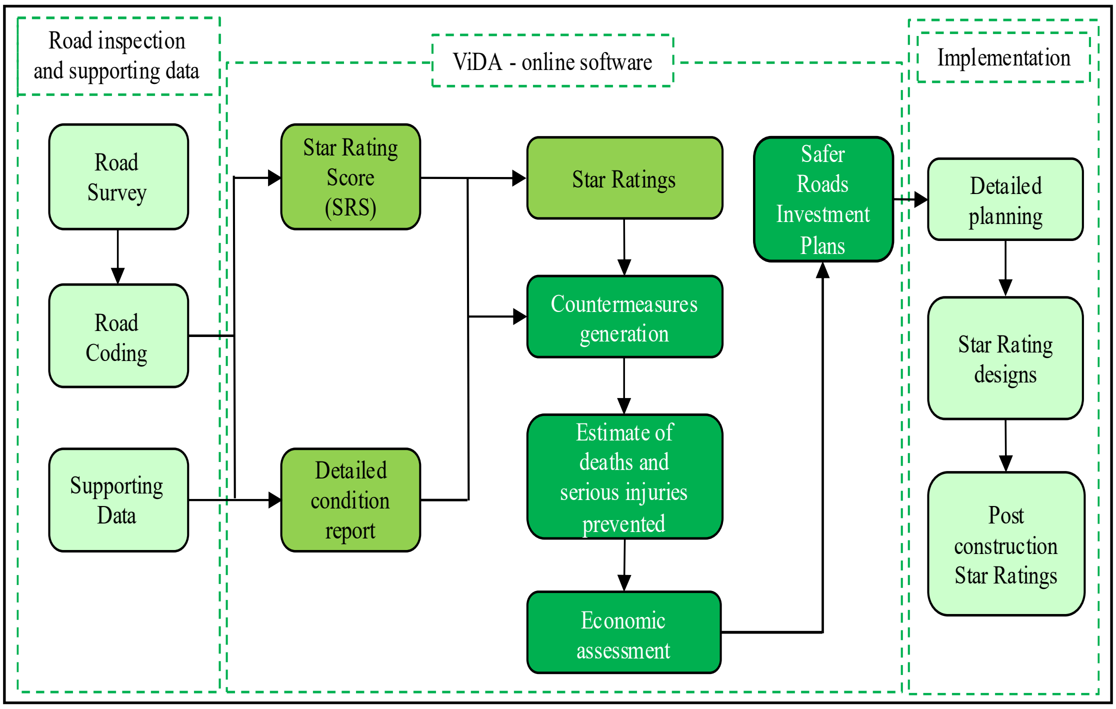

Figure 3.12 The Star Rating and Safer Roads Investment Plan Workflow Was Adopted from iRAP (2019)

3.7.5.1 Purpose and Importance of Data Coding

Data coding aims to convert raw observational data captured through video and image-based road surveys and GPS logging data into a suitable format that quantifies infrastructure-related road safety risks at the desired road network. By assessing 55.6 kilometers of road segments with more than 90 distinct road attributes, data coding provides a systematic basis for evaluating the road crash likelihood and severity for multiple road user groups, including car occupants, motorcyclists, bicyclists, and pedestrians. The researcher then used these coded data to assign star ratings, identify high-risk segments, and guide the selection of targeted road safety countermeasures, cost-effective countermeasures within the SRIP framework (iRAP, 2014; McInerney & Smith, 2009; Shokat & Jameel, 2023).

3.7.5.2 Segment-Based Road Attribute Coding

The MIROS Road Engineering Video (MiReV) system is a road survey and assessment software platform developed by the Malaysian Institute of Road Safety Research (MIROS) (MIROS, 2017). MiReV is a video-based road inspection system designed by MIROS to capture, tag, and assess road infrastructure conditions in Malaysia, supporting national road safety audits and research. The researcher coded the raw data by following the iRAP's standard practice and using the MiReV system before transferring the data into the ViDA platform. The researcher evaluated each segment for a comprehensive list of infrastructure attributes, including traffic management, traffic characteristics, alignment, pavement surface, area type, cross-section, intersection or access points, roadside features, visual aid, and facilities for Vulnerable Road Users (VRU). This segmentation approach allows the researcher to perform a granular safety assessment that reflects localised road conditions rather than relying on aggregated or averaged data, which may obscure specific risk points (iRAP, 2019). Figure 3.13 shows the data coding process using the MiReV system.

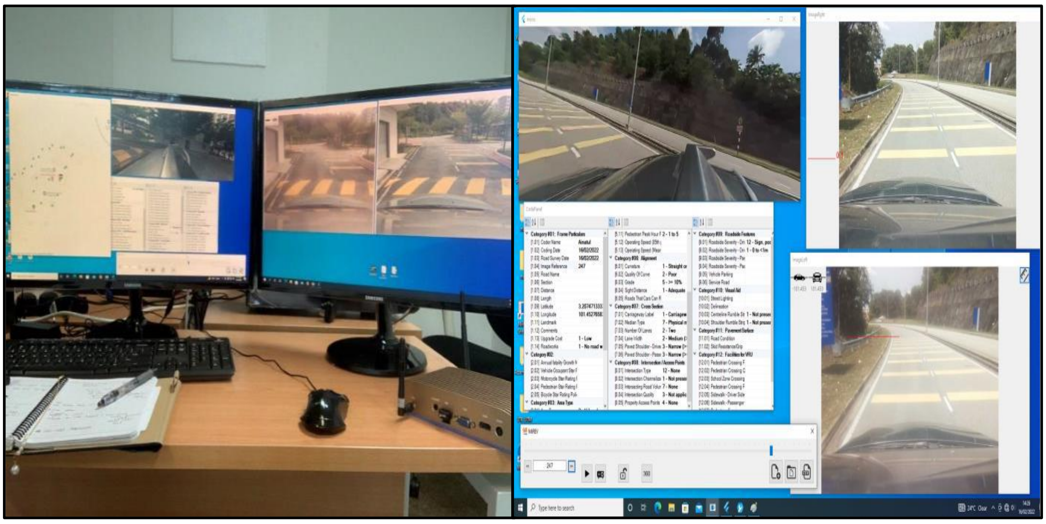

Figure 3.13 The Data Coding Process Using the MiReV System

3.7.5.3 Video Image-Based Desktop Inspection and ViDA Web-Based Coding

After field data collection, the researcher uploads the high-resolution video footage into the ViDA platform. Using the platform's structured interface, the researcher (data coder) conducts desktop inspections of each segment at 100-meter intervals. Each road attribute is visually assessed from the video frames and systematically coded using predefined options outlined in the iRAP Coding Manual (iRAP, 2019). The main forward camera view is calibrated for spatial measurement to accurately determine geometric elements such as lane and shoulder width, distance to fixed hazards, and visibility of markings.

According to iRAP protocols and procedures, the data coder codes each segment's most hazardous observable condition. For example, if both wide and narrow shoulders are observed, the data coder selects the narrowest condition. This precautionary approach ensures the safety assessments reflect worst-case infrastructure risks and provide a conservative basis for countermeasure planning. As mentioned in section 3.7.5.2, the researcher used the MiReV system to code raw data. However, when the video footage is obstructed or unclear, the researcher verifies the road segment using Google Street View or on-site photographs to supplement the dataset and ensure completeness and accuracy. This cross-validation step prevents missing or incorrect entries due to environmental limitations during the video image-based road survey method.

3.7.5.4 Integration with iRAP Star Rating and SRIP Development

After the researcher completed data coding process for the full 55.6-kilometre road network of the research location, the ViDA web-based system automatically generated star ratings for every 100-meter segment. These ratings serve as a direct input for the Safer Roads Investment Plan (SRIP) module, which identifies economically justified treatments and estimates the expected reduction in deaths and serious injuries. As shown in Figure 3.5, this coding phase acts as the central link between raw field data and the final modelling output in the modified model.

The structured nature of data coding ensures the outputs are accurate and also internationally comparable, aligning with iRAP's global objectives of improving road infrastructure safety in low-income and middle-income countries like Malaysia (iRAP, 2019; WHO, 2024).

3.7.6 Road Protection Scores (RPS)

Following the completion of road inspections and data coding, this study employs the ViDA web-based platform to calculate Road Protection Scores (RPS) for each 100-meter segment of the surveyed route. The RPS is a core output within the iRAP methodology and functions as a predictive indicator of road safety performance based on infrastructure conditions (iRAP, 2014; Murozi et al., 2024). An RPS represents the likelihood and severity of a crash for a given road segment, based on an objective assessment of its design features. These features include road geometry, roadside hazards, traffic control measures, and facilities for vulnerable road users. The RPS value reflects how well the road protects different categories of road users, such as car occupants, motorcyclists, pedestrians, and bicyclists from fatal and serious injury in the event of a crash (iRAP, 2014).

The calculation of RPS within the ViDA platform is grounded in empirical crash risk models and infrastructure-based safety algorithms. It considers the probability of crash occurrence and the expected severity of injury, based on known relationships between infrastructure attributes and crash outcomes (McInerney & Smith, 2009). As such, the RPS provides a quantifiable measure of a road segment's protection and is critical for identifying high-risk areas. Furthermore, the RPS serves as the analytical basis for estimating fatality rates across the road network. ViDA uses RPS values in conjunction with traffic volumes and exposure data to forecast the expected number of fatalities and serious injuries under existing conditions. This capability enables the researcher to prioritise road segments for treatment and to simulate the potential impact of applying countermeasures through the Safer Roads Investment Plan (SRIP).

By integrating RPS results with star ratings and proposed road safety interventions, this study enhances its ability to formulate targeted, data-driven infrastructure improvements for high-risk crash locations. The researcher uses the RPS to support current road safety evaluations and strengthen the model evaluation of the modified model developed in this research.

3.7.7 Road Safety Star Rating Score and Colour Bands

The researcher explains the evaluation of infrastructure-related safety levels for different road user groups through the road safety star rating score and colour bands section. The researcher applies the Star Rating Score (SRS) and the corresponding Star Rating Bands methodology, as outlined in the iRAP protocols (iRAP, 2021). The researcher calculates the SRS using ViDA, iRAP's web-based road safety assessment platform, to represent the relative risk of fatal and serious injury based on the presence and quality of road design elements.

3.7.7.1 Star Rating Score (SRS) Calculation

The Star Rating Score (SRS) calculation default setting in the ViDA platform is for each 100-meter road segment for the four (4) primary road user types: vehicle occupants, motorcyclists, bicyclists, and pedestrians. However, this research concentrated on the transport mode with the highest fatal crash frequency along the research location, namely motorcyclists. The researcher calculates the SRS using a compound equation that considers the likelihood of crash occurrence, severity of injury, operating speed, and other modifying factors such as external traffic influences and median traversability (iRAP, 2021).

The general equation is as follows:

$$\text{Star Rating Scores (SRS)} = \sum \text{Crash Type (Likelihood} \times \text{Severity} \times \text{Operating Speed} \times \text{External Flow Influence} \times \text{Median Traversability)} \quad (3.1)$$

Where:

- The SRS represents the relative risk of death and serious injury for an individual road user; and
- Crash Type Scores = Likelihood x Severity x Operating speed x External flow influence x Median traversability

Where:

- Likelihood refers to road attribute risk factors that account for the initial chance that a person will be involved in a vehicle collision
- Severity refers to road attribute risk factors that account for the severity of a vehicle collision
- Operating speed relates to factors that account for the degree to which risk changes with speed
- External flow influence factors account for the degree to which a person's risk of being involved in a vehicle collision is a function of another person's use of the road
- Mediation traversability factors account for the potential for an errant vehicle to cross a median (only applies to vehicle occupants and motorcyclists' run-off and head-on collisions).

Using the defined risk variables, the researcher analyses each crash type relevant to motorcyclists, such as run-off crashes, head-on collisions (including overtaking-related incidents), intersection-related conflicts, and property access crashes. These assessments produce scores aggregated into a single Star Rating Score (SRS) for motorcyclists per 100-meter road segment. This segment-based scoring approach provides a detailed risk profile of the road infrastructure, enabling the researcher to identify locations with elevated crash likelihood and severity caused by specific design deficiencies, including poor delineation, narrow or absent shoulders, hazardous roadside objects, and limited visibility at curves or intersections.

The motorcyclist's SRS equations can be summarised in the following form, as shown in Figure 3.14.

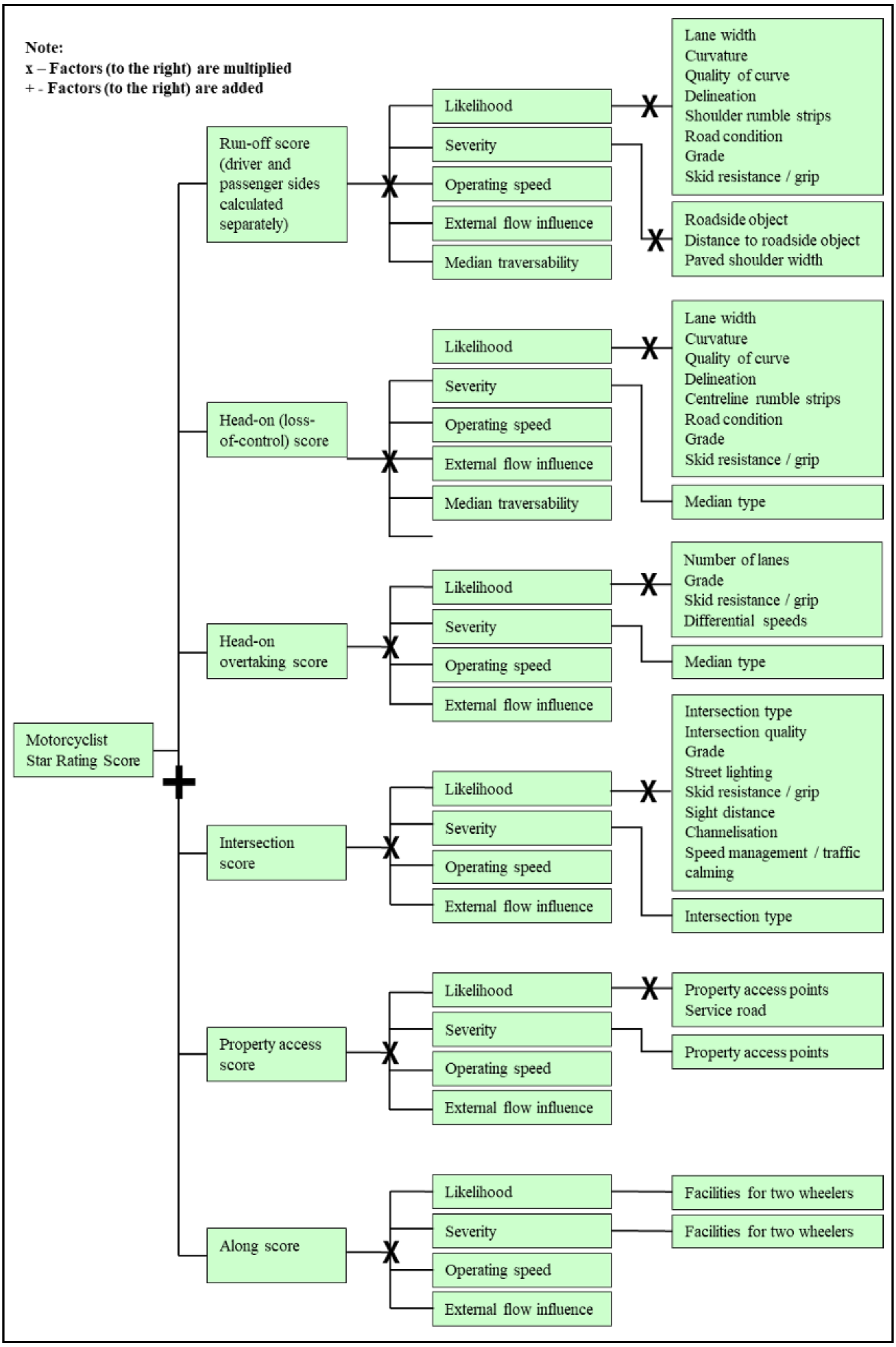

Figure 3.14 Adopted SRS Equations for Motorcyclists from iRAP (2021)

3.7.7.2 Star Rating Colour Bands

After calculating the Star Rating Score (SRS) for each road segment and road user category, the ViDA platform assigned each segment to the corresponding star rating colour band, ranging from 5 stars (lowest risk) to 1 star (highest risk). These colour bands provide an intuitive classification of road safety levels, making visualising and prioritising road safety interventions in a friendly format. The ViDA platform maps the SRS values to star rating colour bands based on defined thresholds that differ by road user group, such as vehicle occupants, motorcyclists, pedestrians, and bicyclists, reflecting their respective exposure and crash characteristics (iRAP, 2021). Table 3.6 explains the interpretation of star rating colour bands as follows:

Table 3.6
Interpretation of Star Rating Colour Bands Safety Levels from iRAP (2021)

Star Rating Score (SRS)	**Road Protection Score (RPS)**				
	Vehicle occupants and motorcyclists	**Bicyclists**	**Pedestrians**		
			Total	**Along**	**Crossing**
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5	5 to < 10	5 to < 15	0.2 to < 1	4.8 to < 14
3	5 to < 12.5	10 to < 30	15 to < 40	1 to < 7.5	14 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15	32.5 to < 75
1	22.5 +	60 +	90 +	15 +	75 +

Note: This figure illustrates the visual representation of safety levels using SRS colour bands, where green (5-star) indicates the safest road segments and black (1-star) indicates the most hazardous segments, as assessed in the ViDA web-based online platform.

The researcher applies the star rating colour bands in accordance with established thresholds by iRAP, as presented in Table 3.6. For example, for motorcyclists, an SRS value below 2.5 corresponds to a 5-star road, while a value exceeding 22.5 corresponds to a 1-star road, indicating a substantially higher risk level. This classification process enables segment-by-segment comparison of safety levels and highlights segments requiring targeted improvement of road safety countermeasures. These colour band classifications are grounded in existing research on road user risk. Studies by Bhavsar et al. (2019), Harwood et al. (2010), and Logan et al. (2013) consistently show that the likelihood of death or serious injury is significantly higher on 1-star roads and decreases progressively with each additional star rating. The star rating framework thus provides an infrastructure risk metric and an evidence-based interpretation of road user-level injury severity risk.

The researcher uses the SRS and star rating colour band classifications to identify segments rated below 3 stars and flags them for further investigation. These segments are considered to pose a disproportionately high risk, particularly to vulnerable users such as motorcyclists and pedestrians. Based on these findings, the researcher proposes "quick win" treatments with low-cost, high-impact road safety countermeasures to the relevant local authorities for implementation where appropriate. This combination of empirical scoring, risk colour band classification, and theoretical grounding ensures that the analysis is both data-driven and contextually validated, supporting practical and targeted infrastructure road safety improvements across the research location's high-risk road network.

3.7.7.3 Application of SRS in ViDA and iRAP@Highlands Model

The ViDA web-based platform automatically generates the star rating scores and colour bands after the researcher completes the data coding procedure in the system. These outputs are then used to (i) identify high-risk road segments for motorcyclist road user group, (ii) prioritise infrastructure improvements under the Safer Roads Investment Plan (SRIP), (iii) monitor improvements through before-and-after star rating score and colour bands comparisons and (iv) support the iRAP@Highlands modified model development, which incorporates SRS as an independent variable in assessing road crash risk. By implementing this methodology, this research ensured a robust, data-driven approach to infrastructure risk assessment along the research location, supporting broader road safety objectives for Malaysia's mountainous road networks.

3.7.8 Safer Road Investment Plan (SRIP)

As part of this research, the researcher employed an infrastructure-based risk management approach and developed a Safer Roads Investment Plan (SRIP) using the ViDA web-based platform developed by iRAP (iRAP, 2021). The SRIP methodology supports the formulation of cost-effective, data-driven infrastructure treatments aimed at reducing crash frequency and severity on high-risk road segments. The investment plan leverages the outputs of the Star Rating Score (SRS) and Road Protection Score (RPS) analyses to identify priority treatment locations across the surveyed road segments of the research location.

The SRIP methodology draws on a globally established library of more than 90 evidence-based road safety countermeasures that have demonstrated success in reducing road traffic fatalities and serious injuries in other countries (iRAP, 2023). These countermeasures include, but are not limited to, the installation of rumble strips, improved signage and delineation, road widening, intersection treatments, pedestrian crossings, roadside barrier systems, and more. The researcher selects the treatments based on the coded road attributes, crash type risk profiles, and infrastructure deficiencies observed during the field road survey and video-imaged-based inspection phases.

To determine the economic viability of each proposed countermeasure, the researcher estimates the expected reduction in crash frequency or severity that would result from its implementation. This safety benefit is converted into a monetary value, using established crash cost figures drawn from secondary sources such as the Malaysian Institute of Road Safety Research (MIROS) and the Royal Malaysia Police (RMP). The researcher obtained crash data and other related data from the M-ROADS and Integrated Traffic Information System (ITIS) databases, which provide historical crash records and severity classifications for research purposes in Malaysia.

The researcher calculates the treatment cost estimates using standardised rates provided by local government agencies, including cost figures for materials, construction, and maintenance. The researcher then subjects each proposed countermeasure to an economic evaluation using the Benefit-Cost Ratio (BCR), where:

$$\text{Benefit-Cost Ratio (BCR)} = \text{Total Estimated Monetary Benefit} \,/\, \text{Total Estimated Implementation Cost} \quad (3.2)$$

Only countermeasures with a BCR greater than a pre-defined threshold (e.g., BCR > 5) are listed for inclusion in the final SRIP, ensuring the investment plan aligns with road safety priorities and fiscal responsibility. This threshold ensures that proposed treatments yield significant societal value per public investment unit. The ViDA web-based platform facilitates this analysis by automatically generating the SRIP outputs based on the road segment-level infrastructure risk profiles, SRS ratings with colour bands, and user-defined cost-benefit thresholds. The outputs include recommended road safety treatment types, associated costs, estimated fatality reductions, economic savings, and treatment impact scores. Through applying the SRIP methodology, the researcher aims to support evidence-based decision-making by local authorities, enabling them to allocate limited resources to the most cost-effective and life-saving road safety treatments. SRIP output is particularly critical in mountainous road environments like the Cameron Highlands, where geometric constraints and environmental exposure increase crash severity risks at the affected road segment.

3.8 Stage 4: Road Safety Risk Assessment Modified Model Using Multiple Linear Regression (MLR)

This section will explain how to quantify the relationship between road infrastructure features and safety outcomes. This research proposes a Road Safety Risk Assessment Modified Model, the iRAP@Highlands model, using Multiple Linear Regression (MLR). MLR is applied to identify, quantify, and model the combined effects of multiple infrastructure and environmental variables on the predicted Star Rating Score, thereby enabling a data-driven modification of the existing iRAP framework. The researcher designed the model to explain variations in the Star Rating Score (SRS), which reflects the relative risk of death and serious injury for road users across 100-meter road segments. MLR is employed as a predictive tool to evaluate the impact of key infrastructure attributes on SRS and to support evidence-based decision-making for road safety improvements, especially in mountainous regions such as the research location.

The researcher selected MLR for its suitability in modelling the linear relationship between one continuous dependent variable (SRS) and multiple independent variables of road safety attributes (Acuria & Rodriguez, 2004; Aminfar et al., 2023; Rusli, 2017). MLR allows the researcher to identify statistically significant predictors, estimate the magnitude and direction of influence, and assess the collective explanatory power of the model (Kutela et al., 2022; Zhu & Srinivasan, 2011). The regression model provides a quantifiable basis for determining which road design features most strongly contribute to increased or decreased risk, thereby guiding prioritised interventions (Arévalo-Támara et al., 2020; Champahom et al., 2023; Varhelyi, 2016).

The SRS is the dependent variable, representing the relative risk of fatal or serious injury for road users across 100-meter segments. Independent variables are selected based on infrastructure features coded via the ViDA platform and identified through prior literature and the iRAP protocol standards. These variables include, but are not limited to, traffic management, traffic characteristics, alignment, paved surface, area type, cross-section, intersection or access points, roadside features, visual aid, and facilities for vulnerable road users.

3.8.1 Data Preparation and Variable Selection

Before modelling, the researcher conducts data cleaning, data coding consistency checks, and outlier analysis to ensure the validity of the dataset. Variables are screened for multicollinearity using the Variance Inflation Factor (VIF) to ensure only statistically relevant predictors are retained (Satiennam et al., 2023). The Variance Inflation Factor (VIF) is an essential diagnostic tool in multiple linear regression analysis for detecting multicollinearity among independent variables. Multicollinearity occurs when two or more predictors are highly correlated, which can inflate the standard errors of the regression coefficients, making them unstable and difficult to interpret. By calculating VIF values, researchers can assess whether any variable's predictive power is overlapping excessively with others, which could distort the proper relationship between predictors and the dependent variable. In the context of road safety modelling, such as the iRAP@Highlands modified model, ensuring low multicollinearity through VIF analysis is crucial for producing reliable, interpretable, and statistically valid results that inform evidence-based infrastructure improvements. Generally, a VIF value above 5 indicates moderate multicollinearity, while values above 10 suggest a serious concern requiring corrective action, such as removing or combining variables. All independent variables are standardised or converted to suitable numerical formats to support regression computation in SPSS software.

The final dataset includes each road segment's SRS (dependent variable) and corresponding road infrastructure attributes (independent variables) matrix. The researcher also examines scatter plots and correlation matrices to validate assumptions of linearity, normality, and independence of errors, prerequisites for reliable MLR application.

3.9 Proposed Road Safety Risk Assessment Modified Model for Motorcyclists along Mountainous Road Network (iRAP@Highlands)

The iRAP model's focus on cross-sectional road features highlights the crucial role of geometric design in improving road safety. Its systematic road safety risk assessment of road curvature, pavement condition, and road alignment facilitates the strategic deployment of engineering countermeasures to reduce crash risks and promote safer mobility environments. However, existing iRAP applications have predominantly concentrated on high-volume federal roads and expressways, with limited adaptation to low-volume, topographically complex road networks, such as those found in mountainous regions. These routes often exhibit sharp curvature, poor pavement conditions, and inconsistent road geometry, all of which elevate crash risk, particularly for vulnerable road users like motorcyclists, who account for a disproportionate number of fatalities in Malaysia's hilly terrains (RMP, 2021; WHO, 2023; Zhou et al., 2021).

This research introduces the modified model, an infrastructure-based risk assessment framework specifically tailored to mountainous road networks, addressing the aforementioned research gap. This modified model was developed to identify and quantify the key geometric predictors contributing to motorcycle crash severity in such settings. Drawing on extensive road inspection data and validated crash patterns, the modified model identifies curvature (i.e., straight or gently curving to very sharp bends), quality of curve, and pavement surface condition as the dominant predictors of road safety risk. These predictors were analysed using a Multiple Linear Regression (MLR) model in SPSS to determine its statistical influence on the Star Rating Score (SRS), a standardised iRAP metric for quantifying road safety performance. The model aims to diagnose infrastructure-related hazards and support evidence-based planning for road safety countermeasure implementation in high-risk, hilly corridors.

The relevance of this model may extend beyond academic contribution. This model can provide a practical decision-support tool for national road safety agencies such as the Malaysian Institute of Road Safety Research (MIROS), and the Public Works Department (JKR), as well as regional authorities involved in rural infrastructure management. Moreover, it aligns with international road safety goals, including the UN Decade of Action for Road Safety 2021–2030 and the Sustainable Development Goal (SDG) 3.6, which targets a 50% reduction in road traffic deaths and injuries by 2030

(WHO, 2023; iRAP, 2023). Figure 3.15 illustrates the conceptual framework of the proposed iRAP@Highlands modified model.

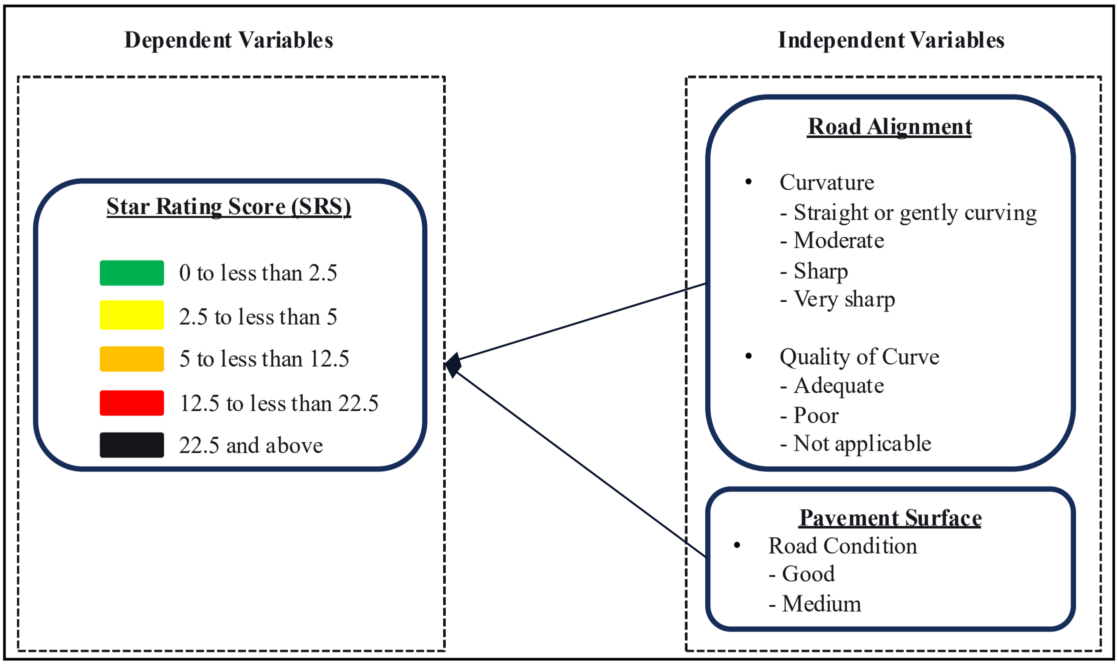

Figure 3.15 The Proposed iRAP@Highland Modified Model

The classification of independent variables for the proposed modified model was guided by the iRAP Fatality Estimation Model calibration methodology, which provides a structured framework for translating roadway attributes into predictive risk factors. The original iRAP model categorises roadway risk characteristics into ten (10) core domains encompassing traffic management, traffic characteristics, alignment, pavement surface, cross section, area type, intersection or access points, roadside features, visual aids, and facilities for Vulnerable Road Users (VRUs). These domains collectively encompass the full scope of factors influencing crash risk across diverse road environments.

