

Original Article

# Developing a Road Characteristics Database to Support Vehicle Safety Testing in Alignment with New Car Assessment Program (NCAP) Protocols

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**Abstract** - Malaysia has been practicing vehicle safety testing based on the ASEAN New Car Assessment Program (ASEAN NCAP) and applies region-specific protocols for evaluating devices for safety assist technologies and motorcyclist safety. The testing needs to be conducted in a real-world environment, which is either urban, suburban, or rural roads. However, searching for roads requires a lot of time as the database that compiles the road characteristics is absent. Thus, standardized road characteristics are required. To fulfill this gap, this study is conducted within scoping on seven vehicle safety tests that were analyzed to determine the key parameters that characterize road testing properties. The methods involved a qualitative analysis of the documents, creating 31 distinct attributes containing them, which are codified into a data dictionary covering data types, value ranges, and testing applicability. These characteristics are used to create a data dictionary and conceptual data model that describes the relationship between road features, test specifications, environmental conditions, and infrastructure components. An analysis was made to compare how road characteristics are incorporated in the NCAP programs with a view to gaining a visualization of the parameters that are similar and the region-specific requirements. Semantic clarity and structural appropriateness of any attribute in the model are maintained with the help of expert validation. Pilot study implements the instrument developed based on the initial literature review and attribute analysis to support the data capture appropriately. It undergoes iterative improvement and is evaluated using a pilot study, tests of Google Maps, and on-site reviews to check compliance with ASEAN NCAP protocols. Data is entered into a MySQL-based database through a customized interface, ensuring consistency and preparedness to undergo an analysis. Generally, this study contributes a methodological framework and a road characteristic database development framework to guide regulators, manufacturers, and researchers. A preliminary system input-output architecture is also suggested, which provides the basis to implement it in the future.

**Keywords** - Data Dictionary, New Car Assessment Program, Road Characteristics, Test Protocol, Vehicle Safety Testing.

## 1. Introduction

Malaysia has been practicing vehicle safety testing based on the ASEAN New Car Assessment Program (ASEAN NCAP) and applies region-specific protocols for evaluating motor vehicles through two of the four pillars, which are (i) Safety Assist Technologies (SAT) and (ii) Motorcyclist Safety (MCS). The protocols are updated every two years and focus on the high-risk conditions in Southeast Asia, that is, traffic that is congested with motorcycles, a hot climate, and align with international standards [1]. The purpose of this adaptation is to empower consumers and encourage the manufacture of safer vehicles that suit the unique road

conditions of the area, and research confirms the life-saving effectiveness of several essential elements. Beyond adhering to established protocols, there is growing concern regarding the configuration of vehicle testing, prompting vehicle manufacturers and research centers to pursue more rigorous and standardized testing methods [2]. Evidence indicates that effective and reliable road-safety testing depends on the accurate representation and standardization of data related to road characteristics [3]. UNECE [4] also notes that different definitions of street surfaces, road signs, or lighting conditions may contribute to unreliable test results, and it implies the unavailability of comparability of safety ratings in different



markets. This shows that there is a need for a standardized road characteristics database to serve this purpose.

In the Malaysian context, however, no dedicated database of road characteristics to specifically serve vehicle testing protocols. The Malaysian Road Transport Department (JPJ) develops a system that connects to a comprehensive database on vehicle registrations and licensing only. Existing open datasets from JPJ primarily provide information on vehicle registrations and licensing information. In addition, the Ministry of Transport's National Transport Policy outlines infrastructure and mobility strategies without reference to road-condition or road-network databases for testing purposes [5, 6]. Consequently, it is vital to explore methods and analytically develop a database that captures road-related attributes to support standardized and repeatable testing procedures [7, 8]. Based on the above gap, this study makes an initial effort to analyze road testing protocols specified in the ASEAN NCAP requirements, selecting seven test protocols under the SAT and MCS pillars as proof of concept.

Thus, standardization of road characteristics is essential in establishing centralized data and ensuring consistency in the safety assessment of the vehicle. Moreover, Toyota Motor Corporation [9] points out that repeatable and measurable test conditions are essential to test safety technologies, especially in Advanced Driver Assistance Systems (ADAS) and automated driving systems. Honda [10] illustrates the utility of such a system in their Honda Sensing 360 platform, where road attributes are used to generate environmental inputs and modeled to provide better predictability of the system and driver alerts. Similarly, Volvo Cars [11] uses road metadata in their crash-prevention algorithms, which includes a description of the road, thus showing how structured road data is the direct basis of implementing smart safety features. For vehicle testing, manufacturers must first identify road segments that meet the specific requirements of each test protocol, and normally, identifying road segments takes several days of site survey. These manufacturers work in silo, and they do not share the collection of road segments that they identified unless requested. Apart from conducting vehicle testing in a few road segments, the testing is repeated many times in a year, each time new safety accessories are introduced to the Malaysian market.

The aim of this study is to construct a database through a systematic approach that fits the ASEAN NCAP specification. Codification through the attributes of the road is made easier by the development of a structured data dictionary and conceptual data model that helps convert the abstract attributes of a road into usable datasets. While the objectives of this study are (i) to identify key parameters of these seven protocols, (ii) to construct a data model for road characteristics, and (iii) to conduct a proof of concept of the database model, complete with a comprehensive. The novelty of this study lies in the development of a data-model

construction framework that is explicitly aligned with all seven ASEAN NCAP vehicle testing protocols. The model comprises validated attributes, definitions, and parameters required to ensure the validity of selected road segments for test procedures. This enables consistent interpretation of road characteristics and enhances the comparability of vehicle-testing outcomes across locations and conditions [7]. A further contribution of this study is the data dictionaries, which suggest data values related to the Malaysian context. The conceptual understanding gained based on road-environment parameters and their influence on safety-testing requirements, and their alignment with ASEAN NCAP specifications. Through these twofold contributions, this study delivers proposed specifications and methodological foundations for structuring road-characteristic data. Collectively, this provides a framework that not only supports technical DBMS development but also fulfills vehicle safety requirements, offering a practical recommendation for researchers and practitioners in the field. By doing so, the framework provides a reusable reference model for researchers and practitioners seeking to integrate real-world road scenarios into vehicle-testing processes while maintaining compatibility with international automotive safety standards [11, 12].

To present the work, this paper is arranged in six major sections. The introduction provides the context of the research, the gaps that exist in the research, and the aims and objectives of the study. The literature review, Section 2, examines the previous studies and identifies knowledge gaps in the current testing protocols of vehicles used in the market. In Section 3, methodology, the process of document analysis, methods of data extraction, and strategies of data validation are explained. Section 4, results and findings, gives the standardized road attributes denoted and the format of the proposed data model. The discussion, Section 5, is an interpretation of the implications of the findings and places them within the larger automotive testing scene. Lastly, the conclusion and future work part summarizes the possibility of designing a standard road characteristics database to help in testing vehicle safety and aligning protocols.

## 2. Literature Review

### 2.1. The Importance of Standardizing Road Characteristics Data

Road characteristics form a fundamental component in the safety testing of vehicles, and they have a great impact on the way the vehicle behaves in both controlled and real environments. Road surface, which includes road texture, slope, and curvature, directly influences the ability to brake, the stability of the vehicle, and the effectiveness of the active safety system, like the Automated Emergency Braking (AEB) and Lane-Keeping Assistance (LKA) [13]. In addition, road markings, visibility, road edge type, and lighting are not only useful to direct human drivers but also important inputs to sensor-based systems in Advanced Driver Assistance Systems (ADAS) and autonomous vehicles [14]. A literature analysis

among major NCAP programs in ASEAN NCAP, Japan NCAP (JNCAP) [15], Australia NCAP (ANCAP)[16], and USA NCAP (NHTSA) [17] has shown some important similarities and differences. As an example, Euro NCAP focuses on pedestrian and cyclist situations in city night-time conditions and must test with a reflective surface and changing light [18].

Conversely, ASEAN NCAP focuses more on environments that are more indicative of the Southeast Asian roads, including high temperatures, motorcyclist interaction, and uneven surfaces. The variety of priorities on a regional level revealed by such comparative studies as MIROS [12] and JNCAP [15] proves that a unified database of standardized road characteristics is necessary. Even though there are test protocols, there exist significant gaps in the incorporation of real road conditions in testing the safety of the vehicle.

According to [14], most of the modern-day tests are based on idealized or homogeneous conditions, which do not reflect the complexities of faded lane markings, mixed road edges, or unpredictable light conditions that are continually experienced during normal day-to-day driving.

The lack of environmental variability in the conventional test tracks also impairs the generalizability of safety performance results.

**2.2. NCAP Test Protocol**

The NCAP is a government and independently run initiative that evaluates the safety performance of new vehicle models and assigns a star rating ranging from zero to five. Its objective is to raise safety standards across the automotive industry while enhancing consumer awareness on vehicle performance under various safety threats, including crash protection and collision-avoidance capabilities [19].

To achieve this, NCAP conducts assessments involving crash tests, safety-assist system evaluations, and other performance-based examinations. The results of these tests are interpreted into a star rating. This provides consumers with a benchmark of vehicle safety and motivates manufacturers to improve the safety features of their designs continuously. The first NCAP was launched in the United States in 1978. Since then, numerous independent NCAP organizations have been established globally, each conducting tests and issuing ratings specific to their region.

**Table 1. Description of test protocols (Source: ASEAN NCAP, 2025)**

No.	Test Protocol	Pillars	Purpose	Device/System Tested
1	AEB Car–Motorcyclist (AEBCM)	MST	To test the capability of a vehicle in automatic detection and application of brakes to prevent or minimize the impact of a car on a motorcycle in various real-world situations.	Autonomous Emergency Braking (AEB) system
2	AEB Car–Car (AEBCC)	SAT	To determine the vehicle's capability to prevent or mitigate rear-end collisions with another vehicle by automatic braking when the driver is not responding.	
3	Advanced Rear Visualization (ARV)	MST	To determine how rearview systems can prevent back-over crashes, particularly when there is a person or an object right behind the car.	Rear visibility systems (camera, sensors)
4	Auto High Beam & Adaptive Driving Beam (AHB & ADB)	SAT	To test a system of automatic headlight adjustment that is able to alternate between high and low beams or can alter beam form to enhance safety and visibility in night driving.	Auto High Beam (AHB) and Adaptive Driving Beam (ADB)
5	Blind Spot Detection (BST)	MST	To identify the vehicles in other lanes that cannot be seen by the driver, and to give timely warnings against unsafe lane changing.	Blind Spot Detection (BSD/BST) systems (radar sensors + alerts)
6	Blind Spot Visualization (BSV)	MST	To test the vehicle system to help in detecting vehicles in the driver's blind spot and giving clear visual cues or warning signs to prevent unsafe lane change.	Blind Spot Visualization systems (camera, indicators)
7	Lane Support System (LSS)	SAT	To find out the ability of a vehicle to identify unintentional departure from the lane and provide aid or caution to the driver to stay safely in the lane.	Lane Departure Warning (LDW) Lane Keep Assist (LKA)

In the ASEAN region, the NCAP has been established to promote vehicle safety. For this study, focus is given to seven specific ASEAN NCAP test protocols: Autonomous Emergency Braking (AEB) Car-to-Car, AEB Car-to-

Motorcyclist (AEBCM), Blind Spot Detection (BSD), Auto High Beam (AHB), Adaptive Driving Beam (ADB), Blind Spot Visualization (BSV), and Lane Support Systems (LSS). These protocols were selected based on their frequent test

occurrences throughout the year and their strong relevance to road and environmental conditions. The protocols and their purposes are summarized in Table 1.

**2.3. Previous Research**

In the United States, the Highway Performance Monitoring System (HPMS) [20] of the Federal Highway Administration is one of the examples of such a comprehensive database on the national level. It assembles and stores details about the length, the state, the performance, the traffic, and the nature of operations of public roads. The system combines administrative records and sample-based data across various functional road classifications, which is critical in transportation planning and policy analysis, as well as making decisions on infrastructure investment. In Thailand, the iRAP [21] program is one of the most impactful that uses a rigorous, evidence-based approach to assess roads and produce star ratings, risk maps, and investment strategies based on the data organized globally to influence safety enhancement. This study demonstrates a unique contribution in the development of data systems for ADAS and vehicle safety when compared to three prior studies. Live Road Assessment Custom Dataset (LiRA-CD) [22] is an open-source dataset for road condition modeling and research, which focuses on providing an open dataset for assessing road surface conditions through image annotations and metadata, supporting machine learning models for road damage prediction.

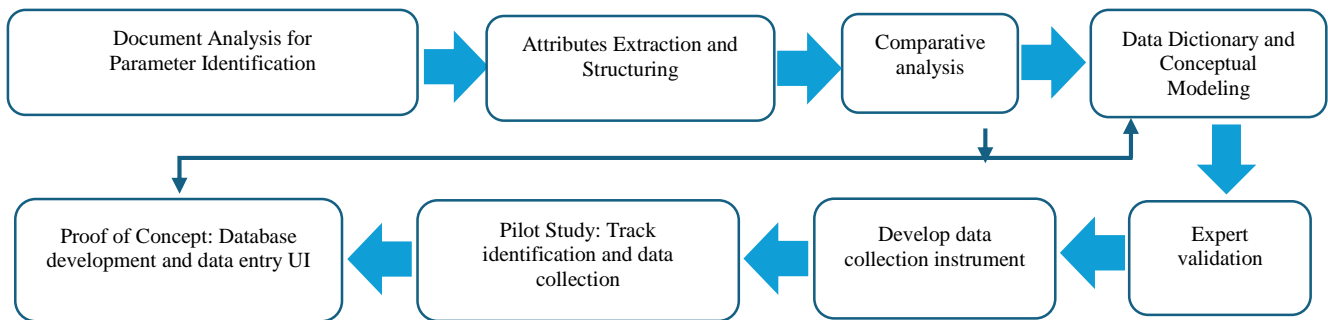
Similarly, the Road-Mark Benchmark [23] provides a dataset for detecting road markings under challenging scenarios, addressing gaps in computer-vision perception. However, it does not offer relational data schemas or dictionaries that suit protocol requirements. The study by Habib *et al.* [24] emphasizes DBMS challenges in managing

data flow, latency, and sensor integration, yet lacks focus on standardizing road attributes and does not map them to NCAP protocols.

In the context of data collection, Wang and Zhang [13] argue that the integration of AI and sensor-driven data collection has the potential to generate more dynamic and empirically accurate safety reports, creating an opportunity to implement continuous feedback processes that will simultaneously test a regulatory system to a greater extent and develop a vehicle system. However, among those, the studies do not develop a data framework aligned with vehicle testing protocols, making the present study more valuable by integrating road attributes into a schema that enables segment validation for tests such as AEB and BSD. The literature is well-informed that a standardized and structured database of road characteristics should be established to add reliability and comparability to vehicle safety testing. With the development of NCAP programs and the evolution of ADAS technologies, the integration of such a data-based framework will become an essential part of the car even more.