In the development of the proposed modified model, the original ten domains were rationalised into five (5) functional domains to reflect the dominant risk mechanisms observed on the Malaysian mountainous road network at the selected site location and to align with available field survey data. This domain consolidation followed the iRAP Fatality Estimation Model Calibration Stage recommendations, which allow domain aggregation when overlapping safety attributes exist and context-specific modelling objectives are required. The five domains considered in this study were (i) roadside features, (ii) visual aids, (iii) cross-section, (iv) alignment, and (v) pavement surface.

Each domain comprised multiple coded attributes defined according to established iRAP survey protocols and scoring matrices. Domain values were standardised before data entry into the MLR model to facilitate statistical comparability and ensure compliance with regression assumptions.

Subsequently, Multiple Linear Regression (MLR) was applied for variable screening and model refinement. During this stage, correlation testing and significance analysis revealed that only two domains, namely (i) alignment (sub-domain of curvature and quality of curve) and (ii) pavement surface (sub-domain of road condition), exhibited sufficient variability and statistically significant relationships with crash outcomes within the study road segments. The remaining three sub-domains demonstrated either limited data variance, multicollinearity, or non-significant associations under the selected modelling conditions and were therefore excluded from the final validation model to prevent overfitting and preserve model parsimony. Model parsimony is the principle of developing a predictive model with the minimum number of explanatory variables necessary to achieve reliable, interpretable results, thereby avoiding overfitting and unnecessary complexity (Ritter & Gallegos, 1997).

The final validated modified model retained these two domains as independent variables, representing the most influential engineering contributors to crash occurrence on mountainous roads. This approach aligns with accepted road safety modelling practices, which prioritise statistical robustness while maintaining methodological consistency with theoretical risk constructs (iRAP, 2022).

While the modified model offers significant insights, it is also subject to research limitations, such as reliance on type of high risk road user, road survey locations, historical data, and existing infrastructure data, as well as the exclusion of transient environmental variables (e.g., weather, fog, or landslides), which may also contribute to crash risk in highland settings. Future research should aim to integrate real-time environmental data and behavioural factors to enhance the predictive capability of infrastructure-based risk models.

3.9.1 Model Construction and Statistical Analysis

The researcher applies step-by-step multiple linear regression analysis to determine the most impactful set of predictors for SRS. The MLR model is expressed in the following general equation form:

$$\text{Star Rating Score (SRS)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \quad (3.3)$$

Where:

SRS = Star Rating Score (dependent variable)

β_0 = Intercept

β_1, β_n = Regression coefficients for each independent variable

X_1, X_n = Independent variables (road safety attributes)

ε = Error term (residual)

The researcher interprets the model output, including coefficients, *p*-values, R^2, and adjusted R^2, to evaluate the model's explanatory strength and the significance of each predictor. Predictors with *p*-values below a 0.05 threshold are considered statistically significant contributors to road safety outcomes.

3.9.2 MLR Application and Integration with iRAP@Highlands Model

The final MLR model provides an empirical framework to estimate infrastructure-related risk levels across selected high-risk road segments identified through the ViDA web-based platform suggested by the iRAP methodology. This model will support local authorities, highway engineers, and stakeholders involved in roadway planning in prioritising treatments, forecasting risk, and evaluating the expected improvement in star rating scores following specific design changes due to mountainous roadway characteristics. The modified model is particularly relevant for road segments in mountainous environments, where standard flatland assumptions may not capture the influence of geometric and environmental factors on crash severity. In essence, this statement highlights that integrating the MLR model into the iRAP workflow strengthens the analytical capability of the assessment. Traditional iRAP outputs are descriptive, focusing on mapping and categorising existing road risks. The MLR-enhanced model, however, enables predictive analytics by estimating how specific engineering features influence the expected Star Rating Score. This shift also supports prescriptive analytics, where the results can guide decision-makers on which infrastructure improvements will produce the most significant.road safety benefits. Therefore, the model provides a more strategic basis for road safety investment planning in Malaysia, ensuring resources are directed toward interventions with the highest impact.

3.9.3 Justification for Using Multiple Linear Regression (MLR) in the iRAP@Highlands Model

The application of Multiple Linear Regression (MLR) in this research is a critical methodological choice to fulfil the objective of proposing a modified road safety risk assessment model, targeted at motorcyclists along the mountainous road network of the research location. MLR is a widely used statistical technique that estimates the linear relationship between a continuous dependent variable and two or more independent variables (Chen et al., 2020; Jain et al., 2020). In the context of this research, MLR facilitates the analysis of how various infrastructure-related attributes, as identified in the iRAP framework, influence the Star Rating Score (SRS) for motorcyclists.

One of the primary advantages of MLR is its ability to assess the simultaneous effect of multiple predictor variables while controlling for potential confounding factors. This advantage is particularly valuable in road safety research, where crash risk is inherently multifactorial, influenced by variables such as road geometry, surface condition, visibility, and speed (Elvik & Katharina, 2023; Wang et al., 2012). By applying MLR, the research can determine which factor has the most statistically significant impact on SRS, allowing for an in-depth and data-driven quick-win of road safety countermeasures.

Additionally, MLR supports the development of a locally calibrated and context-sensitive model, which is essential given the unique characteristics of mountainous road networks in Malaysia. Standard iRAP models, though globally robust, may not adequately reflect the specific crash patterns and risk profiles associated with steep gradients, sharp curves, or narrow lanes prevalent in Cameron Highlands. MLR enables the modification of the iRAP model by incorporating empirically derived weightings based on local road segment data and crash risk indicators.

From a policy and implementation perspective, MLR also offers predictive capabilities. The final regression model enables scenario-based simulation, allowing researchers or practitioners to estimate how adjustments to specific road attributes (e.g., curve radius or shoulder width) might improve the star rating score. The researcher can enhance the practicality of the modified model for infrastructure planning and support evidence-based intervention strategies aligned with iRAP's safer roads investment approach in the future (iRAP, 2022). The use of MLR in this research is justified based on its robustness in modelling complex relationships, capacity to identify and quantify significant predictors of road safety risk, alignment with global and local road safety modelling practices, and utility in informing cost-effective safety upgrades for vulnerable road users, particularly motorcyclists.

3.10 Research Ethical Considerations

This research adheres to the principles of ethical integrity, transparency, and respect for data privacy in accordance with established academic and institutional standards. As this study primarily involves infrastructure-based risk assessment and does not include direct interaction with human subjects, interviews, or the collection of personal or sensitive information, it qualifies for an ethics review exemption under the guidelines of the Universiti Teknologi MARA (UiTM) Research Ethics Committee. The researcher formally submitted the project for ethical screening, and the UiTM Research Ethics Committee granted an exemption from full ethics review, confirming that the research poses minimal or no risk to participants, consistent with institutional and national ethical standards for non-human subject research. The researcher includes the official exemption letter in Appendix 2 for documentation and verification purposes.

Although this study does not involve human participants, it remains committed to ethical data handling and research transparency. The researcher used all secondary data, including crash records and infrastructure information obtained from MIROS, RMP, and other governmental sources, strictly for academic purposes and handled with confidentiality with permission from the related institution. No identifiable personal information was accessed or disclosed at any research stage.

Furthermore, road surveys and video image-based inspections were limited to publicly accessible roadways. All data collection activities complied with local traffic regulations and did not interfere with road users or public infrastructure. The researcher also ensured that using images, GIS maps, and survey visuals respected copyright and data ownership rights, citing sources and references where applicable. The UiTM Research Ethics Committee has officially recognised that this research meets the ethical requirements for non-human subject studies. The exemption ensures that the study is ethically sound while reducing administrative burden for research that does not pose ethical concerns.

3.11 Chapter Summary

This chapter has presented an explanation of the research methodology adopted to achieve the objectives of this research, which aims to propose a modified infrastructure-based road safety risk assessment model targeting motorcyclists as high fatal crash frequency mode of transport on the mountainous road network from Jalan Simpang Pulai to Blue Valley, Cameron Highlands. This chapter is systematically structured around four main stages aligned with the research objectives: (i) Systematic Literature Review (SLR), (ii) Road Crash Data Profiling, (iii) Road Survey and Road Safety Inspection using iRAP Methodology along the Research Location, and (iv) Road Safety Risk Assessment Modified Model using Multiple Linear Regression (MLR).

The SLR served as the qualitative foundation, identifying key crash contributing factors in mountainous regions, while crash data profiling using Tableau software enabled quantitative analysis of historical crash trends and high-risk locations. The road survey phase employed internationally benchmarked iRAP methodologies, including the use of RADIS tools (360-degree video and image-based road inspections), GPS logging, and ViDA web-based platform integration to assess and code road infrastructure attributes for over 55.6 km of federal roads along the research location. These coded data facilitated the calculation of Star Rating Scores (SRS), Road Protection Scores (RPS), and the development of a Safer Roads Investment Plan (SRIP) with cost-benefit justifications for proposed road safety interventions for impacted high-risk road segments.

Finally, the research implemented a predictive modelling approach using MLR to assess the relationship between infrastructure attributes and star ratings. This statistical model supports the proposed modified model, specifically addressing motorcyclist safety concerns because motorcyclists have recorded high-fatality rates in mountainous environments along the research location. The researcher applies rigorous data triangulation and ethical considerations throughout this chapter to ensure methodological reliability and academic integrity. The integrated use of qualitative and quantitative methods reinforces the robustness of this research, making it both contextually relevant and replicable for future research in similar high-risk geographical research settings.

CHAPTER 4
RESULTS OF THE SYSTEMATIC LITERATURE REVIEW AND ROAD CRASH DATA PROFILING FOR THE CAMERON HIGHLANDS ROAD NETWORK

4.1 Introduction

This chapter presents the results of the Systematic Literature Review (SLR) and the road crash data profiling conducted for the Cameron Highlands mountainous road network. The primary purpose of this chapter is to synthesise existing scholarly evidence on crash contributing factors in mountainous roadway environments and to validate these findings using secondary crash data obtained from the RMP and the MIROS through the ITIS and M-ROADS databases.

The chapter was structured into two complementary components. First, the SLR analysis systematically identifies and categorises thematic factors associated with road crashes in mountainous regions. These factors are synthesised into three principal domains: road engineering, driver behaviour, and weather conditions, together forming a conceptual baseline for interpreting crash risk patterns and informing proactive engineering countermeasures. The SLR outcomes provide theoretical support for evaluating roadway safety performance and an evidence-based framework for assessing the local crash characteristics of Cameron Highlands.

Second, the chapter presents descriptive and spatial map profiling of recorded crash data from 2015 to 2018 using Tableau software. Data visualisation techniques are applied to analyse vehicle involvement, crash severity, collision types, traffic systems, roadway geometry, lighting conditions, weather influences, and geographical clustering of crash locations across rural and urban segments of the mountainous road network. This analytical approach enables the identification of dominant crash patterns and high-risk corridors requiring targeted safety interventions.

By integrating SLR findings with real crash data, this chapter provides both theoretical grounding and empirical validation of mechanisms underlying crash causation in mountainous settings. The combined results directly support the research objectives by identifying critical safety risk factors and informing the subsequent development of a modified road safety risk assessment model for mountainous highways in Cameron Highlands.

4.2 Thematic Structure and Key Factors Contributing to Road Crashes along Mountainous Areas Road Network Using Systematic Literature Review (SLR)

Transportation quality and safe travel matter and significantly impact the daily lives of individuals living in urban and rural areas (Othman & Ali, 2020). Globally, countries such as Sweden, New Zealand, and The Netherlands initiated similar visions to Malaysia, where road accidents resulting in death or injury are unacceptable in the travel system through the vision of "A Country with Zero Road Fatality" (Ministry of Transport Malaysia, 2022). The mountainous regions of Malaysia are popular tourist destinations, particularly during public holidays, school breaks, long weekends, and cultural celebrations. Both tourists and locals are drawn to these areas for their natural beauty and recreational opportunities. Ensuring road safety in mountainous areas presents unique challenges due to factors such as terrain, weather conditions, and specific road characteristics to manage the transportation volume and demand for safer operation in mountainous roadway areas road networks (Jain et al., 2020; Shallam et al., 2022).

Particular concern is the fact that nearly half of these road crash fatalities involve vulnerable road users, especially motorcyclists, and their pillion passengers. This statistic underscores the disproportionate risk this group faces, which remains the largest segment of registered vehicles in the country. A growing body of research has examined the specific factors contributing to road crashes, particularly within high-risk environments such as mountainous roadway networks. In these areas, crashes are frequently associated with a combination of natural and human-made hazards. The physical characteristics of the terrain, including steep gradients, sharp curves, and narrow carriageways, significantly increase the likelihood of driver error and loss of vehicle control. Moreover, adverse weather conditions such as frequent fog, heavy rainfall, and reduced visibility further compromise safety (Eusofe & Evdorides, 2017; Hermans, Brijs, & Wets, 2014). Environmental elements like landslides, falling rocks, and poor drainage also contribute to the dangerous nature of these routes.

In addition to these geographic and environmental risks, infrastructural deficiencies such as inadequate road design, lack of guardrails, and poor signage have been consistently identified as contributing factors. Unsafe driving behaviour, including speeding, overtaking on curves, microsleep, and fatigue among long-distance drivers, is another critical factor influencing crash frequency in mountainous regions. The use of older, poorly maintained vehicles, especially heavy commercial lorries and buses with faulty braking systems, further exacerbates the danger (Jawi et al., 2009; Shah et al., 2018).

In contrast, crashes occurring along non-mountainous roads are generally influenced by different conditions. While driver behaviour remains a persistent factor, road safety in these areas is more heavily affected by road engineering flaws, such as poor pavement conditions, insufficient lighting, suboptimal junction design, and lack of pedestrian infrastructure. Other contributory factors include geometric alignment, roadside hazards, and general vehicle conditions (Hermans et al., 2014; Wang et al., 2012). Despite being less complex topographically, these roads often exhibit design and maintenance issues that pose substantial risks, particularly in urban and semi-urban settings.

Past studies have argued and discussed that road safety management encompasses various strategies, policies, and proactive action to prevent and reduce road crashes, minimize injuries, and ensure road users' safety, but failed to control alarming statistics involving fatal injuries in mountainous regions. The initiatives and strategies in (i) implementing and enforcing the traffic laws and regulations are crucial; (ii) progressively and systematically designing and maintaining road infrastructure is essential; (iii) road users should be educated and given awareness about road safety hazards in mountainous road network; (iv) improve road users knowledge about vehicle safety standards; (v) data mining and data analysis to helps authorities in planning proactive action; and (vi) leveraging technology such as intelligent transportation system to improve road safety were found to be beneficial to improve road safety management. Gaps in implementing these strategies and initiatives between mountainous and non-mountainous road networks were also observed, involving challenges in complex geometric alignment, limited sight distance, narrow lanes, heavy traffic flows, rapid development, difficulties and limitations to upgrade roads, and increased road rehabilitation and maintenance costs for construction materials (Aminfar et al., 2023; Choudhary et al., 2024; Martinelli et al., 2023). The objectives of this section are (i) to discuss insight knowledge associated with factors contributing to road crashes along mountainous road networks and (ii) to identify the thematic structure and key factors contributing to road crashes along mountainous regions by exploring proactive road engineering strategies, concepts, and approaches shaping the road safety discourse.

This section sets the research baseline for the best countermeasure for roadway design and provides theoretical support for designing safe roads, especially along mountainous areas, to desired safety standards. The review delves into 34 sub-themes for road engineering factors, 19 for driver behaviour, and 7 for weather conditions, accounting for the peculiarities of mountainous landscapes using the SLR process from 2020 until 2024. The findings consider factors ranging from road engineering to the influence of weather conditions and the behavioural nuances of road users. Notably, the emphasis lies on the proactive measures embedded in road engineering strategies. These findings may help to expand the scholarly discourse within the field of road safety and inspire further research endeavors aimed at fortifying the protection and resilience of mountainous roadways in challenging topographies.

4.2.1 Road Engineering Factors for Mountainous Areas Regions

Road and traffic engineering is a branch of civil engineering dedicated to planning, designing, constructing, and maintaining road infrastructure. Over the years, extensive research has been done on road safety performance to reduce road crashes. Consulting authorities, roadway engineers, traffic engineers, and researchers are very detailed and concerned about finding the best countermeasures for road safety related to the multitudinous nature or mountainous of road networks. Road engineering involves structural design activities such as road layout planning, geometric design for curves and slopes, and pavement design for durability (Aminfar et al., 2023; Joseph et al., 2023). It also involved expertise in traffic engineering to suit the real-time efficient flow of hydraulic design for drainage.

Furthermore, it involved construction management activities, including earthwork and pavement laying, ongoing maintenance efforts, and measures to enhance road safety and comply with environmental considerations (Choudhary et al., 2024). This multidisciplinary road engineering field aims to create a safe, efficient, and sustainable road network that supports the movement of people and goods while considering environmental impact and legal compliance. Managing more than two decades old (road construction completed by the year 2004) road network stretch (Federal Route F185) of Jalan Simpang Pulai required a detailed road safety inspection for road user protection from time to time to suit road capacity and operations. Table 4.1 exhibits the detailed theme and sub-themes of road engineering factors extracted from the SLR process.

Table 4.1
The Road Engineering Theme and Sub-Themes for Factors Contributing to Road Crashes along Mountainous Areas' Regions

Theme 1	No	Sub-Themes Factors	References
Road Engineering	1	Inconsistent road geometric design	Choudhary et al., (2024); Elvik & Katharina, (2023); Fitri & Wahyuni, (2022); Goyani et al., (2022); Peng et al., (2021)
	2	Roadside topography spatial features	
	3	Cross-sectional elements	
	4	Road delineation	
	5	Pavement skid resistance value	
	6	Pavement surface condition	
	7	Acute deflection angle	
	8	Steep gradient	
	9	Degree curvature	
	10	Overtaking and passage lanes	Hu et al., (2023); Martinelli et al., (2023); Mehrara & Ksaibati (2021); Moomen, et al., (2020)
	11	Carriageway structural stability	
	12	Tapered lane width	
	13	Number of lanes	
	14	Auxiliary lane	
	15	Tangent length	
	16	Shoulder width	
	17	Downgrade length	
	18	Curve length	
	19	Curve angle	
	20	Vertical curve radius	
	21	Horizontal curve radius	
	22	Combination of vertical and horizontal curve radius	
	23	Adjacent curve	
	24	Reverse curve	
	25	Spiral transition	
	26	Speed Limit	Peng et al., (2021); Safarpour et al., (2020); Tang et al., (2023); Patil et al., (2021)
	27	Annual Average Daily Traffic (AADT)	
	28	Performance of traffic flow, traffic volume, and traffic density	
	29	Guardrails and barriers	
	30	Densely spaced access point	
	31	Rut depth	
	32	Limited sight distance	
	33	Limited accessibility	
	34	Elevation fluctuation	

The top 9 sub-themes of road engineering are related to the implication of accurate road engineering design, which correlates with road safety and the well-being of road users. Inconsistencies in geometric design, variations in roadside topography, and inadequate cross-sectional elements can lead to road user confusion and increase the risk of road crashes on mountainous roads (Choudhary et al., 2024). Clear road delineation through the best signage and marking quality, along with attention to pavement skid resistance, surface conditions, and the design of acute angles, gradients, and curves, is essential for promoting safe driving conditions (Fitri & Wahyuni, 2022). This statement is supported by research findings from Peng et al. (2021), who stated that hazardous section classification is greatly affected by the horizontal curve's horizontal radius, grade, and declination angle. A well-thought-out road engineering design will not only guide traffic and road users effectively but also minimises hazards and challenges that could compromise driver control (Goyani et al., 2022). Prioritising these design aspects ensures a road infrastructure that prioritises road safety, contributing to the overall well-being of road users (Elvik & Katharina, 2023).

The following 16 sub-themes focus on optimal designs to ensure efficient traffic flow and enhance road safety. Sub-themes such as well-planned overtaking and passage lanes, stable carriageway structures, tapered lane widths, and appropriate lane numbers directly impact how vehicles navigate the road (Hu et al., 2023). According to Martinelli et al. (2023), the right combination of tangent and curve lengths, along with a suitable radius, are crucial for maintaining driver comfort, control, and visibility. Factors like shoulder width, downgrade length, and the integration of auxiliary lanes contribute to the overall stability and safety of the road structure (Mehrara & Ksaibati, 2021). Furthermore, proper road design for smooth transitions in curves, such as adjacent and reverse curves, minimises sudden changes in direction and reduces the risk of road crashes along mountainous roadways (Moomen et al., 2020). In essence, a thoughtful approach to these design considerations is the key to creating a road infrastructure that prioritises efficient traffic management and the well-being of road users along mountainous roadways.

The remaining 9 sub-themes explain the key to safe journeys and efficient traffic, starting with the appropriate design of speed limits by considering the Annual Average Daily Traffic (AADT) to gauge traffic performance (Patil et al., 2021). In addition, guardrails and barriers should be strategically located to inhibit road crashes on mountainous roads (Peng et al., 2021). Access points management will help maintain smooth traffic flow while addressing rut depth, which is crucial for pavement durability and vehicle stability (Safarpour et al., 2020). A sensible design to mitigate the limited sight distance and accessibility challenges proactively is necessary to improve road safety along mountainous roadways. Also, managing elevation fluctuations will ensure smooth road transitions (Tang et al., 2023). Other challenges along mountainous roadways are limited parking space, leading to difficulties and high road rehabilitation and maintenance costs, rapid and insensitive development, traffic congestion, and heavy goods vehicle (HGV's) speed issues. A holistic approach to these road engineering factors is vital for prioritising safety and efficient traffic management for the best design of mountainous roadways.

4.2.2 Driver Behaviour Factors for Mountainous Areas Regions

Fatigue is a critical factor influencing driver behaviour, particularly in mountainous regions where the driving conditions are inherently more challenging (Yuan et al., 2021). The complex terrain, characterised by sharp curves, steep gradients, and frequently changing elevations, demands heightened attention and continuous physical effort from the driver. These conditions, coupled with the extended periods of driving often required in such areas, can lead to significant physical and mental fatigue. Fatigue reduces a driver's ability to maintain focus, impairs reaction times, and diminishes the capacity to make sound judgments, all of which are crucial in navigating the demanding road conditions typical of mountainous areas (Elshamly et al., 2017; Yuan et al., 2021). The risk of road crashes increases as drivers underestimate the extent of their fatigue or overestimate their ability to compensate for their body condition, particularly when faced with sudden changes in road conditions or unexpected obstacles. Moreover, the lower oxygen levels at higher altitudes in mountainous regions create a common feature in the human body that can exacerbate fatigue, further impairing cognitive and motor functions (Cáceres et al., 2021). The relationship between fatigue experienced by the human body and the unique environmental challenges of mountainous region driving experience underlines the importance of understanding and mitigating fatigue-related risks to enhance road safety in mountainous regions.

According to road safety research articles, driver behaviour encompasses road users' discernible actions and decision-making processes while navigating road networks (Ha et al., 2023). These behaviours act as critical parameters for road safety assessment and intervention strategies. Essential considerations include compliance with traffic regulations, effective response to varying road conditions, and interactions with other road users. Road engineers and researchers should analyse various driver behaviour factors meticulously to identify road crash patterns that will influence road safety. This data-driven approach informs the development of engineering solutions that enhance road safety. It involves scrutinising factors such as speed limit adherence, proper utilization of signals, maintenance of optimal following distances, and strict adherence to traffic signs and regulations (Satiennam et al., 2023). The comprehensive examination of driver behavior factors will help road engineers understand the complex human elements that affect road safety. This understanding will enable the development of specific interventions, improvements to road design, and educational programs to reduce the risk of crashes and enhance the overall safety of vehicular traffic infrastructure. Table 4.2 demonstrates the theme and sub-themes of driver behaviour factors extracted from the SLR process aligned with researchers' findings and road engineering principles.

Table 4.2
The Driver Behaviour Theme and Sub-Themes for Factors Contributing to Road Crashes along Mountainous Areas' Regions

Theme 2	No	Sub-Themes Factors	References
Driver Behaviour	1	Fatigue	Beaulieu et al., (2023); Bobermin et al., (2021); Champahom et al., (2023); Ha et al., (2023); Hasan et al., (2023); Love et al., (2024); Satiennam et al., (2023); Singh & Kathuria, (2023); Staton et al., (2023); Phithak et al., (2023); Laliberté & St-Laurent, (2020)
	2	Controlling speed and vehicle positioning	
	3	Traffic condition	
	4	Careless	
	5	Roadside distraction	
	6	Mobile phone usage	
	7	Driving skills	
	8	Impede visibility	
	9	Overtaking and manoeuvring vehicle	
	10	Usage of emergency, stopping, maintenance, and repair lanes	
	11	Lane changing	
	12	Presence of road marking	
	13	Presence of warning signs	
	14	Presence of wildlife and environmental hazard	
	15	Advanced Driver Assistance System (ADAS) or related technologies	
	16	Driver education and awareness	
	17	Emergency response preparedness	
	18	Vehicle check and maintenance	
	19	Attitude and mental health	

Researchers have frequently discussed the correlation between road safety and numerous driver behaviour factors. The sub-theme of controlling speed and precise vehicle positioning while driving along mountainous roadways plays a focal role in road crash prevention and traffic safety (Beaulieu et al., 2023). The dynamic nature of traffic conditions along mountainous areas demands continuous attention and adaptability from road users (Champahom et al., 2023). Occurrences of driver carelessness, roadside distractions, and mobile phone usage pose significant risks and require proactive strategies to alleviate these behaviours (Bobermin et al., 2021; Ha et al., 2023).

Driving skills directly influence road safety outcomes, such as the driver's ability to overtake and maneuver vehicles, practical usage of emergency lanes, and navigating lane changes are different from driving skills in other types of roadways like highways and expressways (Hasan et al., 2023). Issues and challenges that impact road user visibility along mountainous roadways, such as faded road markings, broken warning signs, wildlife trespassing, and environmental hazards, should be given attention by road engineers and local authorities (Love et al., 2024).

Recent technology integration of Advanced Driver Assistance Systems (ADAS) built into new vehicle models at the marketplace, for instance, Automatic Emergency Braking (AEB), collision warning system, Lane Departure Warning (LDW), Lane Keeping Assist (LKA), Blind Spot Detection (BSD), parking assistance, cross-traffic alert, driver attention monitoring, traffic sign recognition, and collision avoidance system will reduce the risk from driver behaviour factors towards road safety by providing real-time guidance and warnings to road users while travelling along mountainous roadways (Satiennam et al., (2023). Comprehensive road safety education for road users, awareness programs, and emergency response preparedness contribute to proactive strategies to elevate road safety culture among road users (Singh & Kathuria, 2023). Moreover, regular vehicle inspection, maintenance, and attention to drivers' attitudes and mental health collectively foster an environment where road safety is prioritised (Phithak et al., 2023; Staton et al., 2023).

Another challenge to road safety along mountainous roadways is unpredictable traffic congestion during the festive season and special holidays. This situation does not impact traffic safety due to the narrow lane but will affect drivers due to significant changes in car-following behaviour (Li et al., 2024). Satienman et al. (2023) found that combined engineering and enforcement measures, including counterflow lane implementation and automated detection camera systems, contributed to improved traffic compliance and a measurable reduction in hazardous riding behaviours among young motorcyclists. Issues related to young motorcyclist road crash cases, cannabis addiction, and drunk driving have been given less attention by researchers along mountainous roadway studies.

These findings underscore the need to design infrastructure that accommodates the unique challenges of mountainous terrains and proactively mitigate the risks associated with driver behaviour factors. A road engineer should emphasize the importance of incorporating features such as enhanced signage, reflective road markings, and barriers to guide drivers through sharp curves and steep gradients along mountainous roadways. Additionally, implementing technologies like weather-responsive speed limits and dynamic message signs or Variable Message Systems (VMS) could provide real-time updates to road users, helping them adapt to changing road conditions and reducing the likelihood of road crashes caused by fatigue or inattention while driving along mountainous roadways.

Moreover, a road engineer might advocate for integrating Advanced Driver Assistance Systems (ADAS) into road safety strategies, suggesting that infrastructure should be designed or retrofitted to support these technologies, ensuring compatibility and effectiveness. For example, using well-marked lanes and clear signage would enhance the performance of lane-keeping assist systems. At the same time, strategically placed sensors could aid in the functionality of collision warning systems. The expert view would also likely focus on continuous maintenance and monitoring of road conditions, particularly in mountainous areas where environmental factors such as landslides, snow, and wildlife crossings pose ongoing challenges to road users.

Regular inspections and timely repairs of road surfaces, barriers, and signs are crucial in maintaining safety standards and preventing road crashes in mountainous regions. Overall, it is essential to have a holistic approach that combines robust infrastructure design, advanced technology integration, and ongoing maintenance to address the complex interplay of factors influencing driver behavior and road safety in mountainous regions.