**3. Materials and Methods**

The study used a qualitative document analysis approach, and the study began with a thorough analysis of the ASEAN NCAP protocols. The analytical framework for this study comprises eight phases, starting with document analysis, parameter identification, and followed by its extractions. Next are activities involving parameter benchmarking, validation, and the application of the road-characteristic data collection instrument in a pilot study. Each component builds on the preceding phase, and at certain steps, for example, at the instrument development phase, an interactive process has been conducted. The workflow of the research is shown in Figure 1.



**Fig. 1 Study flow**

**Phase 1: Document Analysis for Parameter Identification.** The process begins with a document analysis of the ASEAN NCAP Safety Test Protocols (2023–2025), focusing on seven testing protocols. This phase analyses the specification, how the test is being conducted, and identifies parameters required in vehicle testing, for example, track description and features, lane-marking visibility, lighting conditions, geometric

features, and environmental constraints. The aim is to extract key parameters that are road-related technical requirements embedded within the protocols.

**Phase 2: Attribute Extraction and Structuring.** All parameters (which will also be referred to as attributes) identified from document review and benchmarking are

transformed into structured attributes. Each attribute is assigned metadata such as name, description, data type, length, permissible values, and testing usability. This is to support later integration into the data dictionary and model. The purpose is to facilitate the extraction of key attributes and structuring to form the basis of a data dictionary and conceptual data model.

Phase 3: Comparative analysis has been conducted against Euro NCAP, JNCAP, ANCAP, and NHTSA with the aim of evaluating ASEAN NCAP's comprehensiveness and alignment with international standards. This helps to identify common global road-attribute requirements and to discover some data values that correspond to certain attributes that are not mentioned specifically in ASEAN NCAP documents. The aim of this process is to induce generic attribute values as well as for cross-protocol comparability. A comparative matrix is then developed to visualize the presence, absence, and configuration of road-characteristic attributes across NCAP programs.

Phase 4: Data Dictionary and Conceptual Modeling. Based on the extracted attributes, a formal data dictionary is constructed, defining attribute semantics and constraints. The dictionary is then translated into a conceptual data model, establishing logical relationships among entities such as road characteristics, test protocols, environmental conditions, and infrastructure features. A few cycles of cross-validation have been conducted to ensure that semantic clarity, relational correctness, and data normalization have been met.

Phase 5: Expert Validation. Validation is conducted through three independent expert panels of data modelers and civil engineers. Attributes are evaluated based on original NCAP documents, data dictionary, and data model that are suitable for standardized data collection. Refinements made based on the outcome of this stage strengthen the design of the data dictionary and conceptual model.

The validation process, as illustrated in Figure 2, was provided with seven NCAP protocol documents, a list of key parameters linked to thematic categories, a data dictionary comprising attribute definitions, a mapping template for attribute-to-theme alignment, and a data model assessment template. Experts studied these resources, reviewed all supporting documents, and assessed the conceptual and structural integrity of the framework. The experts completed the exercise by filling in a standardized rubric (Appendix B) that captured their judgments across five critical dimensions: attribute clarity, metadata completeness, relevance to vehicle safety testing, accuracy of data extraction, and structural fit in the data model.

Phase 6: Develop Data Collection Instrument. A data-collection instrument is then designed to operationalize the validated attributes, covering domains such as geometry,

lighting, infrastructure, environment, traffic control, and pedestrian/cyclist conditions. To test the instrument, a data collection was conducted as a pilot test on the road, namely Jalan Meru Tambahan. The road has been selected for all types of vehicles, such as cars, heavy vehicles like lorries and buses, and motorcycles. It also comprises variations in environmental features, complex, multi-user, including pedestrians of all ages, mixed-terrain characteristics that ensure instrument reliability and alignment with NCAP requirements. The process of modifying the instrument and the data entry form was iterative, and it stops until all attributes in the form really tally with attributes in the database via the data entry form.

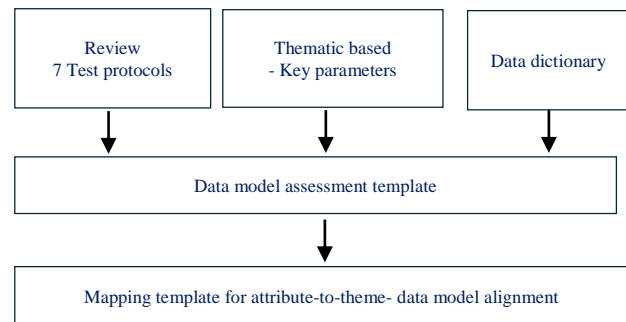


Fig. 2 Expert validation process

Phase 7: Pilot Study. This phase continues and iterative efforts from Phase 7, as it implemented a pilot process to identify suitable roads and segment them into defined tracks, supported by physical road inspections and field testing of the developed data collection instrument. While the data collection form was initially populated using parameter values derived from existing literature, the pilot study demonstrated that actual road conditions and surrounding environments significantly influence the final attribute values. An evaluation of Jalan Meru Tambahan was undertaken, with each road segment assessed against seven safety testing protocols. The combined use of satellite imagery from Google Maps and on-site visual inspections enabled an early understanding of roadside infrastructure and operational constraints. The resulting sample of road segments dataset provides an empirical foundation for data model refinement. Enhancements and modifications to the data collection instrument have been done iteratively, and the final version has been readjusted with the data dictionary and data model.

Phase 8: Proof of Concept. The proof of concept has been carried out afterward based on the outcome of the pilot study. Insights from field implementation were used to validate and standardize attribute definitions, permissible values, and measurement rules. The refined form was translated into a structured data dictionary and subsequently converted into a formal data model with clear entity–attribute relationships. In addition, a User Interface (UI) for data entry was developed to demonstrate practical implementation. Field data are collected, validated, and subsequently integrated into a web-

based PHP-MySQL system developed to ensure systematic data entry, consistency, and structured storage for future analyses. However, the detailed outcomes, system performance, and extended findings of this proof of concept will be discussed in a separate article.

## 4. Results and Analysis

This section contains the findings of the document analysis, benchmarking, comparative insights, data dictionary, expert validation, and pilot study.

### 4.1. Results of Document Analysis for Parameter Identification

Based on analysis of ASEAN NCAP protocols, 31 distinct road characteristics key parameters (later referred to as attributes) were identified. From the analysis, these attributes were categorized into seven thematic groups:

- a. Track Feature
- b. Surface-related characteristics (e.g., surface type, Peak Braking Coefficient (PBC), wet/dry condition)
- c. Slope requirement
- d. Lane characteristics (e.g., lane width, marking type, contrast level)
- e. Environmental parameters (e.g., temperature, wind, humidity, lighting conditions)
- f. Weather conditions
- g. Others: Time, reference system, type of vehicle involved, track spec, regulation measurement, data collection spec, test procedure, and scenario.

All the attributes were translated into a structured format, where each attribute is named and defined. The data type, allowed values, length, and where it is used in the testing process were specified. For instance, the PBC attribute was described as a decimal value, and the accepted range between 0.5 and 0.9 was mapped to AEB testing protocols. Table 2 lists the attributes and their respective test protocol.

Analysis of these attributes across the protocols revealed key patterns in road-related requirements. Road type classification: urban, suburban, or rural, which is consistently required as this reflects the need to assess vehicle performance under diverse real-world conditions. There are three types of road segments that have been identified, which are straight, junction, and roundabout. These segments are also identified as track features, with straight tracks appearing most frequently as baseline features in testing environments. AEB Car-to-Motorcyclist protocols require junctions and AEB Car-to-Car requires roundabouts; thus, both are included selectively, corresponding to scenario-specific assessments such as maneuverability, collision avoidance, and intersection handling. While a controlled straightway tracks across multiple protocols, it highlights the importance of predictable road sections. Additionally, surface-related attributes, including surface type, slope, and PBC, were features that had been noted in several protocols due to their influence on

braking, lane-keeping, and ADAS functionality. Another critical role is in lane-departure and sensor-based testing, which includes lane width, marking type, spacing, and contrast. Nevertheless, environmentally related features such as lighting, visibility, temperature, wind, and background contrast show considerable variability in inclusion, indicating that incomplete standardization may affect cross-protocol comparability. The same goes for attributes for weather-related conditions for braking and sensor performance evaluations.

The track and road selection is influenced by the requirements of each protocol, whether it focuses exclusively on cars or other vehicle types, and the test setup—for example, involvement of motorcycles or alongside country-specific roads. The test protocol is also suitable to be executed at certain times, for AR and BSV testing, for example, can be executed at night and day. It is noticeable that the reference systems are only partially standardized, highlighting procedural differences in data collection and measurement, and are found in the AEB Car-to-Car setup. Overall, the analysis indicates that a main set of attributes is straight tracks, lane markings, and surface characteristics that form the foundation for vehicle testing, while junctions, roundabouts, slope, environmental, and weather conditions are selectively applied according to protocol-specific requirements. Findings from this analysis suggest that there is a need to systematically incorporate scenario-specific features, as doing so would significantly improve repeatability and reliability.

### 4.2. Benchmarking and Comparative Insights

A comparative analysis has been conducted by cross-checking the attributes that are also emphasized in other international vehicle safety assessment systems. Table 3 shows Euro NCAP addresses these attributes: surface type, slope requirement, lane marking, and environment/surroundings visibility. JNCAP incorporates four attributes: surface type, slope requirement, environment/surroundings visibility, and weather conditions. Euro NCAP and JNCAP each cover four attributes, focusing on structural and visibility aspects but omitting weather-related conditions. NHTSA [17] covers surface type and lane width, while ANCAP [16] covers surface type and environment/surroundings. Both NHTSA and ANCAP address two attributes, indicating a narrower scope for basic surface and visibility requirements. It is notable that the results reveal both convergence and divergence across the NCAP programs. All protocols recognize the importance of road surface type and quality, as well as visibility, to support consistent testing environments.

Among those, ASEAN NCAP significantly places emphasis on conditions that reflect the realities of Southeast Asian road environments. It is found that ASEAN NCAP highlights attributes related to motorcyclist interactions and volume, mixed-traffic, uneven or mixed pavement conditions, and weather patterns typical of tropical climates, such as

extreme heat, high humidity, and sudden rainfall, which are not as glaringly featured in Euro NCAP, NHTSA, or ANCAP. By integrating attributes specific to local traffic compositions, infrastructure variations, and climate-driven road wear, the ASEAN framework adapts to the regional setup, and this reflects a more context-sensitive approach to evaluating vehicle safety performance. However, the main purpose of conducting this analysis is not merely to highlight differences

but to identify a generic list of attributes that can be standardized across the data definition. By combining these attributes into common analytical categories, the benchmarking analysis also seeks to establish a baseline to fill in attribute values where gaps exist. This approach would help create a more systematic framework for global vehicle safety evaluations while still allowing for regional customization where necessary.

**Table 2. Identification of common and specific requirements by each test protocol**

Vehicles involved - Car only	Vehicles involved - Car & Motorcycle	The test was conducted at night	The test was conducted during the day only	The test was conducted at night and during the day	The test requires a specific road characteristics					
No	Theme	Attribute Composite		Characteristics						
	Features	Attributes		Test Protocol						
				AR	LS	AEB C M	BSV	AHB &	BSD	AEB C
1	Purpose	Purpose of the test								
2	Road Type	Urban/suburban/rural								
3	Track	Width								
4		Length								
5		Edge								
6		Controlled straightaway track								
7		Junction								
8		Roundabout								
9		Surface type								
10	Surface Type	Peak Braking Coefficient (PBC)								
11	Slope Requirement									
12	Lane Marking & Width	Lane Marking								
13		Width Speculation								
14		Width								
15	Environment	Surroundings								
16		Visibility								
17		Overhead Structure								
18		Light Source								
19		Dark/Low Contrast Background								
20		Ambient Temp								
21	Weather Conditions	Wind								
22		Other Spec								
23		Day or night (AM/PM)								
24	Others	Reference System								
25		Additional Road Characteristics by Country								
26		Participating Vehicle								

27		Specific Test Track Requirement							
28		Regulation							
29		Measuring & Data Collection							
30		Test Procedure							
31		Test Scenario							

Table 3. Benchmarked the most significant attributes

NCAP Program	1	2	3	4	5	6
	Surface Type	Slope Requirement	Lane Marking	Lane Width	Environment/ Surroundings Visibility	Weather Conditions
ASEAN NCAP	YES	YES	YES	YES	YES	YES
Euro NCAP	YES	YES	YES		YES	
JNCAP (Japan)	YES	YES			YES	YES
NHTSA (USA)	YES			YES		
ANCAP (Australia)	YES				YES	

4.3. Data Dictionary and Conceptual Model Results

Based on the main attributes in Table 2 and the literature, other relevant attributes have been derived. A data dictionary defines each attribute formally and within its contextual meaning. Recognizing that road conditions alone do not fully represent the environment for vehicle testing, two contextual elements, namely, amenities and congestion levels, were added. These two attributes help to capture the broader setting in which road segments operate. These factors provide supplementary insights into environmental complexity, user interactions, and potential safety risks, thereby enabling a more complete representation. The final structure of the data dictionary comprises 107 attributes, grouped into categories such as track details, structural characteristics, lighting and visibility, traffic control, junctions, environmental conditions, pedestrian and cyclist considerations, infrastructure and amenities, and contextual factors like congestion and weather.

Attribute types were set into categorical variables (e.g., road type, slope category), numerical variables (e.g., lane width, temperature), and Boolean indicators (e.g., presence of pedestrian facilities). Data entry control has also been suggested, such as valid ranges for numerical values and predefined lists for categorical options. The complete list of attributes in the data dictionary is provided in Appendix 1. The data dictionary has been refined and finally established as a standardized reference framework for all attributes collected during test track evaluations for the pilot study. It also supports the benchmarking process by enabling the identification of generic attribute values that can be applied across different NCAP protocols, filling gaps where data is missing. Following this outcome is the construction of the conceptual data model, and the design of the data model is illustrated in Figure 3. The parameters of seven themes were rearranged based on three key entities, which are road properties, testing protocols, and testing procedure details. Each component is associated with multiple attributes and

connected through well-defined relationships. The road entity captures core characteristics such as type, track properties, surface and slope, lane properties, road users (other vehicles, pedestrians, and two-wheeled cyclic considerations), and environment. In contrast, amenities and congestion levels are two additional attributes defined to fit the real-world applications. This is to ensure that physical and contextual aspects of the test track are comprehensively represented, as the inclusion of contextual factors such as pedestrian or two-wheeled activities, congestion levels, and surrounding infrastructure reflects an understanding that vehicle safety cannot be assessed in isolation from its operational environment. The testing protocol entity defines purpose, device tested, participating vehicles, and time conditions (day/night).