4.2.3 Weather Condition Factors for Mountainous Areas Regions

Weather conditions are critical in road safety, particularly in mountainous regions where the terrain and environmental conditions exacerbate the risks associated with adverse weather. Heavy rain, for instance, can lead to flash floods and landslides, significantly increasing the likelihood of road crashes (Matori et al., 2012). The sudden accumulation of water on road surfaces can reduce tyre traction, making it difficult for drivers to maintain control of their vehicles, especially on steep or winding roads. Additionally, fallen trees caused by heavy winds or saturated soil during storms can obstruct roadways, creating hazardous conditions that can lead to collisions or force drivers to take dangerous indirect routes. A multifaceted approach focuses on preventive measures, and responsive strategies are necessary to mitigate these risks.

Infrastructure design must account for the unique challenges mountainous region's weather conditions pose. Advanced drainage systems will help to prevent water accumulation on road surfaces, and the construction of retaining walls and barriers will help protect against landslides and falling debris (Rashid et al., 2017). Furthermore, regular vegetation maintenance along mountainous roadways is essential to reduce the likelihood of trees falling during storms (Nhu et al., 2020; Yang, 2016).

Technological solutions also play a crucial role in enhancing road safety under adverse weather conditions in mountainous regions. Weather monitoring systems technology can provide real-time data on rainfall intensity and potential flash flood risks, allowing for timely road closures or warnings to road users in this region (Islam et al., 2014). Additionally, advanced warning and monitoring systems that alert road users to the presence of fallen trees or other obstacles on the mountainous roadway can significantly reduce the risk of road crashes. Emergency response plans should be tailored to the specific challenges of mountainous regions, ensuring that road crews are prepared to clear road debris and manage flash flood situations as early as possible to prevent the risk of road incidents (Waseem et al., 2019). Public awareness campaigns that educate road users on the risk of road hazards of driving in heavy rain and the importance of adhering to weather-related road closures can further enhance road safety in mountainous regions (Matori et al., 2012; Yang, 2016). Addressing the impact of weather conditions on road safety in mountainous areas requires comprehensive strategies that integrate robust infrastructure, advanced technology, and proactive maintenance and response efforts. Understanding and mitigating the specific risks associated with heavy rain, fallen trees, and flash floods makes it possible to significantly reduce the incidence of road crashes in these challenging environments. Table 4.3 displays the theme and sub-themes of weather-related factors identified through the SLR and supported by existing research and road engineering principles.

Table 4.3
The Weather Condition Theme and Sub-Themes for Factors Contributing to Road Crashes along Mountainous Areas' Regions

Theme 2	No	Sub-Themes Factors	References
Weather Condition	1	Rain	Aminfar et al., (2023); Huang et al., (2023); Jiménez et al., (2023); Laliberté & St-Laurent, (2020); Martinelli et al., (2023); Peng et al., (2021); Hu et al., (2023)
	2	Wind	
	3	Extreme heat or temperature	
	4	Sunlight or lightings	
	5	Fog	
	6	Snow and ice for certain countries	
	7	Thunderstorms with hail formation	

From the perspective of road safety research and road engineering, the impact of weather conditions on road safety cannot be overstated. Rainfall of varying intensities poses challenges between tyres and road grip and visibility, demanding careful design considerations for adequate drainage at mountainous roadways (Aminfar et al., 2023). Windy conditions affect the stability of high-profile vehicles and necessitate roadside structure considerations along mountainous roadways (Huang et al., 2023; Jiménez-Ramos et al., 2023). Extreme heat or temperature differences along mountainous roadways can affect pavement strength and structural soundness, gradually influencing road durability (Jiménez-Ramos et al., 2023). Intense sunlight or insufficient lighting conditions led to glare and visibility issues for road users along mountainous roadways (Laliberté & St-Laurent, 2020). This issue requires proper road illumination planning during the construction project planning phase.

The merging of research insights and practical road engineering approaches and strategies become a principle to design resilient mountainous roadways that prioritise safety for road users under diverse weather conditions. Mountainous roadways face challenges due to fog issues that differ from highways and expressways. The fog issues require road engineers to apply safety elements in road design for mountainous roadways that enhance visibility and guide drivers while driving (Martinelli et al., 2023). For mountainous roadway regions experiencing snow and ice seasons, modifications to road engineering solutions, such as anti-icing measures, are necessary to ensure road users are safe during winter driving conditions (Peng et al., 2021). Additionally, thunderstorms with hail formation demand resilient road designs and structures to withstand severe weather events along mountainous roadways (Martinelli et al., 2023). Furthermore, a high frequency of road crashes occurs on mountainous roads, specifically at downhill and concave curve road sections, compared to flat road sections. This situation will increase road crash frequency as road surface skidding resistance and road user driving quality decrease during bad weather conditions.

4.3 Road Crash Data Visualisation and Analytics Using Tableau Software for Mountainous Roadway Areas in Cameron Highlands

Jain et al. (2020) and Shrestha and Kumar (2018) identified several factors associated with the frequent occurrence of road crashes in mountainous roadway environments. These include high transport demand, unsafe operational practices, and challenges arising from unpredictable weather conditions. Jawi et al. (2009) similarly noted that adverse weather, combined with human-related factors, significantly contributes to crash risks in these areas. In addition to crash causation factors, mountainous road networks often face structural and financial challenges, such as difficulties in upgrading road alignments and the high costs associated with road rehabilitation and ongoing maintenance (Hamednia et al., 2018; Zhang et al., 2020). Despite the increasing recognition of crash risks in such terrains, there remains a shortage of empirical research using secondary data sources focused specifically on mountainous road networks. Notable exceptions include studies by Shaadan et al. (2021) and Sunkpho and Wipulanusat (2020), which employed crash data analysis in similar topographic settings.

A comparative study by Rusdi et al. (2017), focusing on crash characteristics in both mountainous and non-mountainous areas in Sabah, Malaysia, found that horizontal curve sections, single-vehicle crashes, and weekend traffic patterns were among the key factors that significantly increased crash likelihood along mountainous roads. While past studies have explored various qualitative dimensions of road crashes, such as causal factors, forecasting and predictive models, impacts, and socio-behavioural influences. Thus, limited research has analysed in-depth crash data characteristics for a mountainous environment using data visualisation tools.

Given the increasing volume of traffic data and the complexity of crash data records, there is a growing need for user-friendly, efficient analytical tools that support the exploration of large datasets and generate meaningful insights into crash patterns, trends, causes, and consequences (Sunkpho & Wipulanusat, 2020). To address this gap, this research applies data analytics and visualisation techniques using Tableau software to examine crash data for all main roads connecting to Cameron Highlands. The analysis aims to improve understanding of crash scenarios and patterns in both rural and urban road segments of mountainous road networks and to allow for comparative insights with non-mountainous regions.

The findings derived from this visual analytics approach are presented in the following subsections, offering deeper insight into road crashes' spatial, temporal, and behavioural dimensions. As Sunkpho and Wipulanusat (2020) highlighted, many transport agencies and researchers have increasingly adopted Tableau as a platform for data-driven decision-making in transport safety analysis. This section includes five (5) types of descriptive and frequency-based analyses conducted using Tableau software to uncover key characteristics of the Cameron Highlands crash dataset.

4.3.1 Descriptive and Frequency Analysis

In Malaysia, the POL27 form serves as the official road crash reporting instrument used by the Royal Malaysia Police to document comprehensive crash information, including the date and time of the crash, location, vehicle types involved, injury severity, environmental conditions, and contributing factors. The standardised reporting format also includes narrative descriptions and schematic diagrams of crash events. Data captured using the POL27 form are compiled into the centralised ITIS and M-ROADS databases, which constitute the national repository for road crash statistics and support safety analysis conducted by agencies such as the Malaysian Institute of Road Safety Research (MIROS) and the Ministry of Transport (MoT). The structured consistency of this dataset ensures reliability for subsequent planning activities, policy formulation, and research investigations. This study applies descriptive and frequency-based analysis techniques to examine crash records along the Cameron Highlands mountainous road network for the period 2015 to 2018, with data visualisation undertaken using Tableau software.

Over the four-year study period, a total of 145 crashes were recorded along the primary road network connecting to Cameron Highlands, Pahang. Motorcycles with engine capacities below 251 cc accounted for the most significant proportion of crashes, with 66 cases (45.5%), confirming the elevated exposure and vulnerability of this user group in the mountainous road environment. Tour and excursion buses ranked as the second-most-frequently involved vehicle category, with 25 recorded crashes, followed by lorry trailers and four-wheel-drive (4WD) vehicles, each with 17 crashes, reflecting the significant presence of heavy and utility vehicle traffic along this tourism-intensive road network. Private passenger cars were associated with 11 crash cases, representing a comparatively minor but still notable share of total incidents.

Crash involvement among other vehicle types was comparatively limited. Motorcycles exceeding 250 cc engine capacity, express buses, and taxis each recorded approximately two (2) crash cases, while vehicle categories such as school buses, vans, and rigid lorries exceeding 2.5 tonnes were each represented by only a single reported crash incident throughout the study period. Although these categories constitute a minor proportion of the crash distribution, their involvement highlights the diversity of traffic composition present along the mountainous road network of Cameron Highlands.

The dominance of motorcycle-related crashes observed in Cameron Highlands aligns with national safety trends reported by Idris et al. (2019), who found that approximately 45.89% of all road traffic fatalities in Malaysia involve motorcyclists and pillion passengers. This persistent over-representation reflects the combined influence of behavioural, infrastructural, and environmental factors that disproportionately affect two-wheeled road users, particularly on complex rural and mountainous road networks. Prior studies have associated increased motorcycle crash risk with rider behaviours such as aggressive overtaking on curves, tailgating, excessive speeding, fatigue, and inconsistent helmet compliance, alongside demographic risk factors including younger rider age groups and limited riding experience (Abdul Manan et al., 2016; Idris et al., 2019; Rusli et al., 2017; Yusoff et al., 2022).

From a road engineering and environmental perspective, the physical characteristics of the Cameron Highlands road network further exacerbate these behavioural vulnerabilities. Sharp horizontal curves, steep gradients, narrow traffic lanes, limited paved shoulders, insufficient roadside protection systems, and variable pavement surface conditions introduce high demands on rider stability and vehicle handling performance.

Compounding these challenges are the Cameron Highlands' weather conditions, including frequent rainfall, fog, and reduced visibility, which increase the risk of road skidding and limited sight distance. The shared use of the roadway with large tourism buses and heavy commercial vehicles further elevates conflict potential, reinforcing a high-risk operating environment for motorcyclists.

The disproportionately high involvement of motorcycles with engine capacities below 250 cc indicates a heightened exposure to crash risk among this user group along the primary access route to Cameron Highlands. This pattern reflects not only the numerical dominance of low-capacity motorcycles in Malaysia’s vehicle fleet but also their high reliance on daily commuting, commercial activities, and tourism-related travel, which collectively increase traffic exposure on the mountainous road network. The operational vulnerabilities of this vehicle category, including lower power-to-weight ratios, reduced stability during braking and cornering, limited conspicuity in mixed traffic, and heightened sensitivity to adverse pavement and weather conditions, further compound crash risk in geometrically constrained environments characterised by steep gradients, sharp curves, and narrow cross-sections.

These findings underscore the necessity for motorcyclist-focused road safety interventions that address both infrastructure deficiencies and operational hazards unique to mountainous terrain. Accordingly, future road safety planning at the research location should prioritise the application of motorcycle-friendly roadside barrier systems to mitigate injury severity during run-off-road events, the deployment of high-friction surface treatments to enhance pavement skid resistance under wet and downhill braking conditions, and the installation of advanced curve delineation and conspicuous warning signage to improve rider perception of roadway alignment. Additionally, effective traffic speed management strategies, including targeted enforcement, optical speed reduction measures, and curve-approach treatments, are essential to reduce kinetic energy at high-risk sites. Where right-of-way and geometric constraints permit, the provision of segregated or protected motorcycle facilities should be considered to minimise conflict between vulnerable riders and heavy or opposing traffic flows. Figure 4.1 illustrates the distribution of crash cases by vehicle type, clearly confirming the dominance of sub-250 cc motorcycles in recorded crash involvements during the analysis period and reinforcing the need to prioritise infrastructure interventions that specifically address motorcyclist safety along the Cameron Highlands road network.

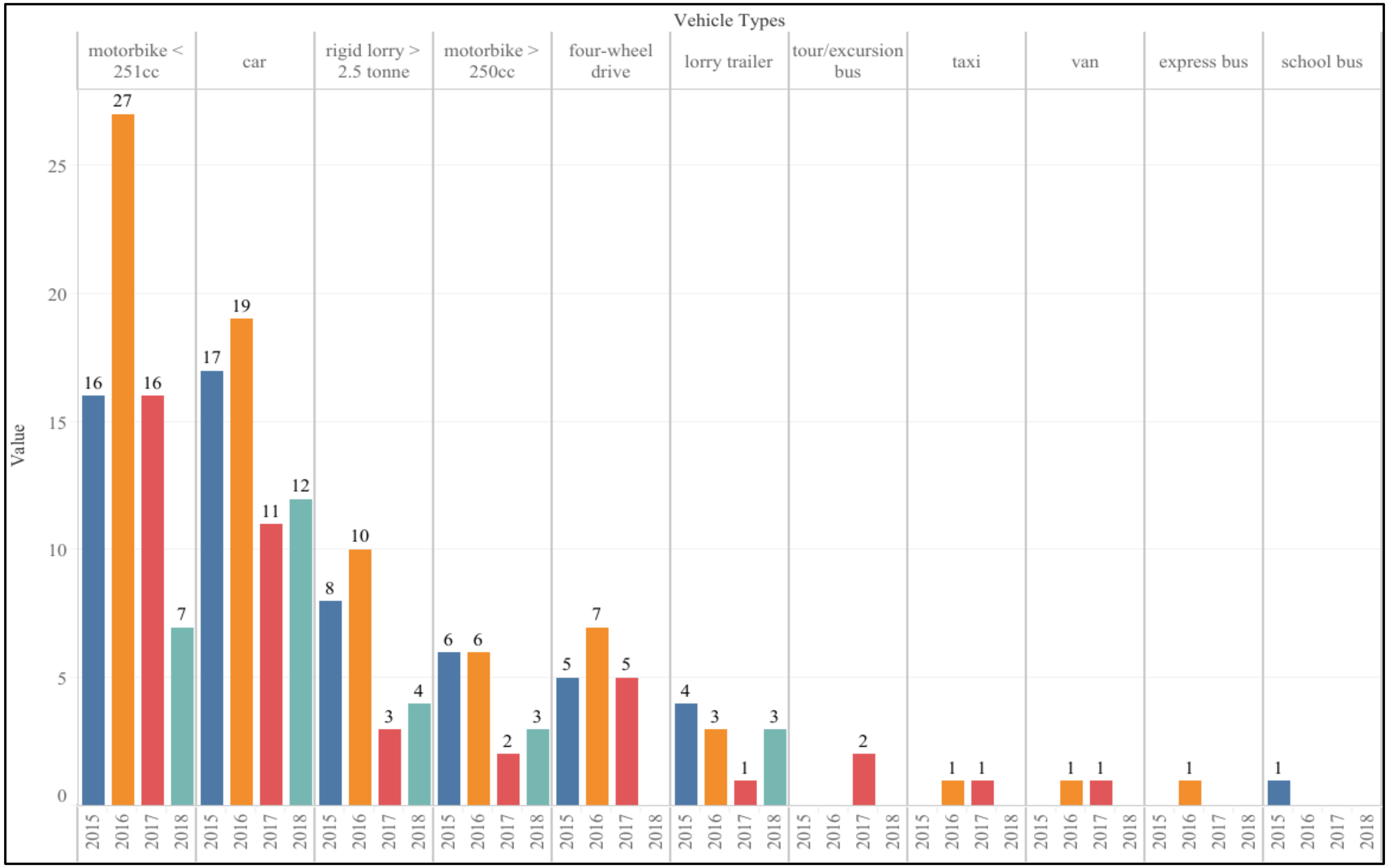

Figure 4.1 Distribution of the Most Dominant Vehicle Types Involved in Road Crashes

4.3.2 Category-by-Category Line Plot Chart

This study categorises crash severity into three levels based on the secondary data used for analysis: (i) Fatal injuries, (ii) Serious injuries, and (iii) Slight injuries. Fatal injuries are defined as crash events in which at least one individual (driver or passenger) dies within 30 days due to injuries sustained in the crash (Elshamly et al., 2017; Peng et al., 2018). Serious injuries refer to cases where at least one person requires hospital admission for medical treatment but survives, while slight injuries denote minor abrasions or bruises that do not require hospitalisation or extensive medical care.

For fatal injuries, head-on collisions consistently account for the largest share of crash records in all four years. In 2015, fatal head-on collisions represented 7.483% of all crash records, followed by out-of-control crashes (4.762%) and smaller contributions from pedestrian and sideswipe collisions (each around 0.680%).

A similar pattern is observed in 2016, where head-on collisions again constitute the largest proportion of fatal crashes (6.803%), while out-of-control collisions contribute 5.442% and other collision types, such as angular and rear-end. Pedestrian-related crashes contribute approximately 0.680% each.

In 2017, the proportion of fatal crashes decreased across most collision types; however, head-on collisions remained the leading contributor (4.082%), followed by out-of-control crashes (3.401%) and smaller contributions from rear-end and sideswipe collisions (about 1.361% each).

In 2018, fatal involvement rose again, with head-on collisions accounting for 6.803% of all crash records and pedestrian-related collisions contributing approximately 5.442%, indicating a renewed concentration of high-severity crashes among vulnerable road users in the final year of the study. Figure 4.2 illustrates the annual distribution of crash severity across different collision types from 2015 to 2018. The percentages shown in the figure represent each collision type's proportion relative to the total number of crash records in the dataset, thereby providing an overview of how different collision mechanisms contribute to the overall burden of crash severity.

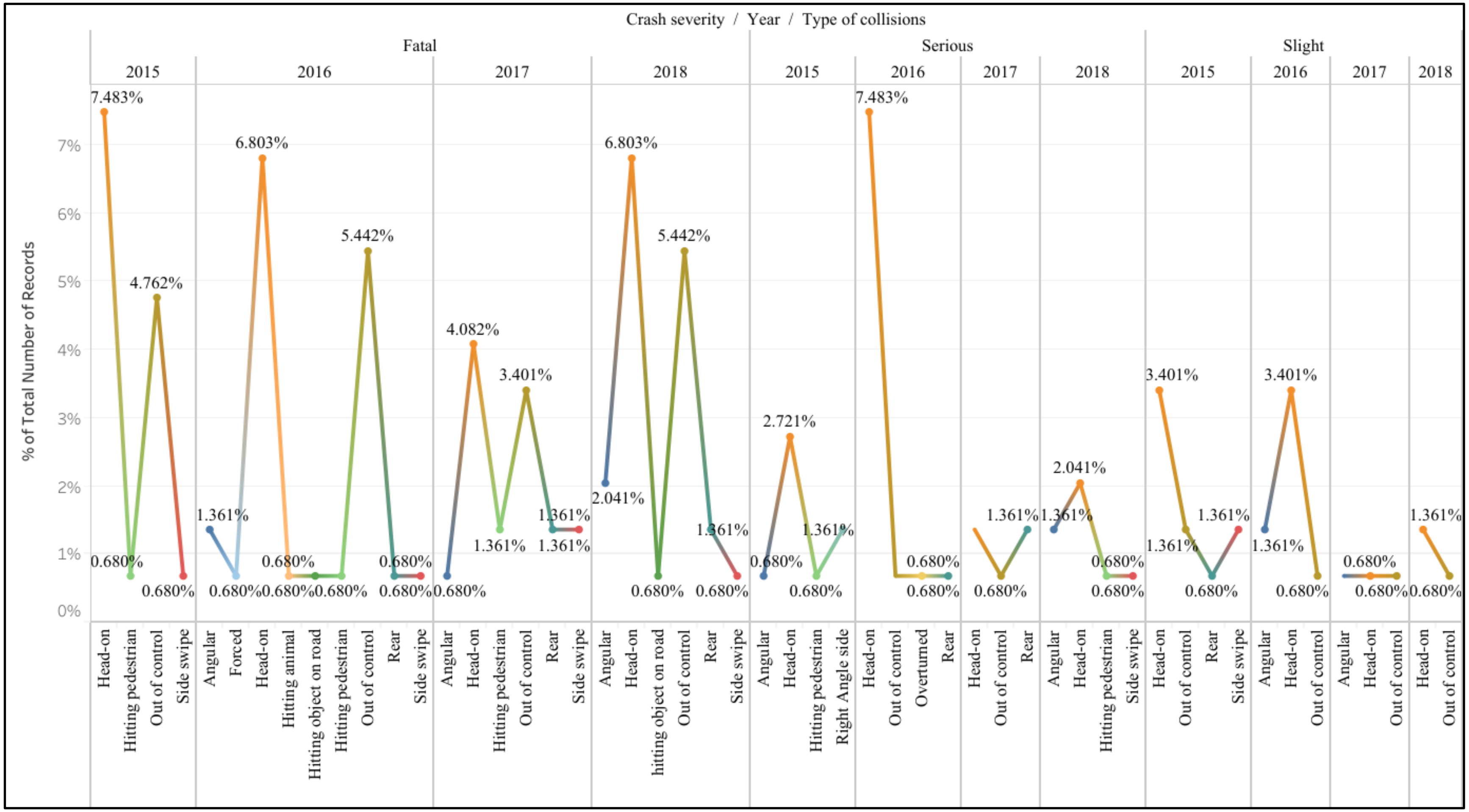

Figure 4.2 Crash Severity versus Type of Collision by Year (2015 –2018)

For serious injuries, Figure 4.2 indicates that 2016 records the highest overall proportion compared with the other years. Serious head-on collisions in 2016 account for 7.483% of total crash records, with additional contributions from out-of-control and rear/overturned collisions (around 3.361% and 1.361%, respectively). In 2015, serious injuries were moderately distributed across several collision types, with out-of-control crashes contributing about 3.361%, head-on collisions 2.721%, and pedestrian and sideswipe collisions approximately 1.361% each. In contrast, 2017 shows very low proportions of serious injury crashes, generally around 0.680% across collision types. In 2018, serious injury crashes increased slightly again, with head-on collisions accounting for about 2.041% and out-of-control crashes accounting for about 3.361% of the total records.

Slight injuries are most prevalent in 2015 and 2016, with head-on collisions accounting for approximately 3.401% of total crash records in each year, while other collision types, such as out-of-control, rear-end, and sideswipe crashes, contribute smaller shares (around 1.361% or less). In 2017 and 2018, the proportions of slight injury crashes declined markedly, with most collision types contributing between 0.680% and 1.361% of total records.

Overall, the patterns in Figure 4.2 demonstrate that head-on collisions persist as the dominant contributor to crash records across all severity levels, while out-of-control and pedestrian-related crashes form the second tier of high-risk collision types. These results align with previous findings by Peng et al. (2018), who reported a strong association between head-on collisions and fatal outcomes, particularly along mountainous or winding roadway environments. The recurring prominence of head-on and out-of-control crashes in the fatal and serious injury categories underscores the need for targeted engineering and enforcement countermeasures in Cameron Highlands, including median separation, improved curve delineation, roadside safety barriers, and speed management interventions along high-risk segments.

The traffic systems analysed in this study include four configurations, namely (i) Dual carriageway, (ii) One-way road, (iii) Three-lane road, and (iv) Two-way road. The crash data illustrates that head-on collisions occur most frequently in two-way traffic systems, where vehicles travel in both directions without physical separation. Figure 4.3 presents a multi-category area plot chart that visualises the distribution of road collisions in Cameron Highlands by traffic system and collision type from 2015 to 2018.

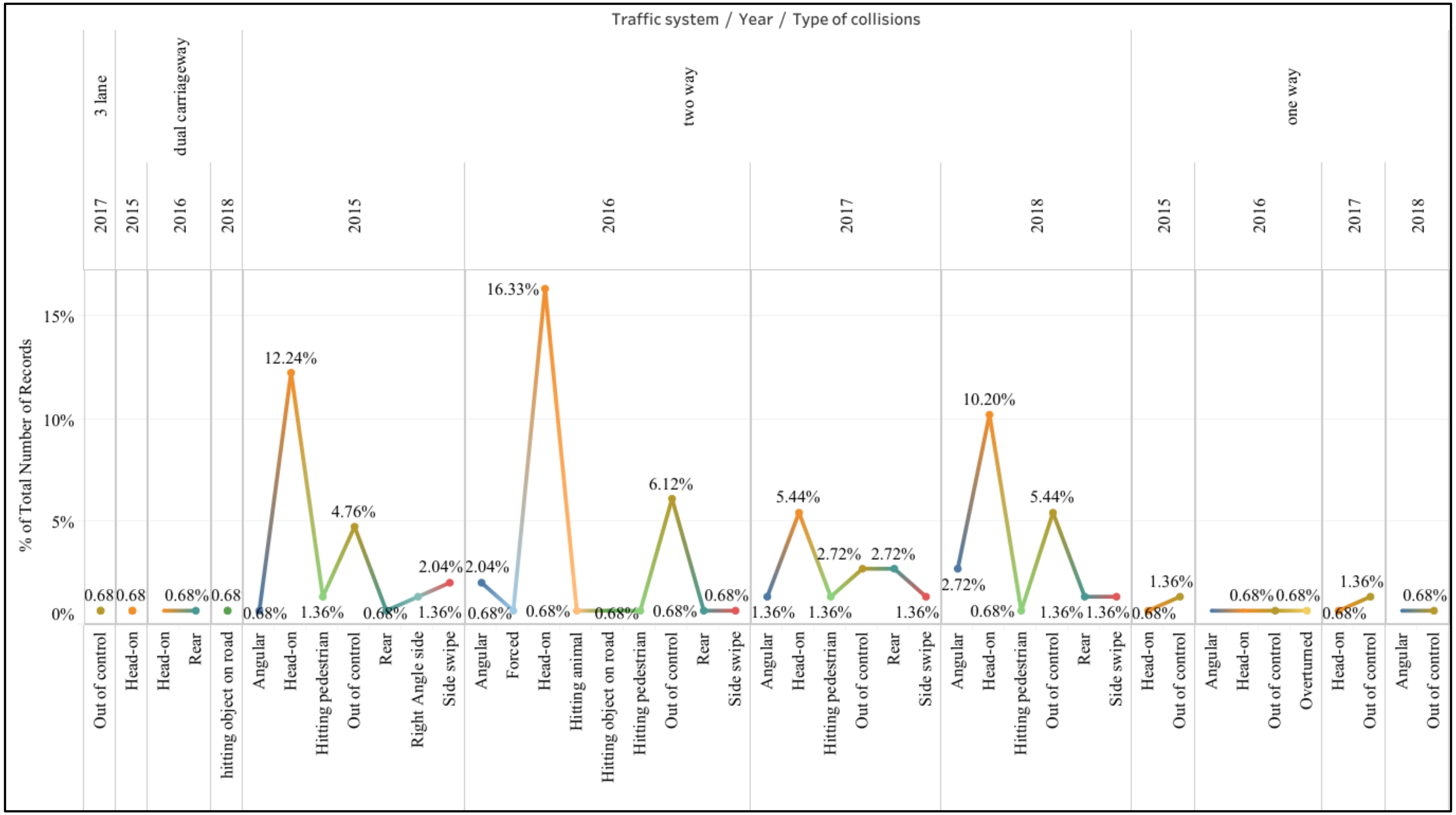

Figure 4.3 Traffic System versus Type of Collision by Year (2015 – 2018)

In particular, the highest head-on collision concentration indicates 16.33% of total recorded cases in 2016 on two-way roads. Additional spikes case appeared in 2015 (12.24%) and 2018 (10.20%), further reinforcing this crash pattern. Two-way traffic systems dominate the crash statistics for several other collision types as well, including out-of-control crashes, particularly in 2016 (6.12%) and 2018 (5.44%), rear-end and sideswipe collisions, and forced or angular collisions, especially under constrained geometry. These results highlight an apparent vulnerability in undivided two-way rural roads, particularly when combined with the geometric and environmental challenges common in mountainous regions such as Cameron Highlands. The findings align with those reported by Cáceres et al. (2021) and Maksid and Hamsa (2014), who concluded that head-on collisions are closely associated with poor geometric road design. Their research found that the likelihood of a head-on crash increases significantly on road sections with the following characteristics: widths of 7 meters or more, encouraging high speeds, horizontal curves without sufficient visibility, sudden narrowing or elevation changes, wet or slippery surfaces, particularly during adverse weather, twilight or low-visibility conditions, improper overtaking behaviour, and inadequate median width or unpaved shoulders. The interaction between geometric road elements and driver behaviour, especially in rural two-way road contexts, plays a substantial role in the frequency and severity of head-on and out-of-control collisions in the highland environment. These findings underscore the need for countermeasures such as centreline rumble strips, overtaking restrictions, and physical separation (e.g., flexible posts or medians) in identified blackspots along the Simpang Pulai to Blue Valley road network as future consideration to improve road safety in the research location.

4.3.3 Area Pattern Chart with Multiple Categories

The area pattern chart categorises crash occurrences according to three land use-based location types, namely rural, urban, and built-up areas, while at the same time categorising crashes by road segment and year of crash occurrence. In this study, urban areas refer to road sections within towns or where residential, commercial, or mixed land uses predominate and traffic activity is higher, but that do not yet exhibit the continuous roadside development characteristic of a built-up road network. Meanwhile, built-up areas are densely developed roadway environments characterised by continuous frontage, frequent access points, roadside businesses, pedestrian activity, and on-road parking. Rural areas correspond to road segments traversing sparsely developed terrain with minimal roadside development, typically associated with mountainous or forested landscapes. Figure 4.4 presents a multidimensional visualisation of road crash data across three districts, namely Cameron Highlands, Gua Musang, and Ipoh, over four years (2015 to 2018).