The testing procedure entity specifies operational details such as measurement and data collection techniques, test scenarios, track specifications, weather conditions, and related matters. The relationships between these entities are in the form of a many-to-many relationship between road and testing protocol, implemented through an associative entity labeled “on,” allowing multiple roads to be linked to multiple protocols. Similarly, the testing protocol connects to the testing procedure via a one-to-many relationship, and this enables each protocol to encompass several procedures. Cardinalities such as 1:m and m:n enable expansion for expanding datasets without redundancy. The design of the database supports horizontal scalability, allowing new attributes (e.g., additional environmental factors or vehicle types) to be added without restructuring core entities. Vertical scalability is achieved through efficient indexing and relational integrity in MySQL, enabling the system to handle large datasets across multiple regions. The normalized structure facilitates integration with external NCAP datasets. Figure 4 presents the input-output architecture of the module for the proof of concept. The input entities comprise three

categories that capture both physical and contextual characteristics of test tracks. These include central track details, structural attributes, lighting and visibility conditions, traffic control measures, junction and roundabout configurations, environmental conditions, pedestrian and cyclist considerations, infrastructure and amenities, testing protocol requirements, road type classifications, and vehicle

involvement. All these inputs feed into a database via a data entry module. For the output, this layer transforms the structured data extracted from a MySQL-based database into a textual user interface and visual story maps. Both textual and visual data enable intuitive representation and analysis of complex datasets as well as enhance interpretability for decision-makers.

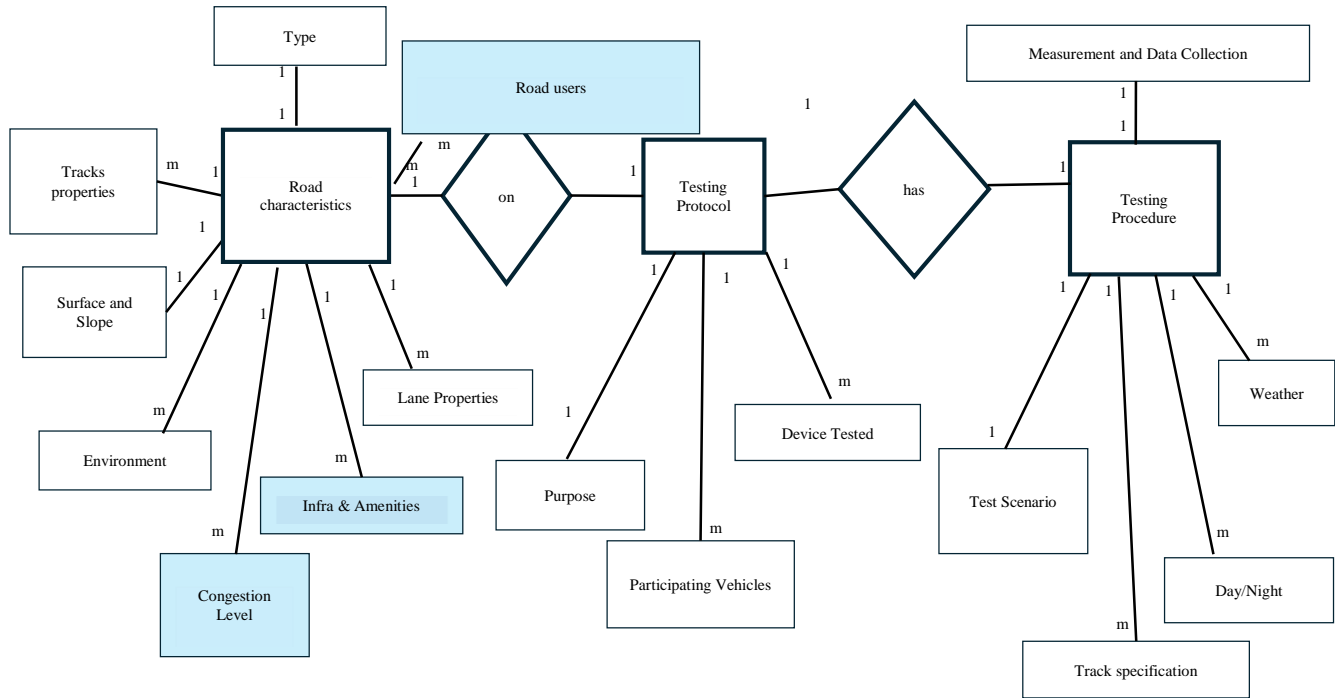


Fig. 3 Conceptual diagram of data model

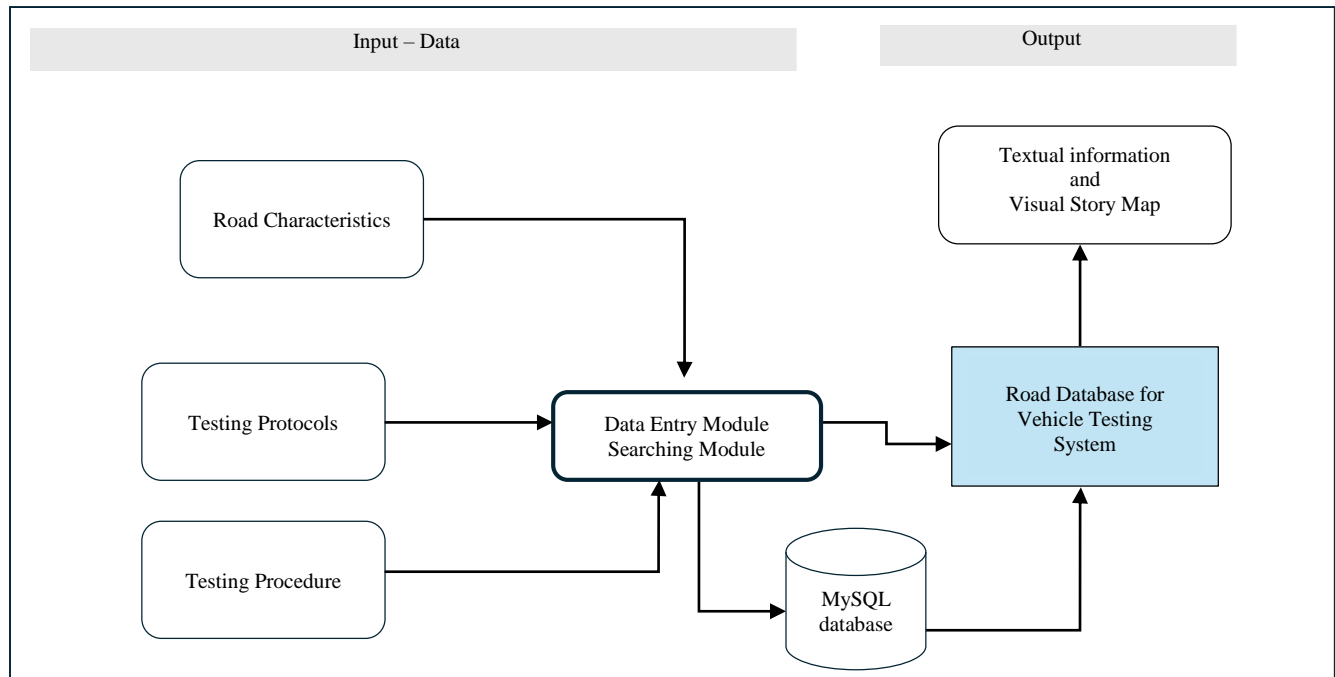


Fig. 4 Input-Output design

**4.4. Findings from Expert Validation**

Findings from experts’ validation in Table 4 mentioned that there is a significant consistency in expert feedback about the appropriateness of the data dictionary and data model. In addition, the feedback also suggested that the selected attributes represent real-world testing conditions and are fit for standardized data collection and analysis. Expert 1 ranked all dimensions at the highest level, emphasizing that attributes extracted from the documents were clearly defined, supported by complete metadata, and basically consistent with the proposed data model. This demonstrates strong alignment with ASEAN NCAP safety testing requirements. Expert 2 indicated similar confidence in clarity and structural fit; he noted gaps in metadata completeness, particularly missing units of measurement, which may possibly introduce ambiguity in certain scenarios. Despite this, the expert verified that attributes remain relevant and logically grouped into an appropriate theme.