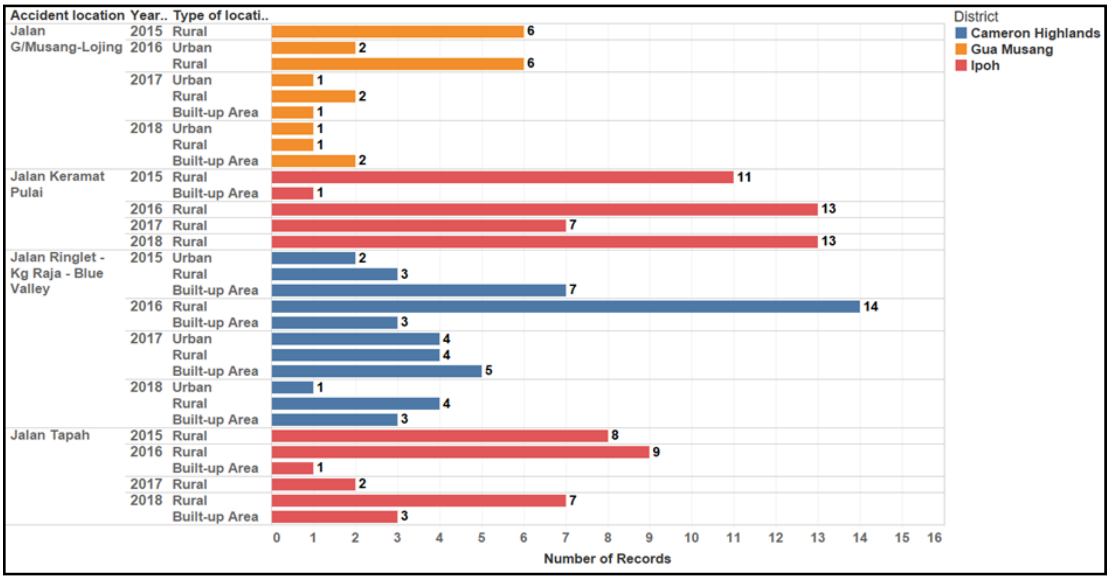

Figure 4.4 Crash Location and Type of Location (Urban and Rural Areas)

Figure 4.4 enables a comparative evaluation of crash distributions across these spatial contexts at the district level for the period 2015 to 2018. The results show that the highest frequency of crashes (n = 14) occurred in rural segments along the Jalan Ringlet – Kg. Raja – Blue Valley road network in the Cameron Highlands district in 2015. This finding underscores the heightened vulnerability of rural mountainous road environments to crash events. These road sections typically traverse topographically constrained terrain and are characterised by inconsistent geometric design, limited recovery space, narrow shoulders, reduced sight distance, and frequent horizontal curvature, often coupled with insufficient safety infrastructure such as guardrails, edge delineation, and hazard warning signage. This observation is consistent with the findings of Shallam et al. (2022), who reported that geometric inconsistencies significantly compromise road safety performance on undivided rural roadways, particularly in highland terrains. The crash clustering observed along the Jalan Ringlet–Kg Raja–Blue Valley route further underscores the need for systematic geometric safety audits and targeted infrastructure upgrades in high-risk mountainous segments.

The data further demonstrate that crash occurrences are not confined exclusively to rural zones. For instance, the Jalan Keramat Pulai corridor in Ipoh district, which traverses both urban transitional environments, recorded persistently high crash counts, with 11 crashes in 2015 and 13 crashes in both 2016 and 2017, predominantly on rural-classified road segments located just beyond the urbanised boundary. This temporal consistency suggests the presence of persistent risk factors along the route, including complex roadway alignment, high traffic volumes linking urban centres to highland tourist destinations, limited overtaking opportunities, and variations in enforcement intensity. These conditions warrant further investigation into speed management adequacy, alignment consistency, roadside protection elements, and driver behavioural compliance along this corridor.

Figure 4.4 also illustrates crash aggregation within urban and built-up environments, particularly along Jalan Tapah and sections of Jalan Keramat Pulai within Ipoh. In these locations, urban segments represent transitional zones at the edges of urban settlements, where through-traffic interacts with local access movements, public transport, pedestrians, roadside parking, and commercial access points. For example, Jalan Tapah recorded nine rural crashes in 2016 and eight crashes within built-up sections in 2015, highlighting the elevated crash risk at spatial transition zones between rural high-speed operation and urban low-speed activity. Such environments are prone to conflict exposure due to mixed traffic streams, sudden speed differentials, frequent driveway access, inconsistent lane configurations, and inadequate transition signage or speed harmonisation treatments.

Collectively, these spatial patterns demonstrate that crash risk along mountainous networks is influenced not solely by land-use classification but by the interaction of roadway geometry, operating speed environment, traffic composition, and roadside development intensity. Rural mountainous corridors remain the dominant high-risk locations due to physical design constraints; however, urban and built-up transition zones also exhibit elevated crash exposure, particularly where inadequate speed management and access control treatments are in place.

Therefore, Figure 4.4 provides critical evidence supporting the need for a context-sensitive road safety approach, in which rural mountainous road segments prioritise geometric realignment, skid-resistant surfacing, roadside protection systems, and enhanced curve delineation. Urban road networks emphasize speed transition treatments, access management, pedestrian controls, and visibility enhancement strategies. Such differentiated road safety interventions are essential to reduce crash risk across varying land-use contexts and to improve transportation safety outcomes within mountainous road networks such as Cameron Highlands.

The area pattern chart also shows groups of crashes happening in developed areas, especially along Jalan Tapah and Jalan Keramat Pulai in Ipoh, suggesting that areas on the edge of towns or cities might also need serious attention to improve road safety. Notably, Jalan Tapah recorded nine crashes in rural areas in 2016 and eight crashes in built-up areas in 2015, indicating that transitional zones between rural and urban contexts can also show elevated crash risk due to mixed traffic conditions and inconsistent road design standards. In conclusion, Figure 4.4 provides valuable insights into the spatial and temporal distribution of crash incidents across varying road typologies and districts. The results underscore the importance of adopting a context-sensitive approach to road safety, particularly for rural and highland road networks. Road designers and authorities should improve geometric design consistency, enhance visibility and signage, and strengthen behavioural interventions through education and law enforcement. These steps are essential to reduce the overall risks found in the crash data and help build safer and sustainable roads, especially in mountainous areas.

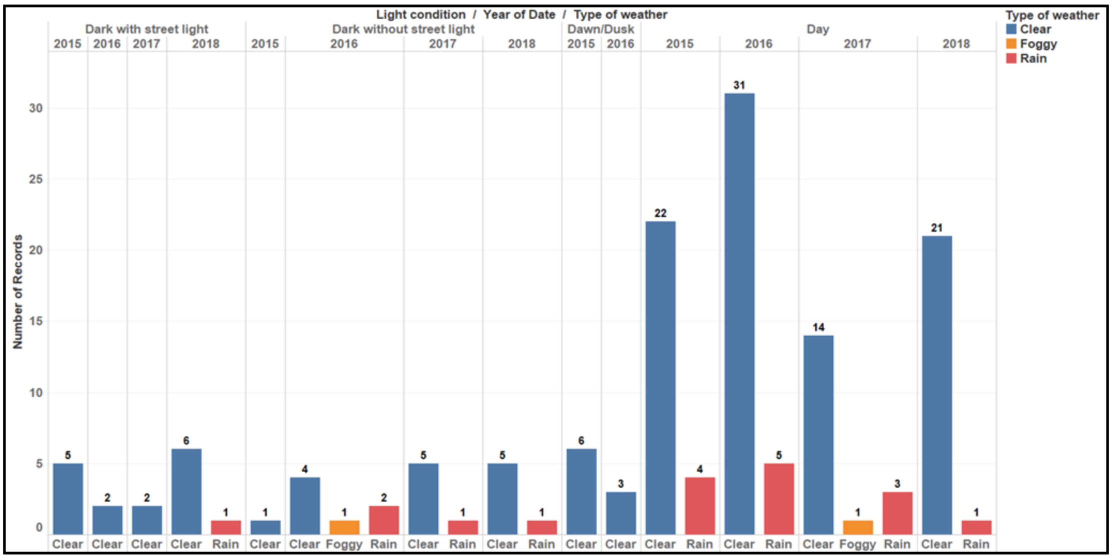

Figure 4.5 Light Condition versus Type of Weather

Figure 4.5 presents a cross-tabulated analysis of road crash occurrences by light condition and weather type for the period 2015 to 2018. Light conditions are classified into four categories: (i) daylight, (ii) dawn/dusk, (iii) darkness without street lighting, and (iv) darkness with street lighting. Weather conditions are categorised as clear, rainy, and foggy. This framework enables assessment of how environmental operating conditions influence crash frequency within the mountainous road network.

The results indicate that the highest concentrations of crashes consistently occurred during daylight under clear weather conditions, with recorded peaks of 22 crashes in 2015, 31 crashes in 2016, and 21 crashes in 2018. These values are substantially higher than all other light weather combinations observed during the study period. Rain-related crashes occurred at moderate levels, particularly under daylight conditions, with the highest values observed in 2015 (4 cases) and 2016 (5 cases). Fog-related crashes were rare, with only one incident recorded each year during daylight hours in 2016 and 2017.

Under nighttime conditions, crash frequencies were markedly lower, regardless of the weather factor. Road segments which classified as dark without street lighting recorded no more than five crashes per year, while segments with street lighting did not exceed six crashes annually. The consistently lower nighttime crash frequencies strongly suggest that traffic exposure levels are significantly reduced during nighttime operating periods, a trend commonly documented in traffic safety studies in which lower traffic volumes correspond to reduced absolute crash counts. These findings align with behavioral crash-risk research reported by Duddu et al. (2020), which demonstrated that driver risk-taking behaviour is more frequently observed during favourable operating conditions, particularly when perceived road safety improves and traffic flow increases.

The dominance of daylight and clear weather crashes observed in Figure 4.5 does not imply that deteriorated weather or reduced visibility conditions are inherently safer. Instead, the pattern indicates that higher traffic exposure, combined with behavioural risk amplification under good driving conditions, produces more absolute crash occurrences. Numerous studies have demonstrated that favorable environmental conditions are associated with higher speeds, reduced headway, and increased overtaking manoeuvres, all of which contribute to increased collision risk despite improved visibility and pavement friction (Duddu et al., 2020). Conversely, adverse conditions such as fog and heavy rainfall are typically associated with reduced traffic volumes and more conservative driving behaviours, which may explain the lower recorded crash frequencies despite the elevated per-vehicle risk.

Overall, Figure 4.5 demonstrates that crash occurrence within mountainous road environments is strongly influenced by a combination of exposure effects and behavioural adaptation, rather than environmental severity alone. The evidence indicates that road safety interventions should not be limited to adverse or nighttime conditions but must also target routine daytime driving behaviour, where the majority of crashes occur. From a policy and engineering perspective, these findings support the implementation of speed management measures, enhanced curve-warning systems, targeted enforcement during daytime peak-traffic periods, and behavioural road safety campaigns designed to mitigate risk-taking behaviour even under optimal weather and lighting conditions.

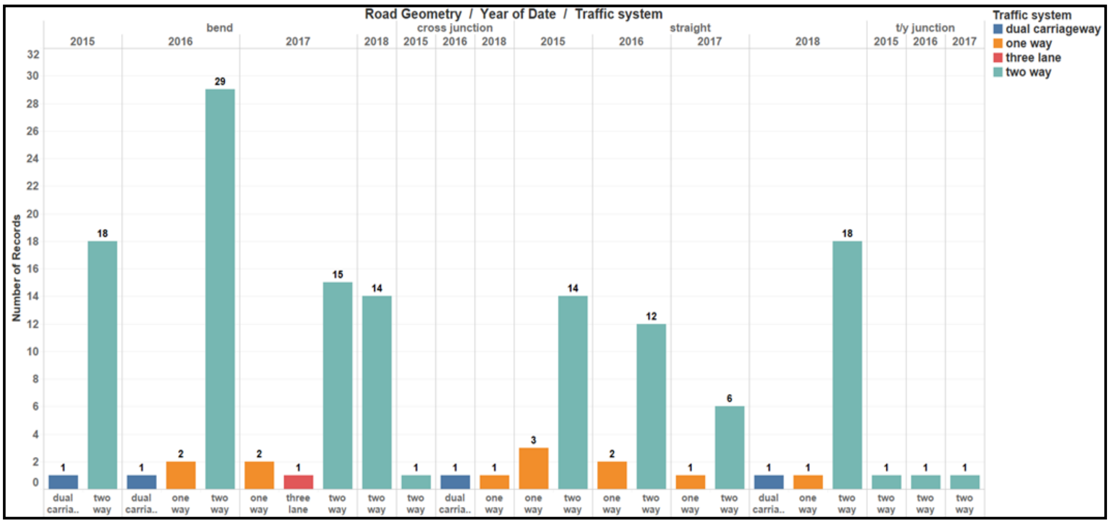

Figure 4.6 Road Geometry versus Traffic System by Yearly

Figure 4.6 illustrates crash distributions across multiple roadway geometries and traffic system classifications for the period 2015 to 2018. The geometric categories include bends or curves, straight sections, cross junctions, and T or Y junctions; meanwhile, traffic systems are classified as two-way, one-way, dual-carriageway, and three-lane road segments. The analysis indicates that the highest single-category crash frequency occurred on two-way road sections with bends, with 29 crashes recorded in 2016. Junction-related crashes were most pronounced at two-way T or Y junctions in 2015, accounting for 18 recorded incidents, representing the peak annual total for this geometry type. Straight two-way sections also displayed elevated crash frequencies, with 14 crashes recorded in both 2016 and 2017, indicating persistent risk associated with undivided straight roadway segments operating under mixed traffic conditions.

These results demonstrate that two-way undivided roads, particularly at curved alignments and junctions, exhibit the highest crash exposure within the mountainous network. This outcome is consistent with the findings of Ingle and Gates (2023) and Joseph et al. (2023), who reported that geometric inconsistencies and restricted sight distances along rural two-way roadways are strongly correlated with crash occurrence and severity. Road sections characterised by sharp curvature, limited forward visibility, variable lane width, and the absence of median separation increase the likelihood of head-on collisions, loss-of-control events, and run-off-road crashes, particularly in mountainous operating environments.

However, this research is subject to a key data limitation: the available crash dataset lacks detailed geometric and operational attributes, such as precise curve radius, roadway gradient (steepness), unobstructed sight distance, effective lane and shoulder widths, or observed operating speeds at specific crash locations. The absence of these micro-level parameters is particularly relevant at high-risk sections identified in Figure 4.6, including the two-way curved segments with peak crash frequencies in 2016 and the two-way T or Y junction areas recorded in 2015. Without such detailed geometric descriptors at these locations, the analysis is limited to interpreting macro-level spatial patterns. It cannot quantify the precise geometric risk thresholds that influence crash occurrence. Future studies incorporating site-specific road geometry measurements and speed profile data at locations such as the bend-dominated sections and junction interfaces identified in this assessment would enable more robust modelling of risk mechanisms and facilitate more precise development of targeted road safety countermeasures for the mountainous road network.

In addition to bends, the data also shows that T and Y junctions and straight two-way roads had a high number of crashes. These findings indicate that complex curves and seemingly simple road sections can be risky, especially when drivers are distracted, overconfident, or lack clear markings and road signage (Rolison et al., 2018; Singh & Kathuria, 2021). Figure 4.6 summarised that the shape of the road and the type of traffic system strongly influence crash risk, especially in rural or less developed areas where the topography only allows road engineers to design and construct two-way roads at the location. These insights suggest that road safety improvements should focus on better road design at curves and intersections, clearer signs and road markings, and traffic control measures to reduce crash risks in known danger blackspot location for mountainous roadways.

4.3.4 Spatial Distribution Pattern of Total Road Crash Cases

This section reveals the spatial distribution patterns of road crash cases in Cameron Highlands, aiming to identify high-risk locations and understand the geographical concentration of incidents along key road corridors between 2015 and 2018. The visual analysis indicates a high concentration of crash incidents along several major road networks connected to Cameron Highlands, with the highest number recorded along Jalan Ringlet – Kg. Raja – Blue Valley (50 cases) and Jalan Keramat Pulai (44 cases). These findings justify the selection of the Jalan Simpang Pulai to Blue Valley road network as the primary research location, given its prominence as a high-risk mountainous route. Other notable crash-prone major routes include Jalan Tapah (26 cases) and Jalan Gua Musang – Lojing (18 cases). Collectively, these corridors represent the most hazardous sections of the Cameron Highlands road network, particularly in rural and terrain-challenging environments. Figure 4.7 presents the spatial distribution of road crash cases in Cameron Highlands from 2015 to 2018.

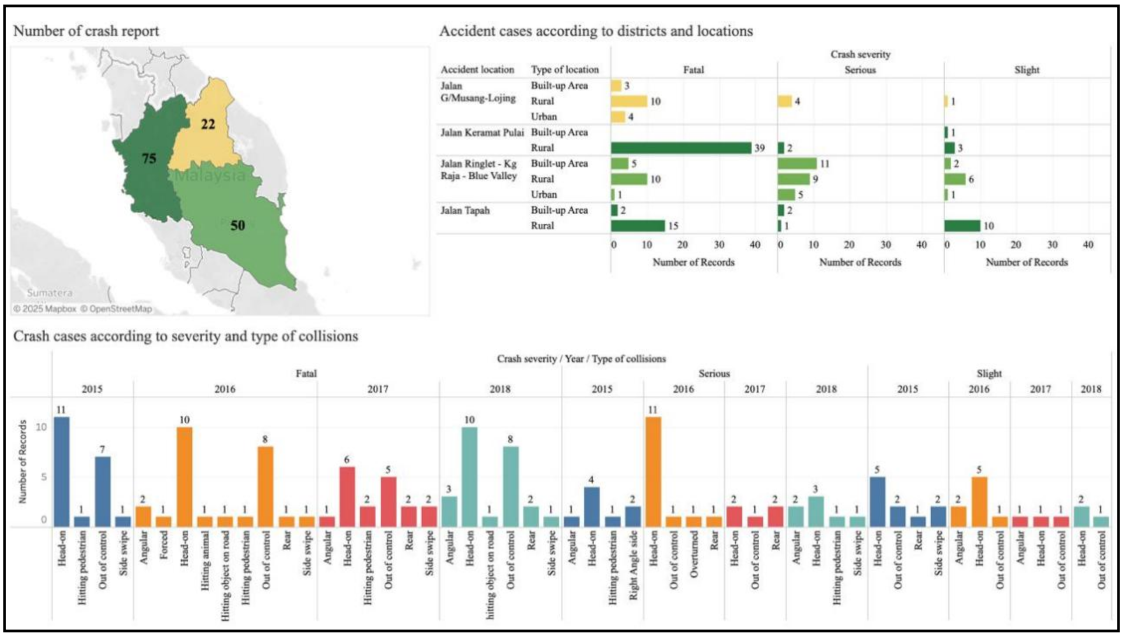

Figure 4.7 Spatial Distribution of Road Crash Cases and Collision Types in Cameron Highlands.

The most frequently recorded crash types include head-on collisions, sideswipe crashes, vehicle out-of-control incidents, forced collisions, right-angle side impacts, collisions with roadside animals, and pedestrian impacts. These types of crashes, especially in rural two-way roads, are often associated with fatal or serious injuries, reflecting the high-risk nature of mountainous and geometrically challenging road environments.

Furthermore, analysis across crash severity categories of fatal, serious, and slight injuries indicates that head-on collisions were consistently present in all severity levels, with the highest number occurring in 2015 and 2018. These incidents are predominantly observed along two-way rural roads, where vehicles travel in opposite directions without physical separation. Many of these crashes occurred under clear weather conditions, at bends or curves, T or Y-junctions, and on straight road segments, suggesting that infrastructure-related factors and driver behavior both contribute significantly to crash occurrences. The detailed spatial and frequency analysis underscores the importance of location-specific interventions in crash-prone corridors. By identifying high-risk segments through spatial analytics, this research provides evidence-based insights that can guide geometric design improvements, traffic management strategies, and targeted road safety enhancements. Specifically, applying a spatially informed approach in mountainous regions such as Cameron Highlands can support more effective policy and infrastructure responses to reduce crash severity and improve overall road safety performance.

It is important to acknowledge that the crash data utilised in this research are derived exclusively from police-reported records (POL27 through ITIS and M-ROADS) and therefore reflect only reported incidents rather than the absolute number of crashes. Previous road safety research has consistently demonstrated that under-reporting data is particularly prevalent for non-fatal crash severities, especially cases classified as slight injuries or damage-only incidents, which are frequently not reported to police due to reliance on private medical treatment, insurance self-settlement, or the perception that formal reporting is unnecessary. Consequently, while fatal crash records are generally considered to exhibit high reporting completeness, the observed frequencies of serious and slight injury crashes in Figure 4.7 are likely conservative estimates of the true injury cases along the mountainous road network. This limitation should be considered when interpreting severity distributions; nevertheless, the dataset remains highly reliable for the identification of dominant crash mechanisms, spatial risk trends, and road engineering safety deficiencies, which are the primary objectives of this research.

4.4 Number of Fatalities by Collision Type

Motorcycle safety remains a critical concern in mountainous regions such as the Jalan Simpang Pulai to Blue Valley route in the Cameron Highlands, where unique road conditions increase motorcyclists' vulnerability. This section explains the rationale for selecting motorcyclists as the focus of this research. Table 4.4 shows that the high percentage of motorcycle fatalities, as reflected in RMP data (62% of total fatalities from 2015 to 2018), underscores the urgent need for targeted interventions. These fatalities, predominantly resulting from head-on and run-off-road collisions, highlight the interplay of road infrastructure, environmental conditions, and behavioral factors in shaping road safety risks. The analysis of this data through theoretical lenses, such as Haddon’s Matrix and iRAP’s star rating methodology, provides valuable insights for developing effective safety measures.

Table 4.4
The Motorcyclists' Number of Fatalities by Collision Type

Category	**Vehicle Occupant**				**Motorcyclist**				
Year/ Collision Type	**Head -on**	**Run -off**	**Others**	**Sub-total**	**Head -on**	**Run-off**	**Along**	**Sub-total**	**Total**
2015	4	1	0	5	2	3	1	6	11
2016	2	0	0	2	2	5	2	9	11
2017	1	0	0	1	2	1	2	5	6
2018	4	2	2	8	3	2	1	6	14
Total	11	3	2	16	9	11	6	26	42
Category Percentage	69%	19%	13%	100%	35%	42%	23%	100%	-
Total Percentage	38%				62%				100%

Mountainous roads pose significant challenges to motorcyclists due to their inherent geometric complexities, including sharp curves, steep gradients, and narrow lanes. The risk of run-off-road crashes (42% of motorcycle fatalities) is exacerbated by inadequate roadside safety infrastructure, such as the absence of crash barriers or forgiving adequate road shoulders. These results align with the findings of Turner et al. (2016), which emphasize that insufficiently protected roads increase crash severity for motorcyclists. Additionally, head-on collisions (35% of fatalities) are often attributable to limited sightlines on curving roads, which compromise the ability of motorcyclists to anticipate oncoming vehicles, especially when overtaking or negotiating sharp bends. Environmental conditions in Cameron Highlands, such as frequent fog, rain, and slippery road surfaces, further heighten the risk of losing control, particularly for motorcyclists whose smaller tires and reduced stability make them more susceptible to skidding. The lack of lighting and adequate road markings in these areas compounds visibility challenges, aligning with studies by Kumar et al. (2020) that highlight poor visibility as a critical risk factor in motorcycle crashes.

Haddon's Matrix provides a robust framework for understanding motorcycle safety risks on mountainous roads by categorizing factors into pre-crash, crash, and post-crash phases. In the pre-crash phase, excessive speeds on steep or winding roads and insufficient enforcement of traffic rules increase the likelihood of road crash cases among road users. The crash phase highlights the physical vulnerability of motorcyclists, who lack the protective enclosures of vehicle occupants. Finally, in the post-crash phase, the lack of prompt medical access in remote mountainous areas contributes to higher fatality rates, as noted in studies by Mohan et al. (2019). Additionally, the International Road Assessment Programme (iRAP) emphasizes the importance of star ratings for road safety assessment. The application of the modified model to quantify risk factors along the research location can provide actionable insights into the safety performance of road infrastructure. The researcher can use this model to prioritize road safety interventions by integrating crash data, geometric attributes, and exposure metrics, thereby achieving the most significant road safety benefits as a research output.

Improving motorcycle safety on mountainous roads requires a multi-faceted approach that addresses both infrastructure deficiencies and behavioral factors. Several engineering measures are recommended, such as the installation of motorcycle-friendly guardrails to reduce the severity of run-off-road crashes. Flexible barriers that absorb impact forces have proven effective in curving and steep sections (Haworth & Debnath, 2014). Findings from the Transport Research Laboratory (2017) support the use of high-friction surface treatments to mitigate skidding risks on slippery roads. Enhanced road markings, reflective materials, and advanced curve warning signs can improve visibility, as demonstrated in studies by Candappa et al. (2021). From a behavioral perspective, educational campaigns targeting motorcyclists can promote awareness of defensive driving techniques and the importance of proper safety gear. Enforcement of speed limits using automated speed cameras can also discourage risky behaviors, aligning with evidence from Scandinavian countries, where speed enforcement reduces crash rates by up to 20% (Elvik & Katharina, 2023). Environmental adaptations such as fog-warning systems and solar-powered streetlights in critical sections can further address visibility challenges.

Finally, the application of the modified model which adapts the conventional iRAP framework by incorporating mountain-specific geometric risk factors (e.g., curvature severity, gradient, and sight-distance limitations), now focussing at motorcyclist risk weightings for two-way undivided roads, and integration of local crash exposure profiles enables the generation of star ratings that more accurately reflect motorcyclist road safety deficiencies along the research location. Researchers can prioritize low-star-rated segments with high crash rates for infrastructure upgrades, such as curve realignments or additional lanes. The iterative process of improving road star ratings aligns with global road safety targets and ensures the cost-effective allocation of resources. In conclusion, addressing motorcycle safety on mountainous roads like those in Cameron Highlands requires an integrated approach that combines engineering, enforcement, education, and environmental interventions. By tackling the unique challenges posed by road geometry, environmental conditions, and motorcyclist behavior, these strategies can significantly reduce fatalities and enhance the safety of one of Malaysia's most scenic but perilous roadways, such as Jalan Simpang Pulai to Blue Valley, Cameron Highlands.

4.5 Chapter Summary

This chapter presents a road crash data profile and spatial distribution pattern using crash data from 2015 to 2018 in Cameron Highlands. Using a combination of secondary data sources and Tableau software for data visualisation, this chapter identifies critical trends, high-risk locations, crash types, vehicle involvement, and contributing factors influencing crash severity in mountainous areas.

This chapter highlights key findings, including the predominance of motorcycle-involved crashes, particularly those involving engine capacities below 251cc and the frequent occurrence of head-on collisions, which researchers strongly associate with fatal injuries. Spatial distribution analysis revealed that Jalan Ringlet – Kg. Raja – Blue Valley and Jalan Keramat Pulai are among the most crash-prone corridors, validating the selection of the Simpang Pulai to Blue Valley route as the central study main road connecting to Cameron Highlands compared to other main routes.

The chapter also identified that most crashes occurred under clear weather and good light conditions, particularly along two-way rural roads with geometric inconsistencies such as curves, T or Y junctions, and steep gradients. This chapter categorised crash-contributing factors into three primary domains through a systematic literature review method: road engineering, driver behaviour, and weather conditions. The SLR analysis identified a total of 34 road engineering sub-factors, 19 behavioural attributes, and 7 weather-related elements as significant contributors to crash risk in mountainous regions. Furthermore, analysis of fatality records from RMP indicates that motorcyclists accounted for 62% of all road traffic fatalities along the study road segments, with run-off-road and head-on collisions identified as the dominant fatal crash mechanisms. In response to these findings, the application of theoretical frameworks, specifically Haddon's Matrix and the modified model, provides a robust basis for systematically identifying risk factors, quantifying infrastructure road safety deficiencies, and prioritising evidence-based road safety interventions appropriate for mountainous roadway environments.

Collectively, the findings from this chapter form the empirical and conceptual foundation for proposing a modified road safety risk assessment model in subsequent chapters. The insights gained from crash data profiling, spatial analytics, and factor classification contribute to evidence-based strategies for enhancing road safety, particularly for vulnerable road users in mountainous environments such as Cameron Highlands.

CHAPTER 5
RESULTS OF THE DETAILED ROAD CONDITION ASSESSMENT AND MODIFIED IRAP@HIGHLANDS MODEL

5.1 Introduction

This chapter presents the road safety assessment findings for motorcyclists along the mountainous roadway of Jalan Simpang Pulai to Blue Valley using a Modified iRAP@Highlands model developed and tailored in this study from the conventional iRAP framework to reflect mountainous roadway characteristics and motorcyclist risk exposure. Building upon the crash data profiling, spatial analysis, and thematic analysis insights outlined in the previous chapter, this assessment aims to evaluate the road safety performance aspect of road engineering, specifically for vulnerable road users, particularly motorcyclists, who represent a significant proportion of fatalities in this high-risk main road network connecting to Cameron Highlands.

The modified model integrates crash data profiles, geometric design parameters, road safety attributes, and exposure metrics to generate a motorcyclist-specific star rating score and risk assessment profile for the selected research site location road network. This customised model enhances the standard iRAP methodology framework and protocol by incorporating contextual factors unique to Malaysia's highland terrains, including limited sight distances, sharp curves, steep gradients, adverse weather, and the predominance of two-way undivided roads into the modified model. Additionally, the modified model adapts star rating protocols and risk weighting to reflect motorcyclists' behavioural and infrastructural risk maps for the mentioned site location in such environments.