Expert 3 discovered minor conceptual ambiguities and recommended expanding the attribute scope to improve its relevance for complex environments. This expert also observed minor issues and misconceptions during extraction and recommended normalization refinements to reinforce model integrity. Collectively, the scores indicate strong performance in attribute clarity and relevance to safety testing, with minor gaps in metadata completeness and structural normalization. These validation results help in refinements, such as adding missing units, clarifying ambiguous definitions, and refining normalization to enhance clarity, completeness, and interoperability across diverse NCAP protocols.

The rubric for Expert Validation is presented in Appendix 2. The validation scheme uses a five-point rubric scale (0–4), where Score 4 signifies excellent compliance and Score 0 indicates deficiencies requiring major revision.

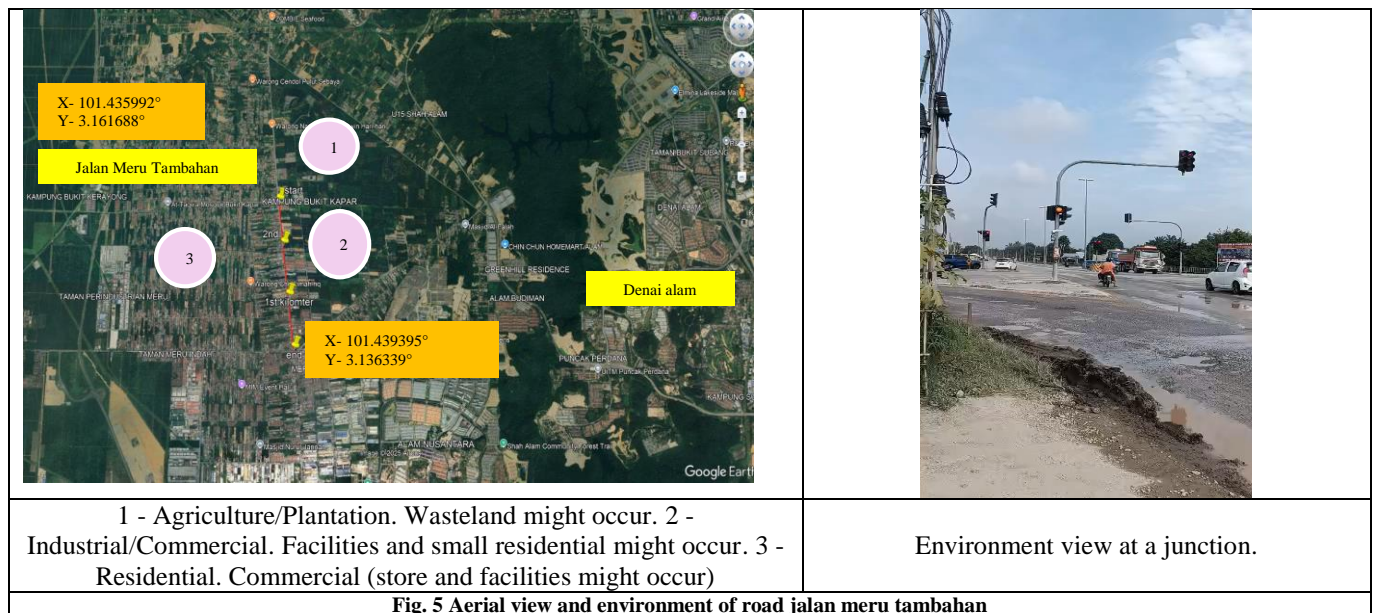
**Table 4. Results expert review from thematics analysis**

Expert	Attribute clarity	Metadata completeness	Relevance to vehicle safety testing	Accuracy of data extraction	Structural fit in the data model
1	4 Clear and well-defined	4 Complete metadata provided	4 Highly relevant	4 Accurate extraction	4 Fits well in the model
2	4 Clear and well-defined	3 Good, but lacks some units	3 Relevant to the NCAP frontal impact	4 Accurate extraction	3 Well integrated
3	3 Minor ambiguity noted	4 Complete metadata provided	2 Relevant but broader scope needed	3 Minor misinterpretation	3 Needs normalization improvement

**4.5. Pilot Study and Field Data Analysis**

The purpose of the pilot study is to simulate the collection using the data collection instrument built based on the data dictionary constructed previously. This section presents the outcome of the pilot study that involved track identification

and the dataset collected. The process involved a systematic identification based on recommendations made by experts, followed by the selection of the busiest road and evaluation of the road, which is named “Jalan Meru Tambahan”.



To initiate identification, Google Maps was utilized to conduct a preliminary assessment of geographic layout, road geometry, surrounding land use, and environmental conditions. The 12 km road has been observed and divided into 12 segments of 1 km each. Each segment was screened against the seven safety testing protocols. The sequence of satellite imagery and street-level visual inspection has been used as it provides an early understanding of traffic patterns, roadside infrastructure, and possible constraints. One of the observations is summarised in Figures 5 and 6. Next, all of the segments were visited for an on-site verification.

The on-site verification noticed that there are some differences between Google Map images and the real-world environment, such as lane visibility, surface friction, gradient, lighting conditions, and roadside features. The discrepancies have been noted and taken as a suggestion to improve the data collection instrument. Obviously, the differences in the data collection form for each track vary in geometry, operational characteristics, and environmental complexity, offering a diverse representation of real-world tropical urban conditions. The data collection takes place once each segment has been mapped to a suitable testing protocol and the instruments have been refined. The data collection has been performed for two weeks. Table 5 presents the track compatibility assessment conducted at Jalan Meru Tambahan, assessing six identified tracks against seven test protocols (TP1–TP7).

The outcomes confirm that a single road segment can feasibly accommodate more than one test track, provided that the geometric and surface characteristics meet the protocol requirements. Each track represents an approximately 1 km road segment, demonstrating that a single road passageway can support multiple testing scenarios through spatial segmentation and controlled test allocation. Through this process, out of 26 tracks identified in the initial observation, only 24 viable tracks were identified as fit for implementing

all of the test protocols. It is also found that within the road, a total of 24 tracks is well-suited, with the highest appropriateness observed for ARV (TP7) and AEB Car-to-Motorcycle / LSS (TP1 and TP6), each recording four to five compatible instances. This demonstrates that Jalan Meru Tambahan’s versatility as a real-world testing environment for the protocol, focusing on this study.