This chapter is structured to present the modified model development process, the data inputs used for the assessment, and the outcomes of the star rating analysis. It also includes the identification of hazardous road segments, road safety deficiencies, and potential road safety countermeasures to be implemented at the mentioned site location. The road safety assessment outcomes are visualised through risk maps, road attribute evaluations, and star rating distributions to support targeted infrastructure improvements. The results generated by the modified model provide a data-driven foundation for proposing actionable and cost-effective road safety interventions tailored to motorcyclists at the research location.

5.2 Overall Star Rating Results of the Research Location for Motorcyclists

The road safety assessment using the iRAP Star Rating Model (Version 3) reveals that the research location road network exhibits significant road engineering factors regarding road infrastructure safety shortcomings, particularly for vulnerable road users. The star rating analysis, summarised in Figure 5.1, shows that the entire 55.6-kilometer stretch of the surveyed road network fails to meet minimum road safety star rating thresholds for all user groups.

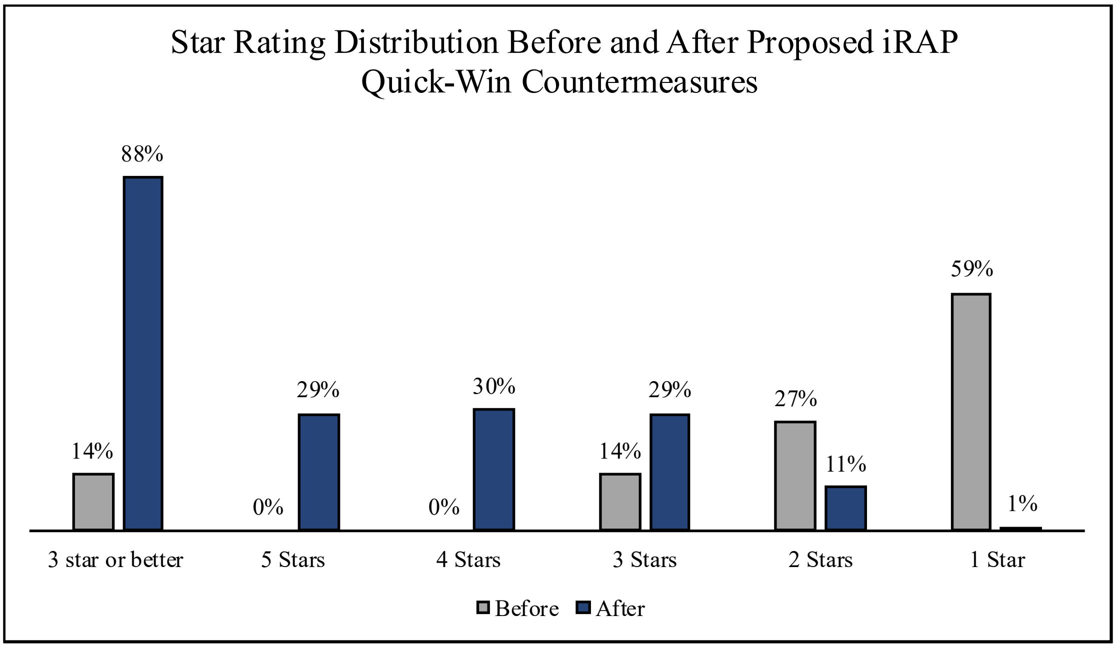

Figure 5.1 Star Rating Map for Motorcycle Road User Type: Smoothed Data Before Road Safety Intervention

Note: The researcher generated the star ratings using the iRAP Star Rating Model, Version 3, over a 55.6 km road segment.

The star rating assessment for motorcyclists along the research location mountainous road segments reveals substantial improvements in road safety performance following the implementation of the proposed iRAP quick-win countermeasures. Under baseline conditions (pre-intervention), the road network exhibited critically unsafe operating conditions, with 59% of the corridor rated at 1-star and a further 27% rated at 2-stars. Together, these low ratings indicate that 86% of the assessed route exposed motorcyclists to unacceptably high crash risk, attributable primarily to a combination of hazardous horizontal curvature, narrow undivided carriageways, roadside hazards, inconsistent delineation, limited recovery zones, and absence of motorcycle-targeted protective features. Only 14% of the corridor achieved a minimum acceptable road safety threshold of 3-stars or better, while no road section reached 4- or 5-star standards, underscoring a pervasive lack of adequate safety design for this vulnerable road-user group.

The introduction of targeted, cost-effective, quick-win road engineering treatments resulted in a substantial improvement in motorcyclist safety performance compared to the pre-intervention results. Post-intervention results demonstrate a pronounced redistribution of the star-rating profile toward higher safety categories. The proportion of 1-star road segments decreased dramatically from 59% to only 1%, while 2-star segments fell from 27% to 11%, reflecting a substantial mitigation of the most hazardous roadway conditions. In parallel, the share of roads achieving 3-stars or better expanded sharply from 14% to 88%, with the upgraded profile consisting of 29% 3-star, 30% 4-star, and 29% 5-star segments. This shift reflects a systematic improvement in road safety quality across the corridor rather than isolated local upgrades.

The scale of this road safety improvement demonstrates the effectiveness of targeted engineering countermeasures in addressing key crash risk factors for mountainous motorcycle riders. Road engineering treatments such as enhanced curve delineation, improved pavement skid resistance, motorcycle-friendly roadside barriers, speed management features, shoulder sealing, and upgraded signage directly target the dominant crash mechanisms in this setting, namely loss-of-control events at curves, roadside run-off crashes, and conflicts within two-way undivided sections. The results confirm that, even without major geometric reconstruction, the strategic application of proven road-safety treatments can produce rapid, measurable improvements in road-safety outcomes for vulnerable road users, such as motorcyclists.

Critically, the post-intervention star distribution aligns closely with global safe-system objectives, which advocate that road networks achieve 3-star or better performance to reduce fatal and serious injury risk substantially. Achieving 88% compliance with this benchmark represents a significant advance toward safer infrastructure conditions for motorcyclists in high-risk mountainous terrain. These findings provide strong empirical justification for the proposed quick-win programme as a cost-effective, immediately actionable strategy to reduce motorcycle crash risk along the research location road network, while serving as a scalable model for the safety upgrading of similar mountainous road networks across Malaysia.

5.2.1 Star Rating for Motorcycle Road User Type: Before Road Safety Intervention

Figure 5.2 illustrates the motorcycle star rating distribution along the research location, before implementing road safety interventions. In contrast, Figure 5.3 visualises the star rating map for motorcycles road user type before road safety intervention in detail for every 100 meters of road segments along the site location. Both visual representation reveals a critical road safety shortfall for motorcyclist road users throughout the 55.6 kilometers road segment.

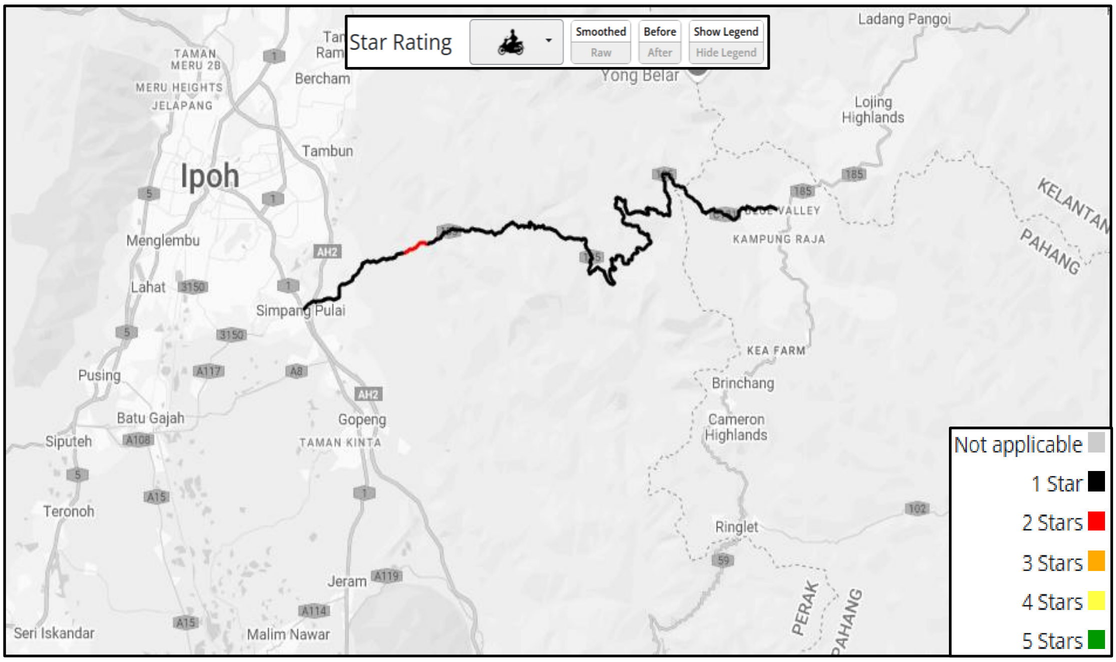

Figure 5.2 Star Rating Map for Motorcycle Road User Type: Smoothed Data Before Road Safety Intervention

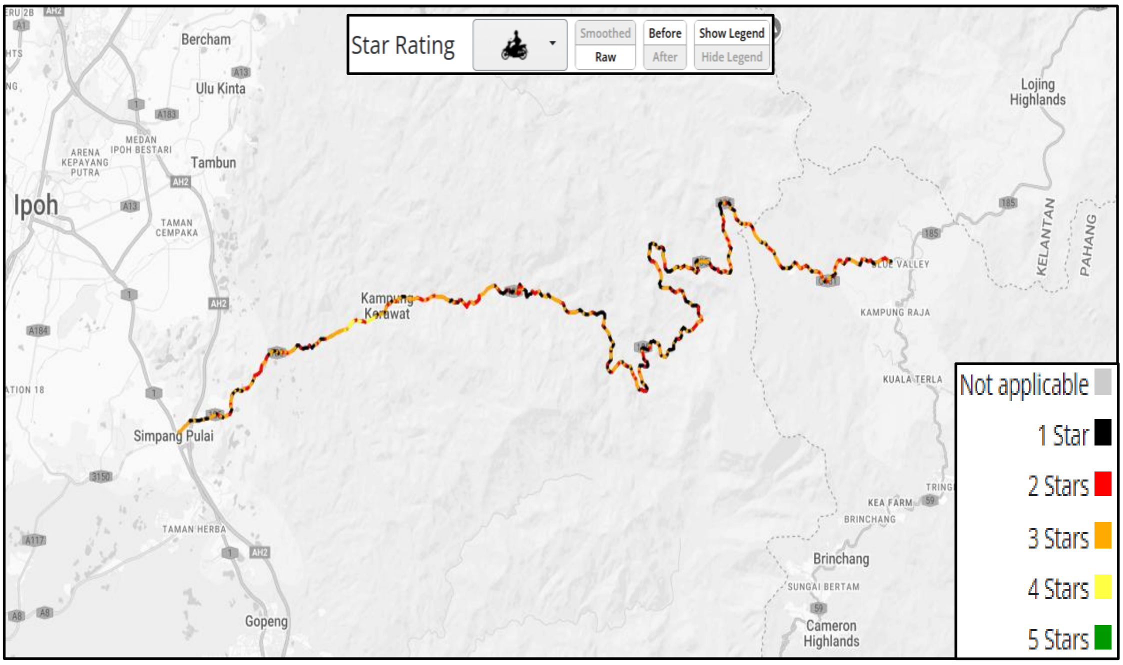

Figure 5.3 Star Rating Map for Motorcycle Road User Type: Raw Data Before Road Safety Intervention
(Detail Risk per 100 Meters of Road Segments)

The iRAP star rating assessment indicates that 97% of the road length (53.9 km) is rated at 1-star, representing the highest risk level for motorcycle users. This finding signifies that the entire route offers minimal road safety protection for motorcyclists, particularly in high-speed environments with challenging road geometries, narrow carriageways, and mixed traffic conditions. The lack of physical separation between motorcyclists and other road users, especially heavy goods vehicles, compounds the high risk of head-on collisions and run-off-road crash incidents. Only 3.1% of the route (1.7 km) achieves a 2-star rating, which still falls below the internationally accepted benchmark for minimum safe road conditions in terms of road engineering aspects. This research highlights the urgent need for targeted road infrastructure improvements due to the absence of road segments rated 3-stars or higher, especially since tourists, local commuters, and long-distance motorcyclists frequently use this route between Perak and Pahang to commute to Cameron Highlands.

In the map shown in Figure 5.2, the dominant black colour segments correspond to 1-star-rated road sections spanning the entire mountainous stretch from Simpang Pulai to Blue Valley, Cameron Highlands. A small section marked in red colour near Simpang Pulai indicates the short 2-star-rated segment. Notably, the star rating map has no yellow, green, or blue colour sections, confirming the absence of 3-star to 5-star-rated road segments for motorcycle road user type at this site location.

The concentration of low star ratings correlates with the known hazardous characteristics of this mountainous route, including risk factors such as narrow lanes with no motorcycle-exclusive lanes, steep gradients, sharp horizontal curves, lack of roadside safety barriers, poor visibility, and inadequate signage in critical sections. These findings demonstrate that, under current conditions, the existing road does not meet safe design standards for motorcycle users. The assessment classifies the road segment as 1-star based on a combination of road engineering design deficiencies and operational hazards that substantially increase the likelihood of fatal or severe injuries for motorcyclist users. The combination of steep gradients, sharp curves, limited recovery zones, and high motorcycle crash involvement along the Cameron Highlands road network necessitates the implementation of road engineering safety countermeasures. Priority actions include motorcycle-friendly safety barriers, targeted geometric improvements, selective motorcycle segregation where feasible, and strengthened speed management on steep descent sections. These interventions directly address the dominant crash mechanisms identified in this research and align with the engineering-led priorities of Malaysia's Road Safety Plan 2022–2030. Collectively, these initiatives support Malaysia's commitment to achieving a minimum 3-star iRAP safety rating, providing a clear policy basis for upgrading this high-risk mountainous road network. The following section will explore targeted countermeasures to improve the road safety rating for motorcyclists in this road network using the iRAP methodology approach.

5.2.2 Star Rating for Motorcycle Road User Type: After Road Safety Intervention

Following the proposed road safety interventions along the research location road network, the iRAP star rating model was re-applied to evaluate improvements in the star rating conditions specifically for the motorcyclist road user type. Figure 5.4 visualises the resulting star rating distribution and clearly demonstrates a significant upgrade in road safety performance compared to the pre-intervention existing road condition. In contrast, Figure 5.5 illustrates the star rating map for motorcycles after road safety intervention in detail for every 100 meters of road segments along the site location.

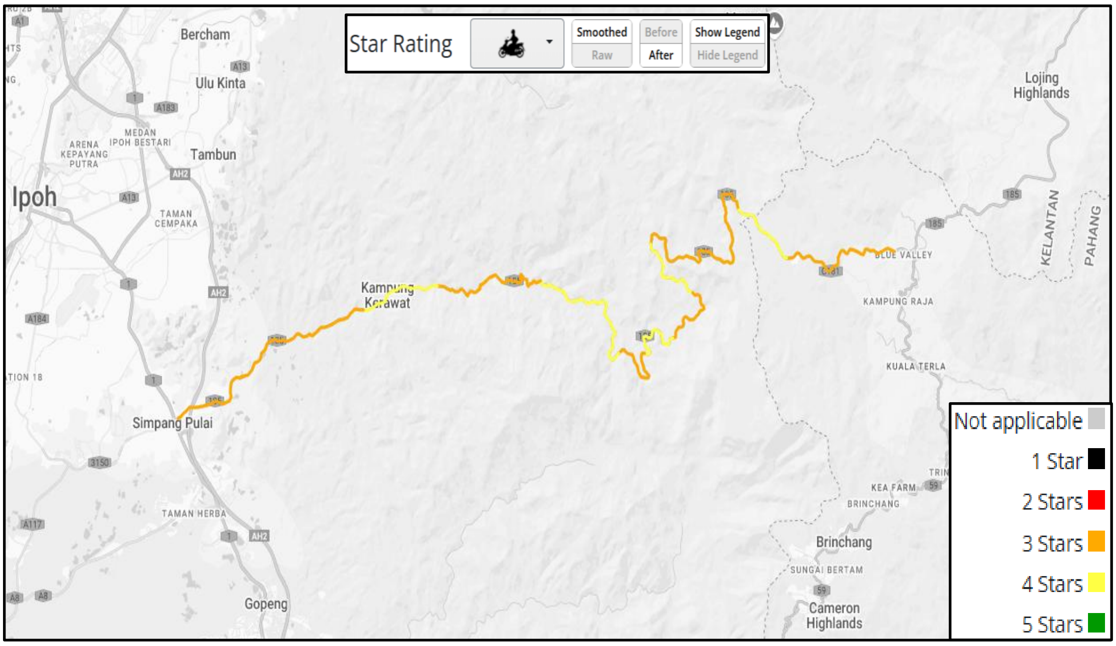

Figure 5.4 Star Rating Map for Motorcycle Road User Type: Smoothed Data After Proposed Road Safety Intervention

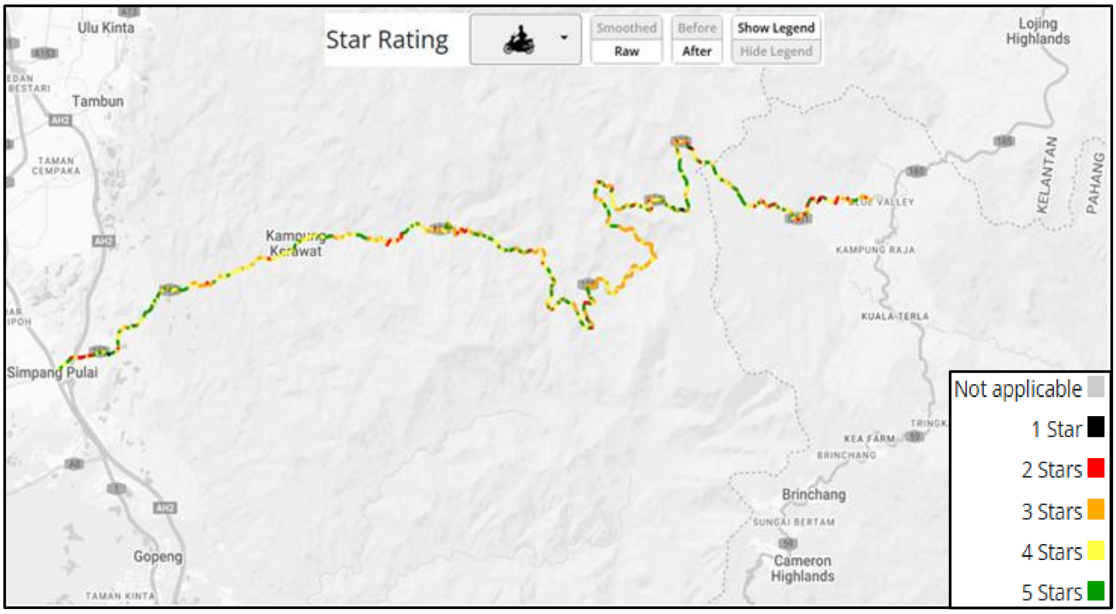

Figure 5.5 Star Rating Map for Motorcycle Road User Type: Raw Data After Proposed Intervention (Detail Risk)
(Detail Risk per 100 Meters of Road Segments)

The revised road safety risk assessment demonstrates a measurable improvement in star ratings following the implementation of specific iRAP-recommended quick-win countermeasures along the research location road network. The intervention process involved identifying high-risk segments through the baseline iRAP assessment, selecting appropriate treatments, and applying these measures to the road model in ViDA software. As a result, the updated road safety risk assessment now shows the emergence of 3- and 4-star segment ratings, which were absent from the original baseline iRAP model. These improvements are most evident as extensive 3-star (orange) sections and several 4-star (yellow) stretches along the central curved segments near Kampung Raja and at selected locations approaching Simpang Pulai and Blue Valley.

The star-rating enhancements reflect the direct impact of the quick-win countermeasures applied during the intervention phase. Key improvements incorporated into the revised model include: (i) motorcycle-friendly crash barriers in high-hazard roadside areas; (ii) enhanced lane markings, delineators, and reflective signage to improve curve visibility; (iii) geometric upgrades such as shoulder widening, curve realignment, and improved slope transitions; (iv) provision of motorcycle priority space or widened shoulders where feasible; and (v) strengthened speed-management controls on steep or high-risk gradients. By addressing these deficiencies, this process captures a tangible reduction in roadside hazards, improved sight distance, better lane guidance, and lower operating risks. These upgrades have directly contributed to an 8% reduction in the high-risk 1-star and 2-star segments, compared with the earlier assessment, in which 97% of the road network was rated 1-star for motorcyclists. The near elimination of black and red segments in the revised risk assessment indicates a substantial uplift in safety for vulnerable riders, particularly along sections characterised by steep gradients, sharp bends, and limited recovery areas.

While engineering improvements are generally expected to improve road safety outcomes, the significance of this research lies in demonstrating, through empirical modelling and measurable star-rating evidence, how a customised, context-specific intervention model can transform the road safety performance of a high-risk mountainous road network. The main contribution of this study is the development and application of the modified model, which integrates local geometric, environmental, and motorcycle-specific risk factors not fully captured in standard iRAP assessments. Through this enhanced methodology, this research provides evidence-based, modeldriven justification for improving mountain road safety through a structured countermeasure selection and re-rating process. It also identifies which interventions yield the most significant safety benefit in steep-gradient and sharp-curve environments, knowledge previously unavailable for highland roadways. The resulting model offers a replicable, data-driven approach for road authorities to prioritise investments, target blackspots effectively, and predict the road safety return on investment of proposed treatments with quantifiable precision.

Moreover, the post-intervention outcomes align with international best practices and reinforce a proactive, infrastructure-focused strategy to strengthen motorcycle safety in challenging terrain. The results confirm that targeted road infrastructure countermeasures can significantly elevate iRAP star ratings, reduce crash severity, and save lives along the mountainous road network. The following section provides a detailed road condition report generated using the iRAP methodology.

5.3 Detailed Road Condition Report by Blackspot Location for Motorcycle Road Users along the Research Location

This section presents a targeted road safety assessment of motorcycle-specific blackspots along the research location road network based on outputs from the spatial crash data analysis in the iRAP methodology procedures. Figure 5.6 illustrates the results in a "Risk Worm" chart plot, which graphically represents fluctuations in average motorcycle SRS along the road network.

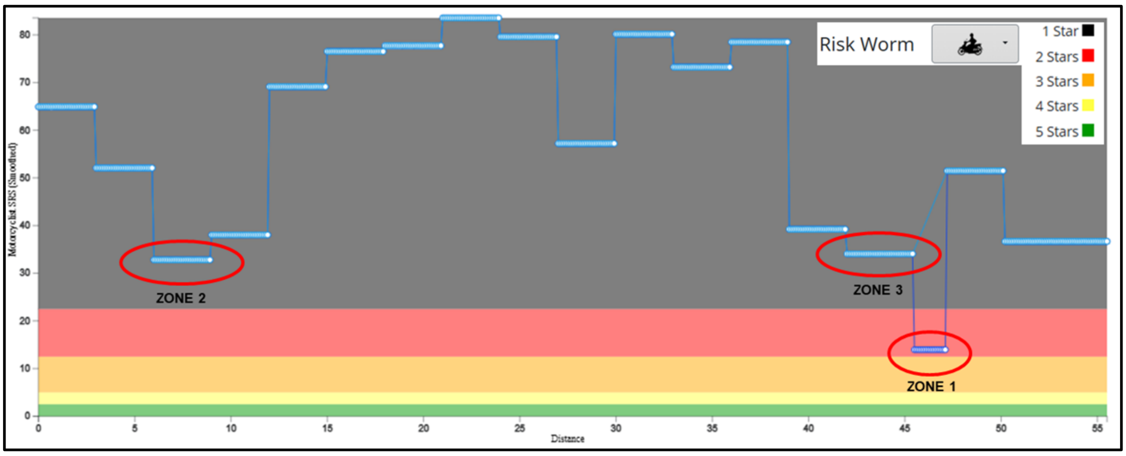

Figure 5.6 The Detailed Risk Worm and Star Rating Score for Motorcyclists along the Research Location

The detailed road condition report identifies and prioritizes high-risk segments where road geometry, infrastructure deficiencies, and crash patterns intersect, significantly increasing crash risks for motorcyclists along the research location. The researcher evaluated the 55.6-kilometer mountainous road segments of the research location, to classify them into a detailed star rating score (SRS) performance at each 100-meter segment. The colour bands, ranging from green (5-star) to black (1-star), indicate varying levels of safety, while the blue line tracks the SRS at each point along the 55.6-kilometre road network from the research location.

5.3.1 Data Analysis Scope Delimitation and Road Segment Selection Rationale

The complete length of the road network assessed in this research, from the research location, spans approximately 55.6 kilometers and is divided into 556 sub-road segments, each measuring 100 meters in length. The researcher initially intended to apply the modified model across the entire road network. However, the extensive demands of data processing, including road segment-level data coding, GIS referencing, infrastructure attribute scoring, and crash risk profiling, led the researcher to adopt a strategic focus to maintain depth, quality, and feasibility within the research timeline. Given the substantial time and resources required to analyse each road segment, the researcher prioritised three critical blackspot zones: Zone 1, Zone 2, and Zone 3, comprising 90 sub-road segments (approximately 9 kilometers or 16.2% of the entire road network). The researcher selected these zones due to their significantly low Star Rating Scores (1-star and low 2-star ratings), frequent crash occurrences, and evident road safety deficiencies, including poor pavement quality, hazardous curves, and a lack of roadside protection. The data presented in the motorcycle star rating risk profile (Figure 5.6) justifies this focused approach, as these three zones consistently recorded the lowest safety performance for motorcyclists. Moreover, the data analysis of road safety countermeasure feasibility using the iRAP methodology will help demonstrate that the quick-win approach confirms these zones are the most feasible and potentially the most suitable road segments for upgrading to 3-star and above, making them ideal for targeted road safety interventions within the study's scope.

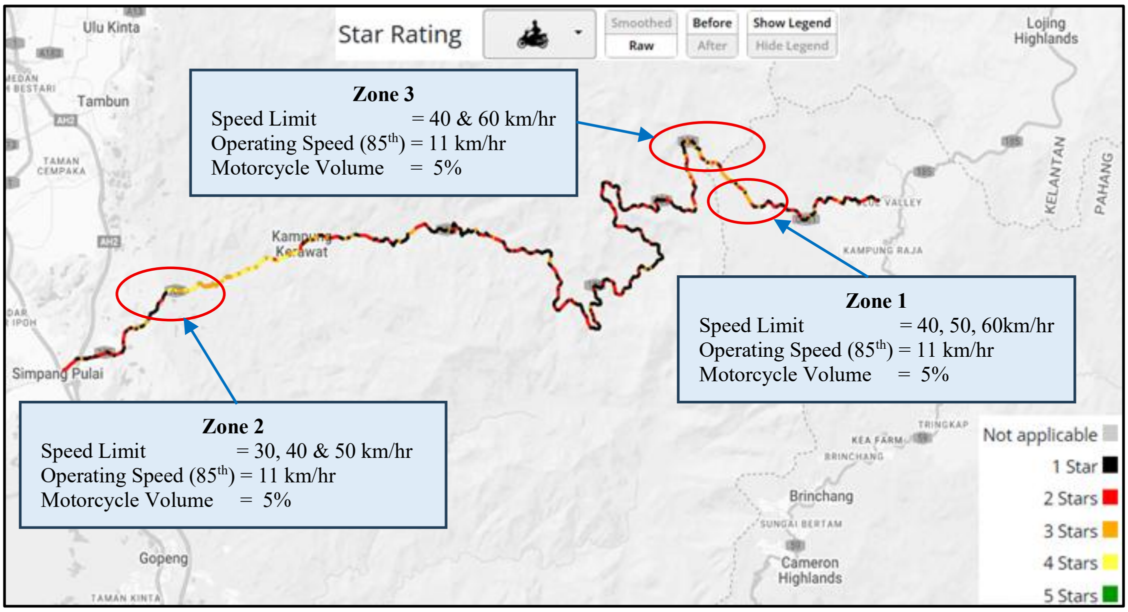

Figure 5.7 The Detailed Speed Limit, Operating Speed (85th), and Motorcycle Percentage According to Zone

The analysis of operating speed (85th percentile) in relation to posted speed limits across the three identified zones provides important insights into driver behaviour, road design limitations, and potential road safety concerns along this mountainous road network. Zone 1 encompasses the road segments between Kampung Raja and Blue Valley. The posted speed limits in this zone vary between 40 km/h, 50 km/h, and 60 km/h. However, the recorded 85th percentile operating speed is significantly lower at 11 km/h, indicating a substantial inconsistency between regulatory limits and actual driving behaviour. These results suggest that most road users, particularly motorcyclists, are traveling well below the speed limit, likely due to the presence of severe horizontal and vertical alignments, limited lane width, constrained road shoulders, and possibly poor surface conditions. The reduced speed may also reflect increased caution taken by drivers in response to frequent fog, unpredictable weather, and limited overtaking opportunities at the location.

Furthermore, Zone 1 serves as a key access point to Cameron Highlands from the north, resulting in an estimated Annual Average Daily Traffic (AADT) of 5,000 vehicles, with notably higher volumes during weekends and public holidays. The low operating speed, despite moderate to high traffic demand, implies that the infrastructure is under pressure and may not adequately support the functional demands placed on it, particularly for vulnerable road users such as motorcyclists. These findings reinforce the need for targeted road safety upgrades and enforcement strategies to align actual travel speeds with the intended road design at Zone 1.

Zone 2 occupies the mid-section of the corridor and includes posted speed limits ranging from 30 km/h to 50 km/h, depending on the road geometry and segment-specific risk factors. Despite this, the recorded 85th percentile operating speed remains 11 km/h, indicating a consistent pattern of significantly reduced speeds across this road segment. The persistently low operating speed suggests that motocyclists are encountering severe road constraints, such as severe horizontal curves, steep gradients, abrupt elevation changes, or narrow carriageways, characteristics typical of highland road networks. From a critical perspective, the low operating speed in Zone 2 may also indicate that the road design speed does not align with the actual driving conditions, particularly for motorcycles, which dominate traffic on this route. These findings can increase driver concentration demand, reduce road safety margins, and amplify crash risk due to sudden braking or poor lane discipline on curves.

Furthermore, with limited opportunities for safe overtaking, psychological pressure or driver impatience may increase among drivers, further compounding road safety challenges in this segment. The mismatch between posted speed limits and actual operating behaviour necessitates a reassessment of speed zoning policies and engineering countermeasures to improve motorcycle safety at Zone 2.

Zone 3 spans the uppermost section of the road network, near the transition from the Perak to the Kelantan and Pahang borders, including the region near the Lojing Highlands. Here, the posted speed limits are 40 km/h and 60 km/h, yet the 85th percentile operating speed remains at 11 km/h, consistent with the other zones. The uniformity of this low operating speed across all three zones suggests a systematic influence of topographical constraints, geometric design deficiencies, and potentially high volumes of slow-moving vehicles such as heavy trucks and tour buses navigating steep grades and sharp curves.

Road alignment for Zone 3 is particularly challenging due to frequent switchbacks (sharp turns or zig-zag patterns that allow vehicles to climb or descend gradually), along with elevation drops and constrained right-of-way conditions, leaving little room for error or steering mistakes, especially for motorcyclists. The high frequency of red and black segments on the iRAP Star Rating map (1-star and 2-star ratings) in this area further validates the road safety concerns. The consistently low operating speed suggests that the road's functional design does not adequately support the posted speed limits, and drivers are intuitively adjusting their behaviour to account for risk, although at the expense of efficiency and capacity.

From a policy and design standpoint, this mismatch necessitates a review of road classification, signage accuracy, and the need for geometric upgrades, including climbing lanes, enhanced curve delineation, and motorcycle-friendly barriers. Additionally, the introduction of ITS-based solutions (e.g., real-time warning systems or variable speed limits) may help mitigate risk in these high-exposure road segments.

By concentrating efforts on Zones 1 to 3, this research achieves a data-driven balance between analytical depth and practical constraints. Attempting to conduct detailed modelling and intervention planning across all 556 segments would likely result in delayed completion and compromise the focus needed for actionable insights. This scoped analysis serves as a replicable model for phased implementation, with future studies encouraged to expand upon this framework for a detailed road network-wide assessment. The risk worm chart provides an integrated visual summary of motorcycle safety risk distribution across the road segments. These zones reflect poor road engineering conditions that pose serious road safety hazards to motorcyclists, particularly on steep gradients, sharp horizontal curves, and poorly maintained road surfaces. In total, there are 90 key blackspot points (divided into three zones of sub-road segments) of site observations from the risk worm chart, as shown in Table 5.1.

Table 5.1
Key Observations from the Risk Worm Chart Plot Summary

Zone	Length	Star Rating Score (SRS)	Hazards
1	2.5 kilometers	2-star	Poor shoulder conditions, insufficient crash protection, and steep descents near curve sections.
2	3.5 kilometers	1-star	Damaged pavement, lack of edge protection, and narrow lanes with no rumble strips.
3	3 kilometers	1-star	Tight bends without proper signage, inconsistent delineation, and barrier absence.

The blackspots correlate with frequent motorcycle loss-of-control incidents, especially during downhill riding in wet or foggy road conditions characteristic of the Cameron Highlands terrain. Further analysis of these zones revealed several infrastructure-related road safety deficiencies, including absence of shoulder rumble strips to alert motorcyclists veering off-lane, lack of advance warning signage at critical curve approaches, inadequate lane markings and visibility at curve entries/exits, dangerous unprotected roadside elements, such as deep drains, steep slopes, or fixed objects close to the travel lane. The researcher tabulates the summary of road inspection results for all domain items in the iRAP methodology before and after implementing the iRAP quick-win road safety countermeasures.

Table 5.2
List of Before and After Proposed Quick-Win Recommendations for All Domain Items

iRAP Model Domain	Item No.	iRAP Model Sub-Domain	Item Before	Item After	Changes	Modified Model Quick-win Recommendations
Roadside Features	1	Roadside severity - driver-side distance	2	2	NO	1 to <5m 5 to <10m
Roadside Features	2	Roadside severity - driver-side object	12	5	YES	Safety barrier - metal Safety barrier - concrete Safety barrier - motorcycle friendly Upwards slope - no rollover gradient Semi-rigid structure or building
Roadside Features	3	Roadside severity - passenger-side distance	3	3	NO	1 to <5m 5 to <10m >=10m
Roadside Features	4	Roadside severity - passenger-side object	14	9	YES	Safety barrier - metal Safety barrier - concrete Safety barrier - motorcycle friendly Aggressive vertical face Upwards slope - no rollover gradient Tree >= 10cm dia. Semi-rigid structure or building Unprotected safety barrier end None
Visual Aid	5	Shoulder rumble strips	2	2	NO	Not present Present
Visual Aid	6	Centreline rumble strips	2	2	NO	Not present Present
Visual Aid	7	Delineation	2	2	NO	Adequate Poor
Visual Aid	8	Street lighting	2	2	NO	Not present Present
Cross Section	9	Paved shoulder - driver-side	3	3	NO	Wide (>= 2.4m) Medium (>= 1.0m to < 2.4m) Narrow (>= 0m to < 1.0m)
Cross Section	10	Paved shoulder - passenger-side	4	4	NO	Wide (>= 2.4m) Medium (>= 1.0m to < 2.4m) Narrow (>= 0m to < 1.0m) None
Cross Section	11	Carriageway label	2	2	NO	Carriageway A of a divided carriageway road Undivided road
Cross Section	12	Median type	2	2	NO	Centre line Safety barrier - wire rope

Cross Section	13	Number of lanes	3	3	NO	One Two Two and one
Cross Section	14	Lane width	1	1	NO	Wide (>= 3.25m)
Cross Section	15	Upgrade cost	1	1	NO	Medium
Cross Section	16	Roadworks	1	1	NO	No road works
Alignment	17	Curvature	4	4	NO	Straight or gently curving Moderate Sharp Very sharp
Alignment	18	Quality of curve	3	3	NO	Adequate Poor Not applicable
Alignment	19	Grade	1	1	NO	>= 0% to <7.5%
Alignment	20	Sight distance	2	2	NO	Adequate Poor
Pavement Surface	21	Road condition	3	2	YES	Good Medium
Pavement Surface	22	Skid resistance or grip	1	1	NO	Sealed - adequate
Roadside Features	23	Vehicle parking	2	2	NO	None One side
Roadside Features	24	Service road	1	1	NO	Not present
Intersection or Access Points	25	Intersection type	3	3	NO	3-leg (unsignalised) with protected turn lane 3-leg (unsignalised) with no protected turn lane None
Intersection or Access Points	26	Intersection channelisation	2	2	NO	Not present Present
Intersection or Access Points	27	Intersecting road volume	3	3	NO	100 to 1,000 vehicles 1 to 100 vehicles None
Intersection or Access Points	28	Intersection quality	2	2	NO	Poor Not applicable
Intersection or Access Points	29	Property access points	3	3	NO	Commercial Access 1+ Residential Access 1 or 2 None
Traffic Characteristics	30	Motorcyclist observed flow	1	3	YES	None 1 motorcycle 2 to 3 motorcycles
Traffic Characteristics	31	Bicyclist observed flow	2	2	NO	None 1 bicycle observed
Traffic Characteristics	32	Pedestrian observed flow across the road	2	2	NO	None 1 pedestrian crossing observed
Traffic Characteristics	33	Pedestrian observed flow along the road driver-side	2	2	NO	None 1 pedestrian along driver-side observed
Traffic Characteristics	34	Pedestrian observed flow along the road passenger-side	2	2	NO	None 1 pedestrian along passenger-side observed
Traffic Characteristics	35	Vehicle flow (AADT)	1	1	NO	5000 - 10000

Traffic Characteristics	36	Motorcyclist percentage (%)	1	1	NO	11% - 20%
Traffic Characteristics	37	Pedestrian peak hour flow across the road	2	2	NO	0 1 to 5
Traffic Characteristics	38	Pedestrian peak hour flow along the road driver-side	2	2	NO	None 1 pedestrian along driver-side observed
Traffic Characteristics	39	Pedestrian peak hour flow along the road passenger-side	2	2	NO	None 1 pedestrian along passenger-side observed
Traffic Characteristics	40	Bicyclist peak hour flow	2	2	NO	None 1 to 5
Traffic Characteristics	41	Operating Speed (85th percentile)	1	1	NO	80km/h
Traffic Characteristics	42	Operating Speed (mean)	1	1	NO	60km/h
Area Type	43	Land use - driver-side	4	4	NO	Undeveloped areas Residential Commercial Industrial and manufacturing
Area Type	44	Land use - passenger-side	4	4	NO	Undeveloped areas Residential Commercial Industrial and manufacturing
Area Type	45	Area type	1	1	NO	Rural / open area
Facilities for Vulnerable Road Users (VRU)	46	Pedestrian crossing facilities - inspected road	1	1	NO	No facility
Facilities for Vulnerable Road Users (VRU)	47	Pedestrian crossing quality	1	1	NO	Not applicable
Facilities for Vulnerable Road Users (VRU)	48	Pedestrian crossing facilities - intersecting road	1	1	NO	No facility
Facilities for Vulnerable Road Users (VRU)	49	Pedestrian fencing	1	1	NO	Not present
Facilities for Vulnerable Road Users (VRU)	50	Sidewalk - driver-side	1	1	NO	None
Facilities for Vulnerable Road Users (VRU)	51	Sidewalk - passenger-side	1	1	NO	None
Facilities for Vulnerable Road Users (VRU)	52	Facilities for motorised two wheelers	1	1	NO	None

Facilities for Vulnerable Road Users (VRU)	53	Facilities for bicycles	1	1	NO	None
Facilities for Vulnerable Road Users (VRU)	54	School zone crossing supervisor	1	1	NO	Not applicable (no school at the location)
Traffic Management	55	School zone warning	1	1	NO	Not applicable (no school at the location)
Traffic Management	56	Speed limit	4	4	NO	<30km/h 40km/h 50km/h 60km/h
Traffic Management	57	Motorcyclist speed limit	4	4	NO	<30km/h 40km/h 50km/h 60km/h
Traffic Management	58	Truck speed limit	4	4	NO	<30km/h 40km/h 50km/h 60km/h
Traffic Management	59	Differential speed limits	1	1	NO	Not present
Traffic Management	60	Speed management / traffic calming	2	2	NO	Not present Present
Total Item			141	130		
Difference Item			11			
Percentage of Difference Item			8%			

Table 5.2 presents a detailed evaluation of road engineering features along the research location, based on the iRAP methodology using MiReV and ViDA software. A total of 141 items were coded during the pre-intervention assessment, with 130 retained post-intervention, reflecting an 8% variation. While numerically modest, these changes represent strategically significant improvements in road safety infrastructure. In a mountainous context where geometric realignment is often impractical or prohibitively expensive, small-scale yet targeted interventions offer high-impact road safety performance outcomes. This approach is consistent with global practices favouring low-cost, high-return road safety countermeasures in geographically constrained or resource-limited areas (iRAP, 2021a).

It is important to note that this research initially identified 18 blackspot zones across the 55.6-kilometer site location. However, due to limitations related to time, data processing capacity, and the scope of field inspection, the study strategically focused on three priority zones (Zone 1, Zone 2, and Zone 3) for in-depth evaluation. The researcher selected these zones based on their extremely low star rating scores, higher crash frequency, and practical potential for infrastructure upgrading. This focused approach ensures depth and data quality while still capturing the most representative high-risk areas for motorcyclist safety in the research location.

One of the most notable improvements observed was the reduction of hazardous roadside objects along both the driver's and passenger's sides. The researcher implemented changes, such as removing trees with a diameter of 10 cm or more, aggressive vertical surfaces, and unprotected barrier ends, replacing them with safer alternatives, including motorcycle-friendly metal guardrails and semi-rigid containment systems. These modifications mirror successful interventions in similar highland road networks in Vietnam and Colombia, where roadside barrier upgrades significantly reduced the severity of run-off-road crashes (iRAP, 2021e; WHO, 2024). The researcher prioritises these countermeasures in the modified model for mountainous road environments, given the high crash risk on downhill curves and the limited shoulder width.

In contrast, alignment-related items such as horizontal curvature, gradient, and sight distance remained unchanged throughout the corridor. This outcome reflects the essential physical constraints of the terrain, where major geometric interventions would necessitate substantial earthworks, significant costs, and potential environmental disruption. Researchers have reported similar findings in other Malaysian highland routes such as Fraser's Hill and Bukit Tinggi, where they manage fixed geometric characteristics through compensatory road safety strategies (MHA, 2019). Therefore, in the context of the modified model, such features are best conceptualised as non-modifiable environmental constraints, with mitigation strategies focused on enhancing visual cues and roadside protection rather than large-scale reconstruction.

Although the number of visual aid items such as delineation, rumble strips, and street lighting remained unchanged between the two assessments, their continued presence plays a critical role in driver perception and reaction, particularly in low-visibility conditions typical of highland roads. Research indicates that high-contrast materials and strategically placed reflective signage can significantly enhance navigation in fog-prone and winding routes (Abrari Vajari et al., 2020; Liang et al., 2023). However, a limitation of ViDA's coding framework is its limited capacity to capture qualitative changes in material quality, durability, or brightness. This methodological shortcoming suggests the need for future iRAP enhancements that incorporate performance-based indicators for visual aids.

In terms of surface condition, the intervention yielded tangible improvements. The road surface, which previously exhibited medium to poor conditions in several segments, was upgraded through resurfacing and patching, resulting in a more uniform and safer surface. This improvement is particularly significant in mountainous terrains, where steep gradients and frequent rainfall reduce tyre traction and increase the risk of skidding. Empirical evidence from safety audits in Kundasang, Sabah, confirms the elevated crash risk for motorcycles under such conditions (MIROS, 2017b; Rusli, 2017). As such, even modest enhancements in pavement friction can yield disproportionately large safety benefits in such high-risk areas.

Despite an observed increase in motorcyclist traffic volume across three coded flow categories, the research did not include any dedicated infrastructure improvements for Vulnerable Road Users (VRUs), such as sidewalks, designated motorcycle lanes, or pedestrian crossings. These findings align with broader national trends, where VRU infrastructure is rarely integrated outside urban centers (Rogers & Hashim, 2011). Highland roads, where space is limited and exposure risk is elevated, lack such facilities and therefore create a significant road safety gap. Since motorcycles account for over 60% of the national vehicle fleet and dominate fatal crash statistics (WHO, 2024), the researcher prioritises VRU-specific countermeasures in the modified model for future implementation phases.

Intersections and access points, including three-leg unsignalised junctions and property entrances, remained unchanged. Similar road networks consistently identify these features as crash blackspot locations, especially when the location lacks proper channelisation (Abdul Manan et al., 2016; Varhelyi, 2016). Although the current quick-win countermeasures do not address these features, long-term road safety planning should prioritise them due to their potential to cause turning conflicts and abrupt stops on narrow, mountainous roads.

Only a fraction of iRAP-coded items changed, but the resulting impact on road safety performance is considerable. The targeted improvements, particularly in roadside hazard management and pavement upgrades, align with global best practices and demonstrate the feasibility of context-sensitive interventions in mountainous settings. At the same time, the lack of progress in VRU infrastructure and junction treatments underscores the need for a more inclusive road safety framework. These findings directly support the refinement of the modified model, enabling it to recommend interventions that are not only feasible within topographical constraints but also tailored to the most pressing risk factors for motorcyclists. Furthermore, the outcomes serve as a valuable benchmark for assessing and upgrading similar highland road networks across Malaysia, including routes in Genting Highlands, Fraser's Hill, and the Ringlet-Tapah area.

5.3.2 Purpose and Application of the Blackspot Data Analysis

This blackspot-level data analysis serves three primary functions: (i) supports a targeted approach to motorcycle safety interventions by identifying and prioritising high-risk locations, (ii) informs a staged investment strategy, and (iii) enables cost-effective implementation of road safety countermeasures where safety impact is most significant. The blackspot-level data analysis complements the overall iRAP star rating assessment by offering data in terms of location-specific diagnostics to guide physical road infrastructure upgrades and policy enforcement.

Each blackspot location will be discussed in the following subsections, detailing data such as kilometer markers and GPS coordinates, observed infrastructure risks that contributed to poor star ratings, historical crash patterns, and recommended road safety countermeasures based on iRAP's quick win information guided by iRAP data coding manual, such as: (i) Motorcycle-friendly crash barriers, (ii) Curve re-alignment or signage enhancements, (iii) Shoulder and surface upgrades and (iv) Delineation and speed management treatments. This section presents the results to bridge risk identification with practical intervention, aiming to improve the road safety performance of this high-risk, high-gradient road segment for motorcyclists. Table 5.2 presents the detailed road condition report, as recommended by the iRAP methodology, for quick-win road safety countermeasures to enhance the star rating at the research location.

The quick-win road safety countermeasures in Table 5.3 are prioritised based on their potential to reduce Fatal and Serious Injuries (FSIs), the present value (PV) of safety benefits, estimated implementation costs, and their corresponding benefit-cost ratios (BCRs). Using the iRAP methodology and protocols, the researcher expects the recommended treatments to save 7,810 FSIs, generate RM3.58 billion in safety benefits, and require a total investment of RM345 million, resulting in an overall program BCR of 10.4. The additional lane (2+1 road with barrier) is the most impactful road safety intervention, contributing the highest FSI savings of 4,190 FSIs across 51.5 km of road with a strong BCR of 16.6. This measure also supports improved overtaking conditions and reduces the risk of head-on collisions for motorcyclists on undivided, high-speed roads. The centreline rumble strip and flexi-post treatment follows, with 380 FSIs saved and a remarkably low cost of implementation, resulting in a high BCR of 30.7. These treatments are cost-effective in alerting drivers to lane departure risks, especially on narrow or winding segments.

Table 5.3
Detailed Road Condition Report and Recommended Quick-Win Countermeasures Based on the iRAP Methodology for the Research Location

Total FSI saved	**Total PV of safety benefit**	**Estimated Cost**	**Cost per FSI saved**	**Program BCR**
7,810	3,580,000,000	345,000,000	44,200	10.4

Countermeasure	**Length / Sites**	**FSIs saved**	**PV of safety benefit**	**Estimated Cost**	**Cost per FSI saved**	**Program BCR**
Clear roadside hazards - passenger side	0.4 km	0.733	336,000	3,270	4,460	103
Shoulder rumble strips	53.7 km	338	155,000,000	3,320,000	9,820	46.7
Centreline rumble strip / flexi-post	10.5 km	380	174,000,000	5,680,000	14,900	30.7
Additional lane (2 + 1 road with barrier)	51.5 km	4,190	1,920,000,000	116,000,000	27,700	16.6
Shoulder sealing driver side (>1m)	53.5 km	185	84,800,000	9,390,000	50,800	9.03
Road surface rehabilitation	42.4 km	627	288,000,000	33,000,000	52,600	8.71
Improve curve delineation	30.7 km	628	288,000,000	39,100,000	62,200	7.37
Central median barrier (no duplication)	4.1 km	100	46,100,000	6,940,000	69,100	6.64
Roadside barriers - driver side	41.1 km	727	333,000,000	52,700,000	72,400	6.33
Roadside barriers - passenger side	43.0 km	542	248,000,000	55,100,000	102,000	4.51
Improve Delineation	11.8 km	30.9	14,200,000	4,360,000	141,000	3.25
Shoulder sealing passenger side (>1m)	10.9 km	54.4	24,900,000	19,200,000	354,000	1.3

The iRAP quick-win results recommend shoulder rumble strip countermeasures as another critical quick-win treatment, projecting them to save 338 FSIs over 53.7 km at a low cost per FSI saved (RM9,820) and a high BCR of 46.7. These results highlight the efficiency in preventing run-off-road crashes, which is especially important in curved mountainous terrains like Cameron Highlands. Clear roadside hazard removal, especially from the passenger side, despite covering only 0.4 km, demonstrates exceptional value with a BCR of 103, the highest in the list. Though the absolute number of FSIs saved (0.733) is low, this intervention is highly effective at minimal cost, suggesting strong returns for focused micro-road safety interventions.

On the other hand, some road safety countermeasures like shoulder pavement sealing (passenger side) yield lower returns, with a BCR of only 1.3 and a high cost per FSI saved (RM354,000). The researcher may deprioritize such road treatments in favor of more cost-efficient options, although they may still offer benefits in localised contexts. Other road safety interventions, such as central median barriers, road surface rehabilitation, curve delineation, and roadside barriers (both driver and passenger sides), also demonstrate substantial safety and economic benefits, with BCRs ranging from 4.51 to 8.71, further reinforcing their value in inclusive road safety planning. The evidence supports that the iRAP quick-win recommendations are a tiered implementation strategy, prioritizing low-cost, high-impact solutions for short-term rollout while gradually investing in structural upgrades with moderate BCRs to sustain long-term improvements. These findings demonstrate the effectiveness of applying iRAP's data-driven methodology to identify cost-efficient, life-saving treatments tailored to the risk profiles of mountainous road networks in Malaysia.

5.3.3 Predicted Casualty Reduction Map Before and After Road Safety Intervention for the Research Location

This section presents the predicted reduction in casualties maps before and after the proposed road safety interventions for the entire study area. The researcher generated these maps for the whole stretch of the research location, using the iRAP quick-win countermeasure framework. This mountainous road network is characterised by steep gradients, sharp curves, variable pavement friction, and recurrent environmental hazards such as fog and landslides, making it one of Malaysia's most technically challenging road alignments. The modelling adopts a geospatial risk approach to visualise expected reductions in Fatal and Serious Injuries (FSIs) per kilometre based on the implementation of low-cost, high-impact engineering countermeasures. The classification scale follows the sequence shown in the iRAP legend, ranging from dark blue (0 FSIs saved), light blue (>0–2 FSIs saved), green (>2–5 FSIs saved), orange (>5–15 FSIs saved), to purple (>15 FSIs saved). This grading system enables the spatially precise identification of road segments with the most significant predicted road safety benefits from road engineering improvements. The approach aligns with international best practices for risk-based crash-reduction mapping in complex mountainous environments (Reddy & Tenepalli, 2025; WHO, 2024). The map in Figures 5.7 and 5.8 visualises the predicted reduction in casualties map results before and after road safety improvements along the route following the application of targeted iRAP quick-win road safety countermeasures, particularly in high-risk blackspot areas.

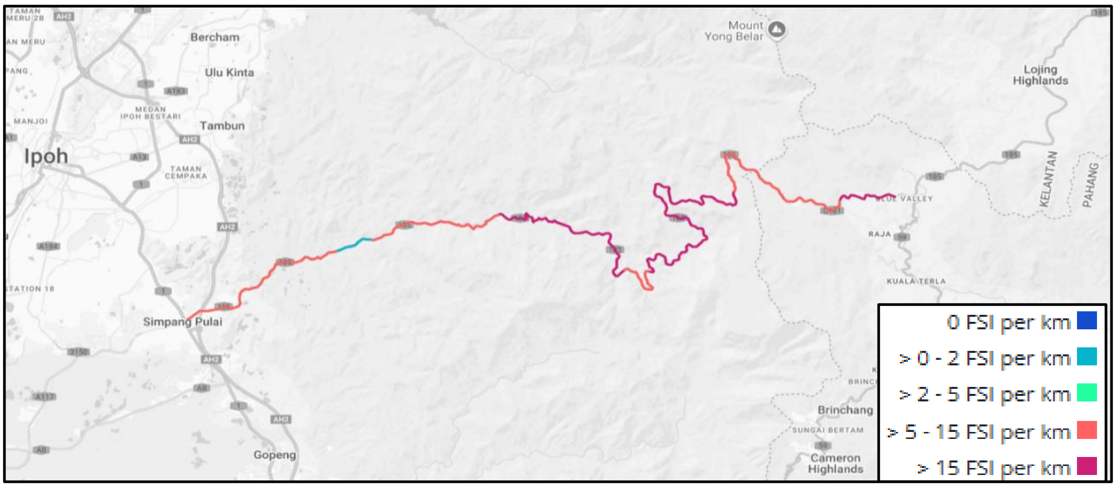

Figure 5.8 Predicted Casualty Reduction Pre-Intervention Map

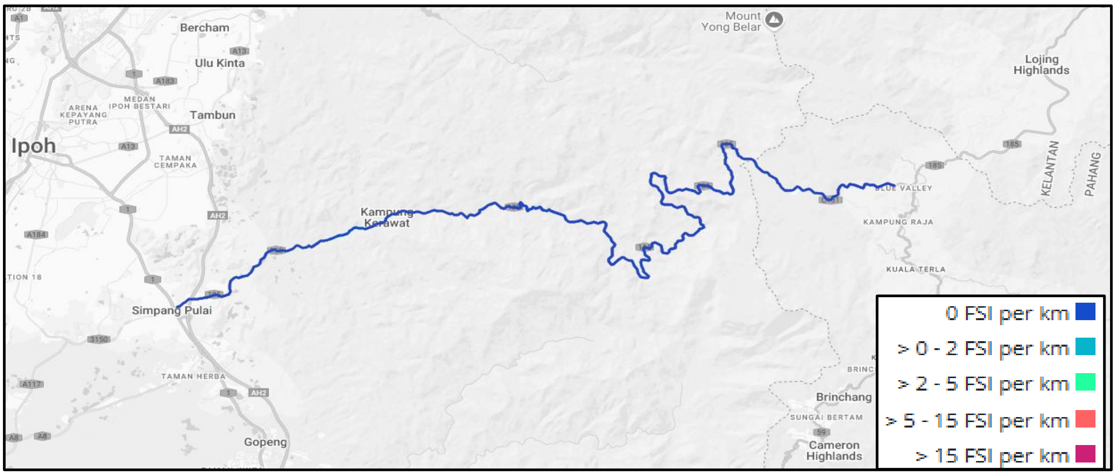

Figure 5.9 Predicted Casualty Reduction Map After Proposed Road Safety Intervention

In the pre-intervention map (Figure 5.8), several critical segments appear in orange and purple, most notably Zone 1 (KM 45) and Zone 3 (KM 42–43), indicating predicted casualty-reduction values exceeding 5 FSIs/km and 15 FSIs/km, respectively. These sections correspond to previously identified high-risk blackspots with combinations of tight curvature, constrained shoulders, and limited recovery space. Similarly, Zone 2 (KM 7–9), near the Simpang Pulai ascent, exhibits higher predicted casualty savings, reflecting exposure to downhill speed-related crashes. These patterns align with findings from other global mountainous road networks, in which targeted, low-cost road engineering measures have produced substantial reductions in crashes despite geometric constraints (Gue & Wong, 2009; Zainal Abidin et al., 2018). Such improvements are particularly relevant, given that run-off-road events and motorcycle skidding predominate in highland crash typologies under low-friction and limited-visibility conditions (Abdul Manan et al., 2016; Varhelyi, 2016).

Following the application of the quick-win road safety countermeasures, the post-intervention map (Figure 5.9) shows a marked transition toward dark blue (0 FSIs saved) and light blue (>0–2 FSIs saved) classifications along most of the corridor. The substantial reduction of orange and purple segments demonstrates that the proposed road safety countermeasures, such as improved delineation, enhanced road-edge visibility, shoulder sealing, hazard removal, and selective barrier installations, effectively mitigated many of the underlying risk factors. Only isolated green (>2–5 FSIs) segments remain, indicating locations where additional geometric upgrades may still be warranted. This before–and–after contrast confirms the efficacy of iRAP quick-win treatments in reducing predicted FSI exposure level along the mountainous road network.

Conversely, several mid-route segments between Kampung Kerawat and Kampung Raja remain in dark blue, indicating that no predicted FSIs are saved. These locations either did not require intervention under the current prioritisation framework or already met minimum road safety performance thresholds. Although the model suggests limited immediate benefit from quick-win treatments in these road segments, periodic review is advisable to assess potential latent risks associated with evolving traffic demands and environmental conditions.

Overall, this geospatial analysis demonstrates that risk-based modelling facilitates efficient resource allocation, enabling road authorities to focus investment on segments with the most significant projected reductions in casualties. By linking infrastructure conditions, intervention types, and predicted road safety outcomes within a geospatial framework, the modified model provides a replicable and scalable tool for road safety planning in Malaysia's hilly and mountainous regions. This visual approach also enhances communication with stakeholders and policymakers, offering a compelling evidence base for sustained investment in engineering-led road safety improvements.

5.4 Road Safety Intervention and Countermeasures Recommended by the iRAP Methodology for Blackspot Zone 1, Zone 2, and Zone 3

Table 5.4 presents a detailed summary of road safety performance across three identified blackspot zones along the F185 road network between Blue Valley and Simpang Pulai, as evaluated through the iRAP Star Rating methodology. The table includes information on the before-and-after star ratings assessment, road section characteristics, geographical location, and segment length of each high-risk zone. Each zone was initially assessed based on existing road infrastructure and crash risk, followed by the simulation of recommended countermeasures within the iRAP model to estimate the potential road safety improvement, expressed in terms of a positive change in star rating outcome, as explained in Appendix 3.