However, not all protocols are consistently supported across tracks, thus it requires selective track–protocol pairing rather than a one-size-fits-all approach. Another important finding is that the busy road with heavy and mixed-vehicle types also indicates that conducting testing within a real road environment introduces additional operational and safety challenges compared to closed test tracks. Thus, a few factors, such as live traffic interaction, roadside activities, variable edge conditions, and environmental uncertainty, require enhanced safety measures, including traffic management plans, buffer zones, observer/enumerators placement, and dynamic risk assessments preceding test execution. While literature prepares baseline parameter ranges, the on-site visit discovered several real-world attributes that are insufficiently represented in existing datasets.

These include, for example, irregularity in edge width, the presence of informal or unmarked roadside parking, and roadside economic activities such as fruit stalls located near the carriageway. Such elements lead to localized constraints and risks that can influence vehicle sensor performance and test repeatability. Findings of this on-site visit also recommend improvement to the data entry by suggesting values for drop-down within the data model to incorporate context-specific information. Literally, the outcomes of this pilot provide enhancement to the data dictionary and data values. The pilot studies are not only as feasibility checks, but as critical methods for bridging the gap between protocol specifications and complex on-road realities.

**Table 5. Track compatibility at jalan meru tambahan**

Track No	Test Protocol	TP1	TP2	TP3	TP4	TP5	TP6	TP7
	Track ID	AEB Car to Motorcycle	BST	AHB	BSV	AEB Car to Car	LSS	ARV
TRACK 1	SELJMT01	✓				✓		✓
TRACK 2	SELJMT02	✓	✓				✓	✓
TRACK 3	SELJMT03			✓	✓		✓	✓
TRACK 4	SELJMT04			✓	✓			
TRACK 5	SELJMT05	✓	✓	✓	✓		✓	✓
TRACK 6	SELJMT06	✓		✓		✓	✓	✓
Total = 24		4	2	4	3	2	4	5

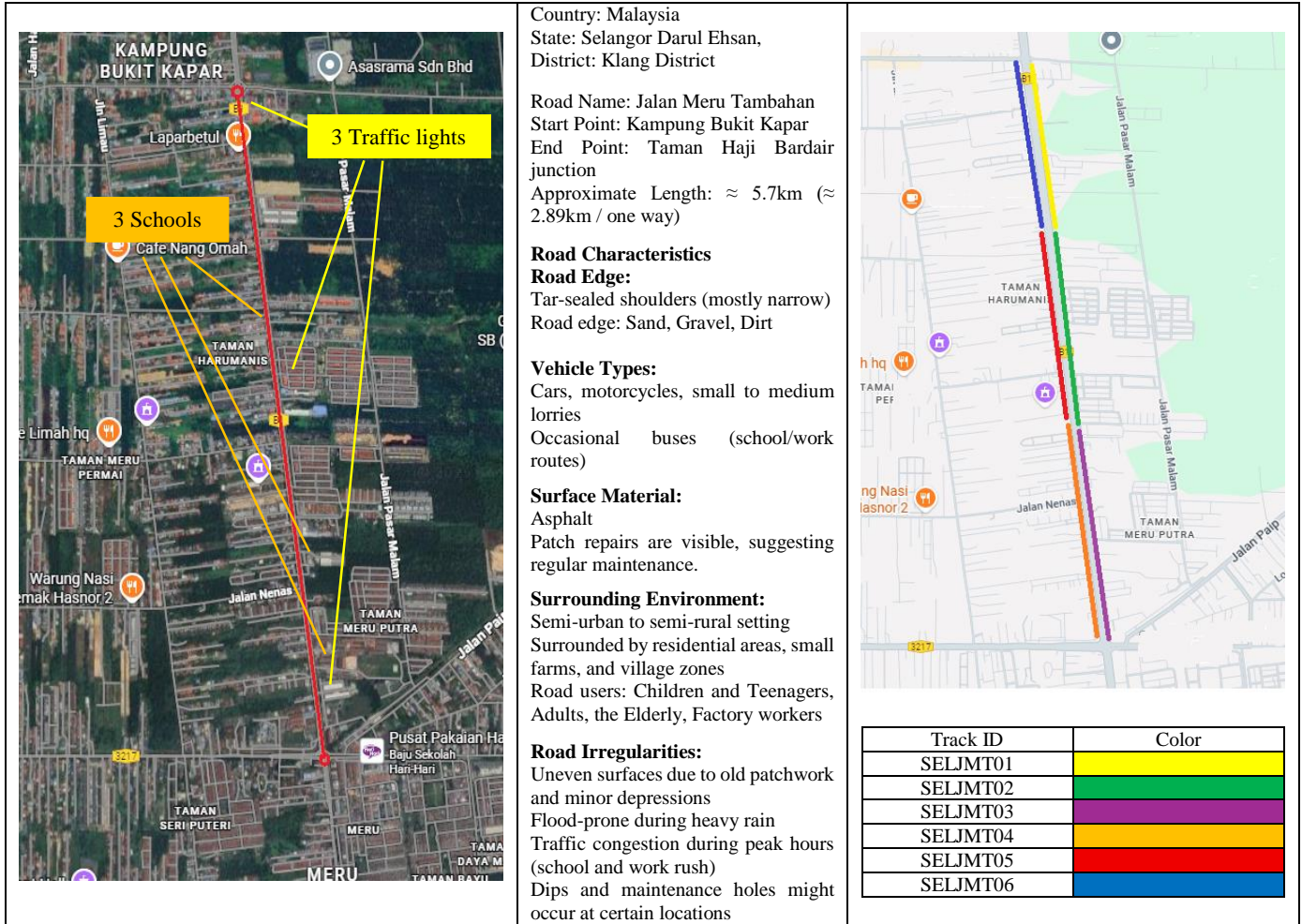


Fig. 6 Visual Representation of the Identified Road and Surrounding Environment

## 5. Discussion

The findings of this research filled the gap with one of the most fundamental requirements of standardizing and managing road features in the context of testing vehicle safety in the real-world environment. The analysis of documents and benchmarking has shown that ASEAN NCAP, Euro NCAP, and JNCAP highlight their own parameters in most controlled safety tests [13, 14]. Ignoring these parameters could decrease the realism and generalizability of test outcomes, especially in sensor-based systems and ADAS [10, 11]. One primary observation during the benchmarking exercise is that ASEAN NCAP pays more consideration to the interaction between tropical and two-wheelers interaction conditions, with its main emphasis on daylight glare, surface heat, and motorcycle detection parameters [12]. Table 6 gives an outline of the main strengths of the database that align with the contribution of this study. These gaps are learned through literature and the creation of a structured data dictionary and conceptual data model within the framework. The framework should pose a standardized and replicable way of defining road attributes, including their values, formats, and applicability to tests [7, 9]. In Addition, a structured database of road features is an

essential resource for enhancing the validity, comparability, and applicability of international vehicle safety tests [17]. The database combines validated parameters such as track details, structural layout, lighting and visibility, traffic and road management systems, junctions and roundabouts, environmental conditions, pedestrian and two-wheeled vehicle considerations, infrastructure and amenities, testing protocol requirements and procedures, road classifications, and vehicle types involved. These items are the base of the system module. The data of road attributes is also standardized, and thus, the database closes the segment between the test protocol requirements and the real testing scenario. Industrial-wise, the research has viable utility to the regulatory bodies and safety testing institutions like MIROS. ASEAN NCAP adds to the concept implemented in iRAP [21], especially in promoting safer vehicles.

### 5.1. Contribution of this study

The contributions of the study are as follows:

Structural Advancement Beyond Conventional Road Databases. Contrasting previous studies that primarily rely on static road inventories or generic GIS representations, this

study introduces an iterative, protocol-driven data modeling approach resulting directly from vehicle safety testing requirements.