Table 5.4
Detailed Blackspot Zone 1, Zone 2, and Zone

Zone	Star Rating Before	Star Rating After	Road Name	Section	Distance	Length	Latitude	Longitude
1	**2 (Red)	****4 (Yellow)	F185	Blue Valley to Simpang Pulai	45.5 – 47.9 KM	2.5 KM	4.564303	101.183675
2	*1 (Black)	***3 (Orange)	F185	Blue Valley to Simpang Pulai	42 – 45.4 KM	3.5 KM	4.571978	101.203755
3	*1 (Black)	***3 (Orange)	F185	Blue Valley to Simpang Pulai	6 – 8.9 KM	3 KM	4.580723418	101.3476891

5.5 Modified iRAP@Highlands Model Using Multiple Linear Regression (MLR)

This section explains the step-by-step procedures used to quantify the relationship between selected road engineering variables and the Star Rating Score (SRS) under the modified model. A Multiple Linear Regression (MLR) analysis was conducted using SPSS software to examine how variations in road engineering factors influence motorcycle road safety performance. In this model, SRS was specified as the dependent variable, representing the safety performance outcome defined by the iRAP methodology, while road condition, curvature, and quality of curve were treated as independent variables.

Each independent variable was operationalised based on the iRAP coding framework and field inventory data. Road condition reflects pavement surface quality and was coded according to observed surface distress and friction-related attributes. Curvature represents the geometric severity of horizontal alignment and was quantified based on curve classification and alignment characteristics along the corridor. The quality of a curve captures the combined effects of its geometry, delineation, and consistency, reflecting how well the curve supports safe motorcycle operation. The MLR model estimates regression coefficients for each variable, thereby quantifying the magnitude and direction of their influence on SRS while controlling for the effects of the other predictors.

The modified model was designed to identify the most critical predictors of motorcycle safety performance along the research location. These variables were selected based on the proposed iRAP quick-win countermeasure and adapted for mountainous terrain, where geometric design constraints and pavement condition are known to play a dominant role in crash risk. By integrating these variables into the original iRAP structure and the adapted modified model, the analysis provides a statistically grounded basis for prioritising road engineering interventions in high-risk mountainous road environments.

5.5.1 Regression Model Results Before iRAP Quick-Win Road Safety Intervention Implementation

This subsection presents the results of the Multiple Linear Regression (MLR) analysis for the original iRAP model before the implementation of quick-win road safety interventions along the research road segments. The analysis was performed using SPSS, with the Star Rating Score (SRS) specified as the dependent variable representing motorcycle safety performance. The independent variables comprised road condition (X_1), curvature (X_2), and quality of curve (X_3), all coded in accordance with the iRAP coding manual.

In order to ensure logical and statistical consistency, road segments coded as "not applicable" by referring to the iRAP coding manual under the quality of curve variable corresponding to straight road sections were treated as system-missing and excluded from the ordinal structure of X_3. As a result, although the full dataset comprised 556 sub-road segments, only 335 observations were included in the regression analysis because of the coding structure applied to straight segments.

The regression results indicate that all three predictor variables were statistically significant ($p < 0.001$). Road condition (X_1) exhibited a negative regression coefficient, indicating that deteriorated pavement surfaces are associated with lower SRS values and increased motorcycle safety risk. Curvature (X_2) also demonstrated a statistically significant negative relationship with SRS, confirming that sharper horizontal alignment contributes to higher crash risk in mountainous terrain. Similarly, the quality of the curve (X_3) had a strong, adverse, statistically significant effect, indicating that poorly designed or inconsistent curves substantially degrade safety performance even after controlling for curvature effects.

Variables relevant to mountainous terrain were incorporated into the original iRAP framework during the development of the modified model. Based on the regression analysis conducted prior to the implementation of iRAP quick-win countermeasures, the estimated regression equation for the original model is expressed as:

$$\text{Star Rating Score (SRS)} = 1.784 - 0.033\,(\text{Road Condition}) - 0.026\,(\text{Curvature}) - 0.304\,(\text{Quality of Curve}) + \varepsilon \qquad (5.1)$$

Where:

SRS = Star Rating Score (dependent variable);
β_0 (Before) = 1.784;
X_1 = **Road Condition** = Surface quality coded ordinal values
(Good = 1, Medium = 2, Poor = 3);
X_2 = **Curvature** = Horizontal alignment coded by severity
(Straight or gentle curving = 1, Moderate = 2, Sharp = 3, Very Sharp = 4);
X_3 = **Quality of Curve** = Adequacy of curve design
(Adequate = 1, Poor = 2, System-missing/ straight road segments = 3);
ε = Error term.

Table 5.5
Summary of Multiple Linear Regression Results for the Original iRAP Model

Predictor Variable	B	β	t	*p*-value
Intercept	1.784	—	—	—
Road Condition	-0.033	-0.123	-2.562	< 0.001
Curvature	-0.026	-0.115	-2.223	< 0.001
Quality of Curve	-0.304	-0.420	-8.174	< 0.001

The magnitude of the standardized coefficients indicates that quality of curve ($\beta = -0.420$) is the most influential predictor of SRS in the pre-intervention condition, followed by road condition ($\beta = -0.123$) and curvature ($\beta = -0.115$). This highlights the dominant role of curve-related deficiencies in contributing to motorcycle safety risk on mountainous roads.

As summarised in Table 5.5, the model explains 25.5% of the variance in SRS ($R^2 = 0.255$) and is statistically significant overall (ANOVA F-test, $p < 0.001$), indicating that the selected road engineering variables collectively exert a significant influence on motorcycle safety performance prior to intervention. Although the explanatory power is moderate, this is consistent with the complex nature of crash risk on mountainous road networks, where multiple interacting factors beyond geometric design also influence safety outcomes. Collinearity diagnostics indicate no multicollinearity concerns, with all Variance Inflation Factor (VIF) values close to 1.0, confirming the stability and reliability of the regression estimates. The following Tables 5.7, 5.8, 5.9, and 5.10 present the MLR analysis results based on data from 556 sub-road segments (prior to the implementation of the iRAP quick-win road safety intervention).

Table 5.6
Summary of Predictor Variables and Coefficients in the Original iRAP Regression Model

Variables Entered/ Removed[a]			
Model	**Variables Entered**	**Variables Removed**	**Method**
1	Road Condition, Curvature, Quality of Curve[b]	.	Enter

a. Dependent Variable: SRS
b. All requested variables entered

Table 5.7
Summary of Multiple Linear Regression Results for Predicting Star Rating Score (SRS) Based on the Original Road Engineering Variables

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0.505[a]	0.255	0.248	0.17350

a. Predictors: (Constant), Road Condition, Curvature, Quality of Curve

Table 5.8
Analysis of Variance (ANOVA) Output for the Original SRS Prediction

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	3.423	3	1.141	37.907	<.001b
	Residual	9.994	332	0.030	—	—
	Total	13.417	335[c]	—	—	—

a Dependent Variable: SRS
b Predictors: (Constant), Road Condition, Curvature, Quality of Curve
c A total of 335 variables was analysed out of 556 variables due to the coding set for system-missing dedicated to straight road segments

Table 5.9
Regression Coefficients for the Original iRAP Model

Coefficient[a]								
		Unstandardized Coefficients		**Standardized Coefficients**			**Collinearity Statistics**	
Model		**B**	**Std. Error**	**Beta**	**t**	**Sig.**	**Tolerance**	**VIF**
1	Constant	1.784	0.071	—	25.263	< 0.001	—	—
	Road Condition	-0.033	0.013	-0.123	-2.562	0.011	0.981	1.019
	Curvature	-0.026	0.012	-0.115	-2.223	0.027	0.845	1.184
	Quality of Curve	-0.304	0.037	-0.420	-8.174	< 0.001	0.850	1.176

a Dependent Variable: SRS

5.5.2 Regression Model Results After Proposed iRAP Quick-Win Road Safety Intervention Implementation

This subsection presents the MLR results following the implementation of the proposed iRAP quick-win road safety interventions along the research road segments. The analysis quantifies changes in the relationship between selected road engineering variables and the Star Rating Score (SRS), thereby evaluating the effectiveness of the intervention in improving motorcycle safety performance.

Following the implementation of the quick-win countermeasures, all road segments previously classified as having poor curve quality were upgraded and consolidated into the “adequate” category. Consequently, the quality of the curve variable became constant across all treated segments. These data were automatically excluded by SPSS, as variables with zero variance cannot be estimated in regression analysis. This outcome reflects a successful intervention effect rather than a modelling limitation.

The post-intervention regression model therefore retained two predictor variables namely road condition (X_1) and curvature (X_2). The analysis was conducted for the zones in which the iRAP quick-win interventions were implemented. As a result, although the full dataset comprised 90 sub-road segments, only 37 observations were included in the regression analysis because of the coding structure applied to straight segments. The resulting regression equation for the modified model is expressed as:

$$\text{Star Rating Score (SRS)} = 4.670 - 0.347\ \text{(Road Condition)} - 0.375\ \text{(Curvature)} + \varepsilon \qquad (5.2)$$

Where:

SRS = Star Rating Score (dependent variable)

β_0 (After) = 4.670;

X_1 = **Road Condition** = Surface quality coded ordinal values (Good = 1, Medium = 2, Poor = 3);

X_2 = **Curvature** = Horizontal alignment coded by severity (Straight or gentle curving = 1, Moderate = 2, Sharp = 3, Very Sharp = 4);

X_3 = **Quality of Curve** = Adequacy of curve design

(SPSS removed these variables due to constant value for all road segments:

Adequate = 1);

ε = Error term.

Table 5.10
Summary of Multiple Linear Regression Results for the Modified iRAP@Higlands Model

Predictor Variable	B	β	t	*p*-value
Constant (Intercept)	4.670	—	—	—
Road Condition	-0.347	-0.437	-3.500	0.001
Curvature	-0.375	-0.465	-3.720	< 0.001

Both remaining predictor variables were statistically significant, with road condition ($\beta = -0.437, p = 0.001$) and curvature ($\beta = -0.465, p < 0.001$) showing strong negative associations with SRS. The standardised coefficients indicate that curvature is the most critical residual factor influencing motorcycle safety performance after improvements in curve quality, underscoring the persistent safety challenges posed by sharp horizontal alignment in mountainous environments.

As shown in Table 5.12, the modified model explains 46.4% of the variance in SRS (R^2 = 0.464), representing a substantial improvement in explanatory power compared with the pre-intervention model. The overall model is statistically significant (ANOVA F-test, $p < 0.001$), and multicollinearity diagnostics indicate that the estimates are robust, with VIF values close to unity for both predictors. These findings indicate that the proposed iRAP quick-win interventions were effective in improving road safety performance and strengthening the regression model's predictive capability. The following Tables 5.11, 5.12, 5.13, and 5.14 present the MLR analysis results using 90 sub-road segments' data entries (after the implementation of the iRAP quick-win road safety intervention).

Table 5.11
Summary of Predictor Variables and Coefficients in the Modified Model

Variables Entered/ Removed[a]			
Model	**Variables Entered**	**Variables Removed**	**Method**
1	Road Condition, Curvature[b]	.	Enter

a. Dependent Variable: SRS
b. All requested variables entered

Table 5.12
Summary of Multiple Linear Regression Results for Predicting Star Rating Score (SRS) Based on the Modified Model

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0.681[a]	0.464	0.433	0.29230

a. Predictors: (Constant), Road Condition, Curvature

Table 5.13
Analysis of Variance (ANOVA) Output for the SRS Prediction Modified Model

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	2.589	2	1.294	15.148	<.001b
	Residual	2.990	35	0.085	—	—
	Total	5.579	37	—	—	—

a Dependent Variable: SRS
b Predictors: (Constant), Road Condition, Curvature
c A total of 37 variables was analysed out of 90 variables due to the coding set for system-missing dedicated to straight road segments

Table 5.14
Regression Coefficients for the Modified Model

Coefficient[a]								
		Unstandardized Coefficients		**Standardized Coefficients**			**Collinearity Statistics**	
Model		**B**	**Std. Error**	**Beta**	**t**	**Sig.**	**Tolerance**	**VIF**
1	Constant	4.670	0.297	—	15.711	< 0.001	—	—
	Road Condition	-0.347	0.099	-0.437	-3.500	0.001	0.981	1.020
	Curvature	-0.375	0.101	-0.465	-3.720	<0.001	0.981	1.020

a Dependent Variable: SRS

5.5.3 Comparative Insights and Implications of MLR Models Before and After Proposed Implementation of iRAP Quick-Win Intervention

The comparative results of the two regression models, as summarised in Table 5.15, demonstrate a significant improvement in road safety performance following the implementation of the proposed iRAP quick-win intervention. The increase in the intercept value from 1.784 in the pre-intervention model to 4.670 in the post-intervention model indicates a substantial improvement in the baseline of the Star Rating Score (SRS) of the treated road segments. This upward shift reflects the cumulative effect of targeted road engineering interventions, including improvements in road surface condition, curve design standardisation, and roadside safety treatments implemented under the iRAP framework.

However, as shown in Table 5.15, curvature remained a dominant negative predictor of SRS in both regression models. In the pre-intervention model, curvature exhibited a statistically significant negative relationship with SRS, indicating increased motorcycle safety risk on sharper horizontal alignments. Following the implementation of the quick-win intervention, curvature continued to exert a strong and statistically significant influence, with a larger absolute coefficient observed in the post-intervention model. This finding indicates that despite overall safety improvements, sharp or very sharp curves continue to pose a critical safety hazard in mountainous terrain. The persistence of curvature as a dominant risk factor reinforces existing evidence that horizontal alignment is a key contributor to motorcycle crash risk on winding roads.

Table 5.15
Comparison of MLR Models Before and After Proposed iRAP Quick-Win Intervention

Metric	Before Intervention	After Proposed Intervention
Dataset scope	Entire corridor (coded segments)	Treated zones only
Road segments analysed	335 (from 556 coded segments*)	37 (from 90 coded segments*)
Intercept (β_0)	1.784	4.670
Road Condition (β_1)	− 0.033 ($p < 0.05$)	− 0.347 ($p = 0.001$)
Curvature (β_2)	− 0.026 ($p < 0.05$)	− 0.375 ($p < 0.001$)
Quality of Curve (β_3)	− 0.304 ($p < 0.001$)	Excluded (constant value)
R^2	0.255	0.464
Adjusted R^2	0.248	0.433
Model significance (ANOVA F-test)	$p < 0.001$	$p < 0.001$
Multicollinearity (VIF range)	1.019 – 1.184	1.020

*System-missing values were assigned to straight road segments under the quality of curve variable, resulting in 335 observations used before intervention and 37 observations used after the proposed intervention in the regression analysis.

In contrast, the role of the curve quality variable changed fundamentally after the road safety intervention phase. As reported in Table 5.15, the quality of the curve was a statistically significant predictor of SRS in the pre-intervention model, reflecting widespread geometric deficiencies along the study corridor. After the implementation of the iRAP quick-win countermeasures, all treated road segments were upgraded to meet the minimum curve quality standard. Consequently, the quality of curve variable became constant across the post-intervention dataset and was automatically excluded from the regression analysis. This exclusion represents a successful engineering outcome rather than a reduction in the importance of curve quality as a determinant of motorcycle safety.

The improvement in road safety performance is further reflected in the model's enhanced explanatory power. As shown in Table 5.15, the Adjusted R^2 increased from 0.248 before intervention to 0.433 after intervention, indicating that the modified model explains a substantially greater proportion of variance in SRS. This improvement was achieved despite the post-intervention analysis being based on a smaller number of treated sub-road segments, suggesting that the iRAP quick-win intervention strengthened the relationship between key road engineering variables and motorcycle safety performance. Nevertheless, the remaining unexplained variance indicates that additional factors beyond roadway geometry and surface condition continue to influence safety outcomes.

Beyond the regression-based comparison, the roadside hazard profile presented in Table 5.16 provides important contextual support for the observed improvement in baseline safety performance. Prior to intervention, the road segments exhibited a high prevalence of rigid passenger-side roadside hazards, including trees, rigid signposts, unprotected barrier ends, and metal safety barriers, which collectively accounted for the majority of identified hazards. These features pose a severe risk to motorcyclists, particularly in run-off-road crashes on curved and mountainous sections. The implementation of iRAP quick-win interventions, such as hazard removal, setback treatments, shielding of barrier ends, and installation of motorcycle-friendly barriers, directly addressed these high-risk roadside conditions, contributing to the improvement in SRS reflected by the increased intercept and model performance after intervention.

Table 5.16
Detailed Result of Clearing Roadside Hazards (Passenger Side) Item for Road Safety Intervention Recommended by the iRAP Methodology

No	Clear roadside hazards - passenger side	Code	Frequency	Percentage
1	Tree (more or equal to 10cm diameter)	11	222	39.9%
2	Rigid sign, post or pole	12	95	17.1%
3	Unprotected safety barrier end	15	70	12.6%
4	Safety barrier - metal	1	62	11.2%
5	Upward slope - no roll over	7	29	5.2%
6	Aggressive vertical face	5	28	5.0%
7	Safety barrier - concrete	2	19	3.4%
8	Rigid structure or building	13	10	1.8%
9	Low rigid object (more or equal to 20cm high)	16	6	1.1%
10	Semi-rigid structure or building	14	5	0.9%
11	Deep drainage ditch	8	5	0.9%
12	No object	17	4	0.7%
13	Downward slope	9	1	0.2%
		Total	556	100%

Although the road safety interventions raised the overall safety standard of the treated road segments, the combined evidence from Tables 5.16 and 5.17 indicates that these measures alone may not fully address the safety needs of vulnerable road users, such as motorcyclists. Persistent geometric constraints, particularly those related to horizontal curvature, require longer-term, infrastructure-focused solutions beyond short-term, low-cost treatments. Accordingly, road authorities should prioritise comprehensive alignment improvements on severely curved segments, while integrating complementary measures such as speed management, rider behaviour interventions, and enhanced traffic control devices further to mitigate motorcycle crash risk in high-risk mountainous locations.

5.6 Chapter Summary

This chapter presents the results of the modified iRAP@Highlands model, which was developed to assess and improve road safety performance for motorcyclists along the 55.6-kilometer road network along the research location. The assessment focused on identifying infrastructure-related risks, analysing blackspot locations, and implementing iRAP-based quick-win countermeasures to improve the Star Rating Score (SRS) for motorcyclists in this high-risk, mountainous environment.

The initial star rating analysis revealed that 97% of the surveyed road segments received a 1-star rating, indicating severe road safety deficiencies for motorcyclists. Following the implementation of targeted countermeasures recommended by the iRAP methodology, such as motorcycle-friendly barriers, improved delineation, and pavement upgrades, the reassessment showed an improvement in road safety performance, with the appearance of 3-star and 4-star road segments. This transition demonstrates the practical applicability and impact of the iRAP methodology in challenging terrains, where full-scale geometric upgrades are often infeasible.

A focused blackspot analysis, based on the SRS risk worm plot, narrowed the road safety intervention scope to three critical zones (Zone 1, 2, and 3), comprising 90 segments out of the total 556. The researcher prioritised these zones due to their extremely low star ratings and observable documented crash patterns. The comparative evaluation before and after road safety countermeasure implementation highlighted significant improvements in roadside safety features, particularly in the reduction of rigid roadside hazards on the passenger side, which is a leading contributor to fatal run-off-road crashes among motorcyclists.

Additionally, this chapter introduced a predicted casualty reduction map, visually demonstrating the impact of iRAP quick-win road safety treatments in preventing Fatal and Serious Injuries (FSIs). The map shows that critical zones could save more than 15 FSIs per kilometre, reinforcing the cost-efficiency and life-saving potential of data-driven road safety interventions in the research location.

This chapter also applied Multiple Linear Regression (MLR) analysis to statistically model the relationship between key road engineering variables and the SRS. The results confirmed that road condition, curvature, and quality of curve were significant predictors of road safety performance, with curvature emerging as the most critical factor both before and after the implementation of road safety interventions. This analytical approach validated the effectiveness of road infrastructure improvements while offering a quantitative framework to inform the proposed modified model.

In conclusion, the findings presented in this chapter validate the modified model as a practical and simplified tool for risk diagnosis and road safety intervention planning in Malaysia's highland road networks. The integration of spatial risk profiling, road engineering diagnostics, and regression-based analysis provides a extensive methodology for guiding road safety policy and future research targeting vulnerable road users, particularly motorcyclists, within similar mountainous contexts.

CHAPTER 6
CONCLUSION

6.1 Introduction

The mountainous road network of Cameron Highlands in Malaysia represents a complex and hazardous terrain, particularly for vulnerable road users such as motorcyclists. This research was situated within the broader context of global road safety efforts, specifically the implementation of evidence-based tools, such as the International Road Assessment Programme (iRAP), to evaluate and improve road infrastructure safety. At the national level, road traffic crashes involving motorcyclists remain a recurring public health concern and a significant road safety issue, with rural and highland routes often being excluded from structured road safety assessments. The centrality of this research lies in bridging that gap by contextualising and modifying the model to suit localised, high-altitude environments with specific geometric and climatic challenges along the research location.

The researcher structured the research activities dedicated to four interconnected objectives. It began with identifying thematic crash risk factors through a Systematic Literature Review (SLR), followed by profiling road crash data using data visualisation techniques in Tableau software. The third objective involved a field-based road inspection using iRAP protocols, focusing on the road network from the research location. Finally, this study proposed a regression-based modified model using SPSS software to quantify the relationship between road infrastructure attributes and the star rating score for road performance, specifically for motorcyclists.

This study addresses a gap in existing knowledge by incorporating a statistical model into the global road safety star rating framework. The theoretical underpinning draws upon the Safe System Approach, which emphasises infrastructure design and proactive risk mitigation, in combination with road safety risk modelling grounded in multivariate statistical theory.

6.2 Conclusions

The main findings of this research are based on the output of the proposed model and related to the research aim and objectives. There are four research questions used to achieve the objectives by inquiring; (i) What are the key factors contributing to road crashes in mountainous road networks?, (ii) How does the road crash data profile explain the high frequency of crashes within Cameron Highlands' mountainous road network?, (iii) Which road segments and infrastructure conditions characterise the main roadway with the highest fatal crash frequency in Cameron Highlands?, and (iv) How can an existing road safety risk assessment tool be modified to more effectively address motorcyclists' safety along mountainous road networks?. The following section describes the primary findings of this research.

6.2.1 The Identification of the Thematic Structure and Key Factors Contributing to Road Crashes in Mountainous Areas of Road Networks.

The first research objective aimed to identify the thematic structure and critical contributing factors to road crashes in mountainous areas through a Systematic Literature Review (SLR). The review revealed a consistent pattern of infrastructure and environmental risk factors, including narrow lanes, poor horizontal alignment, limited sight distances, roadside hazards, and inadequate signage. These findings confirm the claims of earlier studies by Hu et al. (2023), Tang et al. (2023), and Elvik and Katharina (2023) that mountainous roads exhibit context-specific hazards that are not always captured by standard road safety assessment tools.

The methodology employed in the SLR adhered to a rigorous selection protocol, enabling the consolidation of credible evidence across multiple geographies from various regions. This study evaluated existing methods and identified a gap in practical frameworks that can be locally adapted for motorcyclist-focused assessments. While iRAP provides a global road safety model, it lacks the specificity required for terrain-specific risk quantification, especially when dealing with vulnerable users, such as motorcyclists, in constrained environments.

This research thus contributes to theoretical knowledge by synthesising infrastructure-related crash risks into a conceptual framework suitable for regression modelling. It also underscores the limitations of previous approaches, which often neglect road geometry and behavioural interaction in complex terrains. The thematic findings informed the later stages of model design and variable selection in regression analysis.

6.2.2 The Development of a Road Crash Data profile for the Cameron Highlands Mountainous Road Network.

The second objective focused on developing a road crash data profile for the Cameron Highlands using Tableau software. The approach enabled the consolidation of five years of police-reported road crash data into an interactive, spatial-temporal visualisation dashboard. Findings revealed that head-on collisions, prevalent in two-way rural road traffic systems, are a major contributor to all injury types in the research location. These incidents frequently occur in clear weather at bends, T or Y junctions, and straight roads. Understanding these specific locations can lead to improved road safety criteria and geometric design, significantly reducing injury severity.

The use of Tableau for visual analytics enhances the methodological approach of this research by enabling multidimensional insights into crash distribution, time-of-day effects, and vehicle-type involvement. The evaluation of this method confirmed its usefulness for large-scale data exploration. However, limitations included the absence of precise geolocation in some datasets, as also noted by prior researchers (Hu et al., 2023; Waseem et al., 2019).

From a theoretical standpoint, the integration of data visualisation tools in road crash data profiling aligns with the move toward data-driven policy evaluation frameworks. The crash data profile produced by this study provides foundational knowledge that supports targeted road safety inspection site location and modelling, validating the selection of the road segments and focus zones. Additionally, the findings highlight limitations within the existing crash reporting system, particularly in capturing precise crash location data along mountainous road networks such as Cameron Highlands. This underscores the need for more accurate and standardised geolocation mechanisms to support detailed road safety assessments for motorcyclists.

6.2.3 The Establishment of Road Condition Reports for the Main Road That Captured the Highest Fatal Crash Frequency in Cameron Highlands.

The third objective involved establishing a detailed road condition report for the highest-risk road segment of the research location, through an on-site road inspection using the iRAP methodology. This process incorporated video logging, GPS mapping, MiReV, and ViDA software analysis. The iRAP star rating generated for each 100-meter segment revealed that large portions of the route rated 1- or 2-stars for motorcyclists, indicating a high risk of death or serious injury in the event of a crash.

The road survey confirmed many of the infrastructure-related risk indicators identified in the SLR and crash profile, including inadequate delineation, narrow road shoulders, steep gradients, sharp horizontal curves, roadside hazards, inconsistent pavement conditions, and limited barrier protection, are factors known to elevate motorcycle crash risk along mountainous road networks. Frequent presence of unprotected roadside hazards, insufficient road shoulder width, poor curve quality, and inconsistent surface conditions were among the most salient findings. This phase of the research also highlighted the practical limitations of iRAP in its original form, particularly in its handling of motorcyclist-specific risks in highland conditions. Similar criticisms have been raised in iRAP implementation studies in Thailand and Vietnam (iRAP, 2022).

By evaluating the practical application of iRAP tools and comparing them to actual crash hotspots, the study contributed to methodological refinement. The collected ViDA data became a critical input for the regression model, ensuring that subsequent quantitative modelling reflected the actual risk landscape observed on the actual research site location.

6.2.4 The Development of a Modified Road Safety Risk Assessment Model for Motorcyclists (iRAP@Highlands)

The final objective was to propose a modified road safety risk assessment model, specifically for motorcyclists by utilising Multiple Linear Regression (MLR) analysis in SPSS. This model statistically analysed the relationship between infrastructure variables and the iRAP Star Rating Score (SRS) for motorcycle riders. Key predictors, namely road condition, curvature, and curve quality, were found to be statistically significant at the 95% confidence level, indicating that variations in these factors have a measurable and meaningful effect on the Star Rating Score (SRS). Specifically, deteriorated pavement surfaces, tighter horizontal curves, and poor curve quality were associated with lower SRS values, reflecting increased motorcycle crash risk along mountainous road sections. The MLR model demonstrated a strong explanatory power, indicating that infrastructure elements directly contribute to increased or reduced road safety outcomes for motorcyclists. Unlike conventional iRAP assessments, which rely on weighted scoring, the regression-based approach quantifies the relative impact of each variable, offering new insights into prioritisation strategies. These findings address a research limitation in previous iRAP applications, which often lack transparency in risk attribution during the assessment.

From a theoretical perspective, the model bridges the gap between empirical data analysis and road safety design, offering a locally calibrated tool grounded in multivariate statistical theory. It also supports claims in the existing literature that road environment features disproportionately affect the safety outcomes of motorcyclists. Furthermore, this research expands the methodological toolkit available for developing region-specific modifications of international road safety frameworks.

6.3 Practical Applications and Policy Implications

The findings of this research carry significant practical value. The modified model provides a replicable tool for local road authorities to assess and prioritise road safety interventions in the highland road network, especially where resources are constrained. The researcher can incorporate the risk map and star rating profiles into road maintenance planning, road upgrade proposals, and policy advocacy for vulnerable road users. It also aligns with Malaysia's Road Safety Plan 2022–2030 and international targets under the UN Decade of Action for Road Safety (2021–2030), supporting efforts to reduce traffic fatalities by 50% by 2030.

In particular, the iRAP@Highland modified model enhances institutional capacity to perform risk-based budgeting for infrastructure projects and encourages integration between crash data, road engineering audits, and statistical modelling in road design. Road engineers, traffic police, municipal councils, and transportation planners can all benefit from the evidence-based outputs produced by this research.

6.4 Recommendations

Mountainous roadways, such as those in the Cameron Highlands, pose serious safety challenges, especially for motorcyclists, who are particularly vulnerable due to reduced vehicle stability, high exposure to impact, and frequent encounters with steep inclines, winding routes, and adverse weather conditions. Building on the findings of this study, future research should adopt both data-driven approaches and practical frameworks to develop holistic road safety solutions for highland networks.

6.4.1 The Hierarchy of Control Framework

This research recommends applying the hierarchy of control framework to address motorcyclist safety risks systematically. The framework consists of five levels of intervention: (i) elimination, which removes road hazards such as loose debris or obstructive vegetation; (ii) substitution, which replaces high-risk roadway elements with safer alternatives, such as improving pavement materials or replacing hazardous barriers; (iii) engineering controls, which modify the road environment through measures like enhanced delineation, improved curve geometry, warning systems, and shoulder widening; (iv) administrative measures, including speed management, enforcement, and targeted safety campaigns for motorcyclists; and (v) the use of personal protective equipment (PPE), such as certified helmets and protective riding gear. Together, these measures provide a structured framework for reducing motorcycle crash risk along mountainous road networks.

At the elimination level, stakeholders, such as local governments and road agencies, should proactively identify and remove hazardous conditions along high-risk sections, including blind curves, steep descents, and corners obstructed by vegetation. Stakeholders should consider realigning extreme road curvature where feasible. Although the idea of banning motorcycles is not widely applicable in Malaysia, international examples (e.g., Beijing, Lagos, Jakarta) show that restrictions in sensitive or high-risk zones can reduce crash rates when supported by viable transport alternatives. Instead, Malaysian authorities may explore route-specific controls or diversion strategies for heavy motorcycles in a tourism-heavy road network.

At the substitution level, promoting alternative transportation options, such as affordable shuttle buses or ride-sharing systems, can reduce motorcyclist exposure, particularly in tourist zones. Providing incentives for tourists and locals to opt for safer vehicles could support long-term mode shift behavior. Road engineering controls are equally essential. Infrastructure enhancements, such as motorcycle-friendly guardrails, widened lanes, skid-resistant surfaces, improved lighting, and reflective road markings, should be prioritised, especially in areas with frequent rain and fog. These road safety countermeasures align with both iRAP quick-win recommendations and findings from this study's ViDA road inspection.

Administrative controls should focus on education, enforcement, and awareness campaigns tailored to the specific needs of the terrain road networks. Training programmes can improve rider handling skills on steep or slippery roads, and campaigns should highlight common crash causes such as sharp cornering and high speeds. Local authorities should also enforce speed limits and helmet usage laws more rigorously. Lastly, at the Personal Protective Equipment (PPE) level, all riders, particularly those operating high-powered motorcycles, must be encouraged or mandated to wear international-standard helmets, gloves, and high-visibility gear. Collaborative schemes with local suppliers offering subsidies or discounts could increase gear adoption among high-powered motorcycle riders. Beyond practical road safety interventions, future academic research should explore several strategic research directions to enhance the utility and scalability of the proposed modified model:

a) Geographic Extension: The model should be applied to other highland road networks in Malaysia and Southeast Asia to assess its generalisability across similar geomorphological and climatic conditions, for example, the Genting Highlands, Fraser's Hill, Bukit Tinggi, Bukit Larut and other highland regions.

b) Inclusion of Other Risk Variables: To improve predictive accuracy, future models should incorporate behavioural and environmental risk variables, such as vehicle speed, rider demographics, helmet compliance, and weather conditions. A mixed-methods approach integrating rider surveys with statistical modelling may offer deeper contextual insights.

c) Integration of Advanced Modelling Techniques: Future work could explore machine learning or AI-based techniques that surpass the limitations of linear models. These approaches can uncover non-linear interactions between road attributes and road safety outcomes, enhancing model complexity.

d) Longitudinal Impact Studies: To validate the model's practical utility, researchers should conduct pre- and post-intervention studies assessing changes in crash frequency and severity following infrastructure upgrades guided by the modified model.

e) Institutional Collaboration: Researchers should work closely with transport authorities, planning agencies, and municipal councils to embed the model within official road safety planning processes. This can help bridge the gap between academic research and policy execution, ultimately institutionalising a data-informed approach to road safety decision-making.

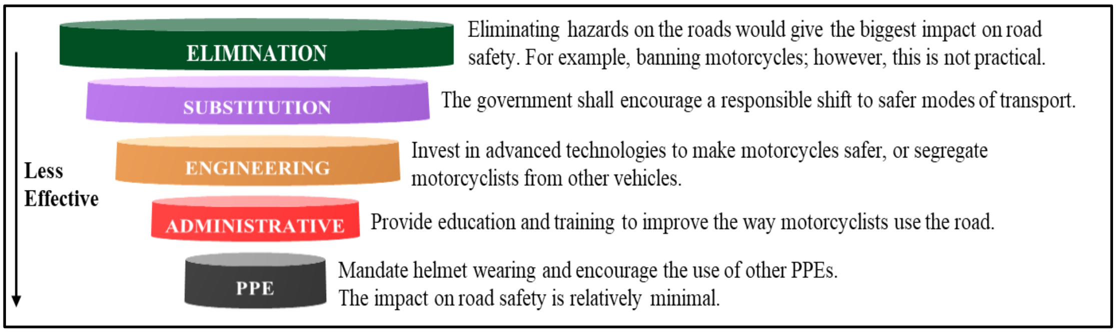

Figure 6.1 Hierarchy of Control Framework Recommendations for Related Stakeholders to Reduce Road Crashes in Mountainous Roadways

Finally, monitoring and evaluating road safety interventions through structured tools, such as the iRAP Star Rating methodology and risk mapping, should become standard practice. Periodic updates informed by field audits, crash data, and stakeholder feedback can support continuous improvement at the research location. Adopting this integrated, evidence-based, and system-wide approach will not only align with the United Nations Decade of Action for Road Safety (2021–2030) but also contribute to the long-term goal of reducing motorcycle-related fatalities across Malaysia's mountainous transport road networks. This recommendation guides stakeholders in implementing a inclusive strategy to mitigate motorcycle-related crashes and fatalities in mountainous areas, utilising an approach rooted in the Hierarchy of Control framework. Figure 6.1 illustrates this framework, outlining the recommended actions at each level, ranging from eliminating road hazards to promoting the use of personal protective equipment (PPE), to support road safety improvement efforts in high-risk road networks, such as the Jalan Simpang Pulai to Blue Valley route in the Cameron Highlands.

6.4.2 Recommendations for Stakeholders

The findings of this research provide several practical implications for key stakeholders involved in road safety planning, implementation, and governance, particularly within complex mountainous environments such as the Cameron Highlands. Targeted engagement among these stakeholders is essential to ensure that research outcomes are translated into meaningful safety improvements and sustainable transport practices.

For academia, universities, and researchers in road safety, transportation engineering, and the built environment, this research can inform the development of methodological frameworks and empirical findings. Future academic efforts should focus on generating new knowledge through advanced modelling techniques, interdisciplinary research, and comparative studies across different mountainous regions. Collaborative research initiatives between institutions can further stimulate methodological innovation, data sharing, and the development of context-specific safety assessment tools.

For the industry, including road engineers, consultants, and transport-related organisations, this research offers an evidence-based foundation for translating research outcomes into engineering practice. Industry stakeholders are encouraged to adopt the identified safety risk factors and predictive modelling approaches in roadway design, safety audits, and asset management processes. Moreover, there is potential for commercialisation through the development of decision-support systems, safety assessment software, and innovative engineering solutions tailored to high-risk mountainous road environments.

From a community perspective, road users, non-governmental organisations (NGOs), and local communities play a critical role in shaping public attitudes and behavioural norms related to road safety. The findings can support awareness campaigns, advocacy programmes, and community-based interventions that promote responsible riding and driving behaviour, particularly among vulnerable road users such as motorcyclists. Enhanced community engagement can strengthen social responsibility and foster a shared commitment to safer and more sustainable road use.

With respect to the environment, this research highlights the need to balance human activity, infrastructure development, and ecological sustainability in sensitive highland areas such as the Cameron Highlands. Stakeholders involved in planning and implementation should consider environmentally responsible engineering solutions that minimise ecological disruption while enhancing road safety. Integrating safety interventions with sustainable drainage systems, slope stabilisation, and environmentally sensitive design can support long-term resilience and environmental preservation in mountainous terrains.

Finally, for government stakeholders, including the Ministry of Transport (MoT) and relevant public authorities, the findings provide empirical evidence to support policymaking, planning, and enforcement strategies. Agencies such as the Malaysian Institute of Road Safety Research (MIROS), the Public Works Department (JKR), and the Royal Malaysia Police (RMP) can utilise the outcomes to refine national road safety standards, prioritise high-risk corridors, and guide the implementation of targeted enforcement and road engineering interventions. Strengthened interagency coordination, supported by data-driven decision-making, will be critical to advancing national road safety objectives and reducing crash risk in mountainous regions.

6.4.3 Recommendations for Future Research

Future research should extend the current modelling framework to enhance its explanatory power, predictive robustness, and policy relevance. First, the integration of behavioural and exposure-related variables is strongly recommended. Incorporating motorcyclist behavioural indicators such as operating speed, helmet compliance, overtaking manoeuvres, and lane-position behaviour together with exposure metrics including Annual Average Daily Traffic (AADT) and motorcycle traffic volume, would enable more realistic estimation of crash risk and improve the predictive accuracy of safety performance models.

This research should be replicated across other mountainous road corridors, such as the Tapah to Ringlet and Gua Musang to Lojing road network. Expanding the geographical scope would allow testing of model robustness under varying geometric, traffic, and environmental conditions, thereby strengthening the generalisability of the findings across mountainous road networks in Malaysia and comparable regions.

Future work should explore advanced predictive modelling approaches. The application of machine learning techniques or Bayesian-based methods could better capture nonlinear relationships, interaction effects, and uncertainty structures that are not fully addressed by conventional multiple linear regression. Such approaches may enhance the precision of risk prediction, particularly for complex road environments characterised by sharp horizontal curvature, steep gradients, and heterogeneous traffic composition.

Greater emphasis should be placed on economic evaluation and policy-oriented analysis. Conducting cost–benefit or cost-effectiveness analyses of proposed countermeasures would provide decision-makers with quantitative evidence to support prioritisation, optimise resource allocation, and justify investment in targeted road safety interventions along the high-risk mountainous road network.

Finally, longitudinal studies are recommended to evaluate the post-implementation performance of the developed model and associated countermeasures. Continuous monitoring of crash frequency, severity, and star-rating outcomes over time would enable assessment of sustained safety benefits, validation of model assumptions, and refinement of intervention strategies based on observed trends in crash reduction and infrastructure performance.

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APPENDICES

APPENDIX 1

Research Copyright Approval

COPYRIGHT ACT 1987

COPYRIGHT (VOLUNTARY NOTIFICATION) REGULATIONS 2012

CERTIFICATE OF COPYRIGHT NOTIFICATION
[Subregulation 8(2)]

Notification Number	:	**CRLY2024W06731**
Title of Work	:	**AN IRAP@HIGHLANDS MODEL FOR ROAD SAFETY STAR RATING (IROSSTAR@HIGHLANDS)**
Category of Work	:	**LITERARY**
Date of Notification	:	**16 OCTOBER 2024**
Date of Creation	:	**01 JANUARY 2021**
Date of First Published	:	**16 MAY 2023**

This is to certify, under the Copyright Act 1987 [Act 332] and the Copyright (Voluntary Notification) Regulations 2012 that the copyrighted work bearing the Notification No. above for the applicant **UNIVERSITI TEKNOLOGI MARA** as the **OWNER** and **FATIN NAJWA BINTI MOHD NUSA (890619145252), CHE MAZNAH BINTI MAT ISA (650211025000), SITI ZAHARAH BT ISHAK (760301055454), ALVIN POI WAI HOONG (810219145613), MUHAMMAD MARIZWAN BIN ABDUL MANAN (770324145275)** as the **AUTHOR** have been recorded in the Register of Copyright, in accordance with section 26B of the Copyright Act 1987 [Act 332].

[redacted]

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APPENDIX 2

Research Ethics Review Exemption by UiTM Research Ethics Committee

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UNIVERSITI TEKNOLOGI MARA

Pejabat
Timbalan Naib Canselor
(Penyelidikan dan Inovasi)

Reference : 600-TNCPI (5/1/6)
Our reference : REC/04/2023 (PG/EX/24)
Date : 7 February 2023

Ts Dr Siti Zaharah Ishak
(Ts Fatin Najwa Mohd Nusa - 2021902405)
Malaysia Institute of Transport (MITRANS)
Universiti Teknologi MARA
40450 Shah Alam
SELANGOR

Dear Ts Dr Siti Zaharah,

ETHICS REVIEW EXEMPTION - UiTM RESEARCH ETHICS COMMITTEE

Thank you for submitting your research proposal to the Research Ethics Committee (REC). After considering your application, the Committee agreed that your proposal titled "The Development of Road Safety Star Rating Score (SRS) Instruments at Hilly Areas Using Modified Road Assessment Programme RAP@Hilly Model" is exempted from ethics review.

Details of the ethics review exemption are as follows:

Ref. number:	REC/04/2023 (PG/EX/24)
Authorised personnel:	1. Ts Dr Siti Zaharah Ishak 2. Ts Fatin Najwa Mohd Nusa

The UiTM Research Ethics Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The ethics review exemption of this project is conditional upon your continuing compliance with these guidelines and declaration.

If you require further information, please contact the REC Secretariat at 03-55448069/03-55442794 or email at recsecretariat@uitm.edu.my.

Yours sincerely,

[redacted]

EMERITUS PROFESSOR DATO' DR RAYMOND AZMAN ALI
Chairman
UiTM Research Ethics Committee

c.c.: Director, Research Nexus UiTM (ReNeU), UiTM

Universiti Teknologi MARA
Aras 3, Bangunan Wawasan
40450 Shah Alam, Selangor, MALAYSIA
Tel: (+603) 5544 2004/2255
Faks: (+603) 5544 2070

ISO 9001:2015 No. Sijil: 10120156

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APPENDIX 3

Detailed Road Safety Improvement and Countermeasures Recommendations for Blackspot Zone 1, Zone 2, and Zone 3

No	Route Section Photo	Issues	Quick-win iRAP Recommendations
Zone 1			
1	 Longitude Latitude: 4.556778 101.183675	• Cat's eye type rumble strips only. • Rapid or unexpected speed adjustment to negotiate the curve. • Lack of advanced signage. • Tree trunk greater than 10 cm in diameter.	• Combination of cat's eye and rumble strips. • Provide chevron alignment markers or other reflective hazard markers. • Provide signage and road marking to judge curvature. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line.
2	 Longitude Latitude: 4.557245 101.184442	• Cat's eye type rumble strips only. • Aggressive vertical face at driver distance is 1 meter to less than 5 meters. • Tree trunk greater than 10 cm in diameter.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove the object with an effective distance of 5 or less than 10 meters from the edge line.

3	 Longitude Latitude: 4.557721 101.185196	• Cat’s eye type rumble strips only. • Aggressive vertical face at driver distance is 1 meter to less than 5 meters. • Metal safety barrier, safety barrier, not a motorcycle-friendly barrier.	• Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists.
4	 Longitude Latitude: 4.558447 101.185726	• Cat’s eye type rumble strips only. • Aggressive vertical face at driver distance is 1 meter to less than 5 meters. • Metal safety barrier, safety barrier, not a motorcycle-friendly barrier. • No shoulder rumble strips present.	• Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver.
5	 Longitude Latitude: 4.558887 101.186497	• Tree trunks greater than 10 cm in diameter at driver distance are 1 meter to less than 5 meters. • Metal safety barrier, safety barrier, not a motorcycle-friendly barrier. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

6	 Longitude Latitude: 4.558845 101.187392	• Tree trunks greater than 10 cm in diameter at driver distance are 1 meter to less than 5 meters. • Metal safety barrier, safety barrier, not a motorcycle-friendly barrier. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature. • Poor quality of curve.	• Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.
7	 Longitude Latitude: 4.558999 101.188273	• Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature. • Poor quality of the curve.	• Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.

8	 Longitude Latitude: 4.559248 101.189137	• Centreline rumble strips not present. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a combination of cat's eye and rumble strips. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
9	 Longitude Latitude: 4.559524 101.189994	• No shoulder rumble strips present. • Unprotected safety barrier end • Metal safety barrier, safety barrier, not a motorcycle-friendly barrier. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide raised profile markings as an audio-vibratory warning to the driver. • Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Provide a safety barrier specifically designed to restrain motorcyclists. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

10	 Longitude Latitude: 4.55983101.190836	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
11	 Longitude Latitude: 4.560246 101.191633	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

12	 Longitude Latitude: 4.560725 101.192396	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
13	 Longitude Latitude: 4.561168 101.193187	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

14	 Longitude Latitude: 4.561394 101.194065	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.
15	 Longitude Latitude: 4.561538 101.194955	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
16	 Longitude Latitude: 4.561715 101.195841	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

17	 Longitude Latitude: 4.562109 101.196653	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve. • Poor delineation.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.
18	 Longitude Latitude: 4.562703 101.197336	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

19	 Longitude Latitude: 4.56334101.197977	• Concrete safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
20	 Longitude Latitude: 4.563936 101.19866	• Concrete safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

21	 Longitude Latitude: 4.564552 101.199329	• Concrete safety barrier, not a motorcycle-friendly barrier. • Aggressive vertical face at driver distance is 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
22	 Longitude Latitude: 4.564623 101.200209	• Concrete safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.

23	 Longitude Latitude: 4.564599 101.201115	• Concrete safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
24	 Longitude Latitude: 4.564578 101.202021	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

Zone 2			
25	 Longitude Latitude: 4.564303 101.202869	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature. • Poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.
26	 Longitude Latitude: 4.564158 101.203755	• Concrete and metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature. • Poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.

27	 Longitude Latitude: 4.564466 101.204611	• Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • The unpaved shoulder and no edge line. • Poor delineation.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.
28	 Longitude Latitude: 4.564807 101.205445	• Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • The unpaved shoulder and no edge line. • Poor delineation.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.

29	 Longitude Latitude: 4.565132 101.206289	• Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • The unpaved shoulder and no edge line. • Poor delineation.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.
30	 Longitude Latitude: 4.565478 101.207132	• Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • The unpaved shoulder and no edge line. • Poor delineation.	• Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.

31	 Longitude Latitude: 4.566049 101.207816	• Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve. • Poor delineation.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.
32	 Longitude Latitude: 4.566512 101.208589	• Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help

		• Sharp curvature. • Poor delineation.	ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles. • Improve centre lines, lane markers, and edge lines. • Add on guideposts and delineators, as well as road studs and hazard markers.
33	 Longitude Latitude: 4.566653 101.209507	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
34	 Longitude Latitude: 4.566744 101.210434	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

35	 Longitude Latitude: 4.567194002 101.2112162	• Unprotected safety barrier end. • Electric poles greater than 10 cm in diameter crossing the road. • Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve. • Poor curvature.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.
36	 Longitude Latitude: 4.568001691 101.2116138	• Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

37	 Longitude Latitude: 4.568804999 101.2120133	• Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
38	 Longitude Latitude: 4.569482181 101.2126038	• Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve.	• Cat's eye and rumble strips combination. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter. Ensure it is 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Installing quality reflective signage, road markings, and adequate street lighting to ensure visibility at night or in poor weather conditions.

39	 Longitude Latitude: 4.570092223 101.213267	• Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
40	 Longitude Latitude: 4.570555861 101.214018	• Rigid sign, post, or pole more or equal to 10 cm in diameter. • Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor curvature and quality of the curve. • Road defects may cause unpredictable impacts on vehicles, especially on motorcyclists.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles. • Seal road surface with edge defects, including any road shoulder.

41  Longitude Latitude: 4.570482576 101.2149167	• Cat’s eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
42  Longitude Latitude: 4.570701606 101.2157754	• Unprotected road safety barrier end. • Cat’s eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.

43	 Longitude Latitude: 4.571210619 101.2165195	• Unprotected road safety barrier end. • Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
44	 Longitude Latitude: 4.57172748 101.2172581	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

45  Longitude Latitude: 4.572064267 101.2180859	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips and shoulder rumble strips not present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.
46  Longitude Latitude: 4.57196939 101.2189742	• Unprotected road safety barrier end. • Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Provide advanced signage and advisory speed signs to slow down vehicles.

47	 Longitude Latitude: 4.57173101.219881	• Cat's eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.
48	 Longitude Latitude: 4.571461 101.220759	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.

49  Longitude Latitude: 4.571326 101.221665	• Unprotected road safety barrier end. • Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor quality of the curve.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.
50  Longitude Latitude: 4.571451 101.222564	• Unprotected road safety barrier end. • Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.

51  Longitude Latitude: 4.571558 101.223487	• Cat’s eye type rumble strips only. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Electricity poles with a diameter of more than 10 cm. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.
52  Longitude Latitude: 4.571589 101.224421	• Unprotected road safety barrier end. • Cat’s eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.

53	 Longitude Latitude: 4.57127101.225278	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.
54	 Longitude Latitude: 4.570913 101.226112	• Cat's eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.

55	 Longitude Latitude: 4.570979 101.227036	• Cat’s eye type rumble strips only. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat’s eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.
56	 Longitude Latitude: 4.57129101.227856	• Centreline rumble strips not present. • No shoulder rumble strips present. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.

57	 Longitude Latitude: 4.571694 101.22868	• Centreline rumble strips not present. • No shoulder rumble strips present. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line.
58	 Longitude Latitude: 4.572083 101.229501	• Centreline rumble strips and shoulder rumble strips are not present. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide centreline rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver.

Zone 3			
59	 Longitude Latitude: 4.572165 101.230389	• Centreline rumble strips not present. • No shoulder rumble strips present. • Metal safety barrier, not a motorcycle-friendly barrier. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.

60

Longitude Latitude: 4.571978 101.231295

- Unprotected road safety barrier end.
- Cat’s eye type rumble strips only.
- Metal safety barrier, not a motorcycle-friendly barrier.
- Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters.
- Centreline rumble strips not present.
- No shoulder rumble strips present.
- Narrow paved shoulder and edge line are very close to the pavement edge.
- Poor quality of the curve.

- Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging.
- Combination of cat’s eye and rumble strips.
- Provide a safety barrier specifically designed to restrain motorcyclists.
- Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line.
- Provide raised profile markings as an audio-vibratory warning to the driver.
- The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.

61

Longitude Latitude: 4.596013647 101.3476891

- A landslide retaining wall will cause a rapid deceleration when a vehicle hits it.
- Rigid sign, post, or pole more or equal to 10 cm in diameter.
- Cat’s eye type rumble strips only.
- Centreline rumble strips not present.
- No shoulder rumble strips present.
- Narrow paved shoulder and edge line are very close to the pavement edge.
- Poor quality of the curve.

- Provide a safety barrier specifically designed to restrain motorcyclists.
- Combination of cat’s eye and rumble strips.
- Provide raised profile markings as an audio-vibratory warning to the driver.
- The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions.

62  Longitude Latitude: 4.595453818 101.3483834	• Landslide risk areas. • Rigid sign, post, or pole more than or equal to 10 cm in diameter. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Poor curvature and quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • The presence of quality reflective signage, road markings, and adequate street lighting will help ensure visibility at night or in poor weather conditions. • Provide advanced signage and advisory speed signs to slow down vehicles.
63  Longitude Latitude: 4.59501519 101.3491582	• Unprotected road safety barrier end. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Used turned-down or buried ends, added a low-level protection shield to the barrier end, and used smooth, deflective geometry to prevent snagging. • Provide centreline rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver.

64	 Longitude Latitude: 4.594652052 101.3499447	• "Orang asli" stall close to pavement edge. • Concrete safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature. • Poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.
65	 Longitude Latitude: 4.594665767 101.3508217	• Cut face of at least 2m height at a gradient of 75° or above, which a vehicle is likely to slide along when struck. • Concrete safety barrier, not a motorcycle-friendly barrier. • Orang asli" stall close to pavement edge. • Concrete safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

66	 Longitude Latitude: 4.594466174 101.3516927	• Irregular rock face, wall or non-standard barrier. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
67	 Longitude Latitude: 4.594479154 101.3525764	• Rigid sign, post, and poles greater than 10 cm in diameter. • Irregular rock face, wall, or non-standard barrier. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

68	 Longitude Latitude: 4.594177241 101.3534217	• Cat's eye rumble strips only. • Retaining walls or stones that will cause a rapid deceleration when vehicle hit. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
69	 Longitude Latitude: 4.593601307 101.3540827	• Cat's eye rumble strips only. • Retaining walls or stones that will cause a rapid deceleration when vehicle hit. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.

70	 Longitude Latitude: 4.592776867 101.3544371	• Rigid sign, post, and poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Retaining walls or stones that will cause a rapid deceleration when vehicle hit. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Combination of cat's eye and rumble strips. • Provide a safety barrier specifically designed to restrain motorcyclists. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
71	 Longitude Latitude: 4.591947713 101.354784	• Rigid sign, post, and solar street lighting poles greater than 10 cm in diameter. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Cat's eye rumble strips only. • Retaining walls or stones that will cause a rapid deceleration when vehicle hit. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

72	 Longitude Latitude: 4.591123403 101.3551399	• Rigid sign, post, and solar street lighting poles greater than 10 cm in diameter. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
73	 Longitude Latitude: 4.590418004 101.3556954	• Cut face of at least 2m height at a gradient of 75° or above, which a vehicle is likely to slide along when struck. • Solar street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

74	 Longitude Latitude: 4.58977664 101.3563239	• Cut face of at least 2m height at a gradient of 75̊ or above, which a vehicle is likely to slide along when struck. • Solar street lighting poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
75	 Longitude Latitude: 4.589158552 101.3569775	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

76	 Longitude Latitude: 4.588819907 101.3577965	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.
77	 Longitude Latitude: 4.588669338 101.3586826	• Cut face of at least 2m height at a gradient of 75̊ or above, which a vehicle is likely to slide along when struck. • Metal safety barrier, not a motorcycle-friendly barrier. • Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

78	 Longitude Latitude: 4.588120568 101.3593736	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.
79	 Longitude Latitude: 4.587419957 101.3599314	• Cut face of at least 2m height at a gradient of 75° or above, which a vehicle is likely to slide along when struck. • Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

80	 Longitude Latitude: 4.586889787 101.3606504	• Cut face of at least 2m height at a gradient of 75° or above, which a vehicle is likely to slide along when struck. • Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
81	 Longitude Latitude: 4.586447211 101.3614326	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

82	 Longitude Latitude: 4.585996233 101.3621993	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Tree trunks greater than 10 cm in diameter at both driver side distance and passenger side distance are 1 meter to less than 5 meters. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Remove or cut tree trunks greater than 10 cm in diameter and ensure they are 5m to less than 10 meters from the edge line. • Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
83	 Longitude Latitude: 4.585237866 101.3626558	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.
84	 Longitude Latitude: 4.584395496 101.3629695	• Small temple that will likely deform slightly when the vehicle hits. • Cat's eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat's eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

85	 Longitude Latitude: 4.583684867 101.3635191	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat’s eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat’s eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
86	 Longitude Latitude: 4.582979443 101.3640781	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat’s eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat’s eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
87	 Longitude Latitude: 4.582167296 101.364463	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Cat’s eye rumble strips only. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Combination of cat’s eye and rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.

88	 Longitude Latitude: 4.58140415 101.3649265	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present.
89	 Longitude Latitude: 4.580891716 101.3656628	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.

90	 Longitude Latitude: 4.580723418 101.3665416	• Rigid sign, post, and street lighting poles greater than 10 cm in diameter. • Metal safety barrier, not a motorcycle-friendly barrier. • Centreline rumble strips not present. • No shoulder rumble strips present. • Narrow paved shoulder and edge line are very close to the pavement edge. • Sharp curvature and poor quality of the curve.	• Provide a safety barrier specifically designed to restrain motorcyclists. • Provide centreline rumble strips. • Provide raised profile markings as an audio-vibratory warning to the driver. • Road shoulder should be paved 1 meter to less than 2.4 meters with an edge line present. • Provide advanced signage and advisory speed signs to slow down vehicles. • The presence of quality reflective signage, road markings, and adequate street lighting will help to judge at night or in poor weather.

AUTHOR'S PROFILE

Fatin Najwa Mohd Nusa obtained her diploma (2010) and Bachelor's degree (2013) in Civil Engineering from Universiti Teknologi MARA (UiTM), Malaysia. In 2016, she obtained her Master of Science (MSc.) in Transport and Logistics from the Malaysia Institute of Transport (MITRANS), UiTM, Malaysia. She is currently pursuing her PhD in the same field of research. She has been serving at UiTM Shah Alam since April 2019 as a lecturer in the Faculty of Civil Engineering. Her research focuses on road safety management, sustainable highways, construction management, and public transportation studies.

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2. Penang International Invention, Innovation, and Design (PIID, 2023), Silver Award, An iRAP@Highlands Model for Road Safety Star Rating (iROSSTAR@Highlands).
3. Penang International Invention, Innovation, and Design (PIID, 2023), Silver Award, A Detect_Analyse High Risk Location for Road Accident at Inter_Urban Expressway (DAHR2).
4. Innovation and Invention Challenge in Engineering and Technology (IICET, 2023), Bronze Award, Performance Measurement Criteria for Sub-Contracting Management (SCM_CRITERION) Framework for Malaysian Construction Project.
5. Jejak Inovasi UTeM (2022), Silver Award, e-Calculator: Development of e-Calculator to ease Construction Player in Understanding of Landed Green Residential Cost.
6. International Borneo Innovation Exhibition & Competition (IBIEC, 2022), Bronze Award, Power Oryx: Renewable Energy From Pedestrian Sidewalks Toward Global Sustainability.
7. Invention, Innovation and Design Exposition (IIDEX, 2020), Silver Award, S2WAMSM: Satellite Shallow Water Mapping Solution.
8. Invention, Innovation and Design Exposition (IIDEX,2019), Silver Award, KL Rush!
9. Invention, Innovation and Design Exposition (IIDEX, 2019), Silver Award, G2R Inventory Management v 1.0.
10. Invention, Innovation and Design Exposition (IIDEX, 2019), Silver Award, Klang Valley Journey Board Game.
11. Invention, Innovation and Design Exposition (IIDEX, 2018), Silver Award, BVDP Vendor Monitoring System.
12. Invention, Innovation and Design Exposition (IIDEX, 2018), Silver Award, BVDP Vendor Monitoring System.
13. Invention, Innovation and Design Exposition (IIDEX, 2018), Bronze Award, Malaysia Logistics Index.