The data structure is purpose-built for ASEAN NCAP applications as it provides compatibility and functional relevance over conventional road datasets.

**Table 6. Key strengths of the database**

Element	Key strength
Data Structure & Format	The study lays a conceptual framework of a data model based on an iterative process of designing survey instruments, therefore, ensuring structural compatibility of attributes of roads collected and the database architecture. The data model consumes a fair deal of software space, which makes the system design particularly suitable for the needs of vehicle safety testing applications that follow ASEAN NCAP protocols.
Attribute Completeness	The database is designed to integrate 32 parameters in 11 domains to cover a wide range of vehicle safety testing purposes that are specific to the ASEAN NCAP protocols.
Integration Readiness	The model is built taking into consideration future interoperability, thus enabling the easy integration with analytics engines, intelligent query systems, and vehicle testing platforms, which can enable the simulation of dynamic scenarios.
Purpose Alignment	It is a unique database as it focuses on vehicle safety testing, thus filling a gap by aligning real-world road samples to test protocol requirements, an area that has received relatively less focus in earlier studies.

Enhanced Attribute Coverage Tailored to Safety Testing Protocols. In contrast to prior research, this study identified 31 parameters across seven themes that aligned with ASEAN NCAP testing requirements. Apart from those 2 themes, which are congestion level and amenities that represent the real-world environment, have also been added as they would help the tester to understand the road environment and its context. Story map embedded also helps the tester, as the data is also supported with visual data and images.

Readiness for Analytical and Testing Platform Integration. This study is prepared for advances toward operational deployment by designing the database specifically for future expansion. The data model is also analytically ready, supporting seamless integration with analytics engines, intelligent query systems, and vehicle testing platforms for dynamic setup and simulation.

Reorientation Toward Protocol-Centric Safety Validation. Distinct from earlier studies that focus on general road condition assessment or traffic management, this study focuses on specific road characteristics data that are fit specifically for ASEAN countries. Furthermore, the protocol-based validation, where empirical and test-ready road datasets have been used, has been conducted.

**5.2. Scalability**

It has a scalable design that allows future requests and is capable of intelligent querying and open for comparison of real-world road segments to protocol specifications. This facilitates testers to ensure the reproducibility of the tests, as well as in decision-making in the selection of appropriate test tracks. The database can be used as a basis for future study for safety systems, and it is capable of further innovation and applicable to ASEAN countries.

**5.3. Recommendations**

This study proposed a methodological framework, data dictionary, and data model. In line with that, four strategic recommendations are provided. First, the database should be expanded to incorporate a comprehensive variation of road characteristics across rural, suburban, and urban environments.

These three types of road environment differ in terms of road features and surface quality, and also in terms of traffic congestion level and the presence of mixed-mode traffic. Second, the standardization of the mechanism and implementation of on-site verification involving real-world road track classification is essential.

These exercises help to reinforce the empirical foundation of the database and ensure alignment with NCAP testing protocols. Third, mechanisms to enable industry benchmarking should be established by providing stakeholders with manual selection and on-site verification of road tracks. This approach facilitates comparability and collaborative engagement in safety performance evaluation. Finally, the incorporation of an AI in recommending road tracks can be leveraged using machine learning algorithms. This system should be capable of analysing attribute similarity, predicting suitability, and producing alternative recommendations for diverse testing scenarios and regional variations.

**5.4. Future Directions**

Future work should address data governance that focuses on data quality and the establishment of standardized protocols for data quality and sharing across platforms. The data entry module needs to be enhanced by re-arranging the themes, and also should prioritize attributes that are critical based on region and each country's environment and context.

## 6. Conclusion

This study has identified important road parameters that are vital to the validity and consistency of vehicle test safety. By analysing the ASEAN NCAP test protocols and comparing them with the international protocols, a base of generic attributes and values can be established that can be used in any variety of testing protocols. The main delivery of this study is the framework and approach used in creating the data dictionary, conceptual data model, and data collection. The study also shows that the use of structured attribute modeling can support system design that follows realistic road conditions and safety test requirements. Moving forward, the future project involves creating and building a full-scale relational database that will incorporate the attributes and relationships of the conceptual model. This database will institutionalize the link between entities like road characters, safety tests standards, and environmental standards, as well as test results. It will help regulatory authorities like MIROS and ASEAN NCAP to enhance the process of safety assessment, and, at the same time, will be a valuable source of information to manufacturers and researchers. The adoption of such a database structure will enhance standardization, interoperability, and data-driven innovation in vehicle safety testing across the globe. In addition, the designed attributes

that were expressed because of this research formed the basis of the further development of the system in terms of testing vehicles.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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## Author Contribution Statement

Siti Salwa Salleh conceptualized and designed the research, led the database architecture, instrument development, experimentation, and prepared the research manuscript. Siti Zaharah Ishak and Najwa Shaari conducted the user requirements analysis and oversaw progress monitoring activities. Abdul Rauf Abdul Rasam, Wan Mazlina Wan Mohamed, and Nur Farizan Taruddin were responsible for data collection, spatial data validation, and site monitoring.

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## Appendix 1

**Table 7. Data dictionary**

No.	Variable Name	Variable Description	Data Types
1.	Track_id	Unique identifier assigned to each test track during the data collection session (e.g., SELKLGJMT00-0XZ)	Categorical
2.	Test_protocol	Test protocol category used for the track evaluation, following defined test procedures (e.g., TP1, TP2, TP3)	Categorical
3.	State	The state in which the track is located, recorded from observation or location data	Categorical
4.	District	the district in which the track is located, recorded from observation or location data	Categorical
5.	Road_name	Official name of the road under observation	Categorical
6.	Geo_location_start	GPS coordinates marking the start of the test track	Categorical
7.	Geo_location_end	GPS coordinates marking the end of the test track	Categorical
8.	Track_begin_point	Specific physical location or landmark marking where the track begins	Categorical
9.	Track_end_point	Specific physical location or landmark marking where the track ends	Categorical
10.	Track_types	Classification of track type observed (e.g., Urban, Rural, Highway, Others)	Categorical
11.	Surface_types	Classification of road surface condition and material (e.g., Dry, Paved, Uniform Surface, Others)	Categorical
12.	Distance	Total length of the track in kilometers	Numeric
13.	Slope_description	Slope gradient category of the track (e.g., Flat, Slight, Moderate, Steep, Very Steep)	Categorical
14.	Type_of_road_divider	Type of road divider present (e.g., Concrete Curb Divider, Metal Barrier, Vegetation, Plastic Modular Dividers)	Categorical
15.	Bumpers	Type of speed control structures present (e.g., Speed Bumps, Speed Humps, Speed Cushions, None)	Categorical
16.	Bumpers_description	Additional notes describing bumper dimensions, placement, or condition.	Categorical

17.	Type_of_lane_marking	Type of lane marking observed (e.g., Single Solid White, Double Solid White, Zigzag Line, None)	Categorical
18.	Lane_marking	Visibility condition of lane markings (e.g., Clearly Visible, Faded, Blurred, None)	Categorical
19.	Lane_width	Measured lane width in meters (average of measurements taken per 100 m segment)	Numeric
20.	Lane_width_description	Lane width category (e.g., Narrow <3m, Medium <6m, Wide ≥6m)	Categorical
21.	Lane_width_description_ext	Additional comments on lane width, irregularities, or variations along the track	Categorical
22.	Overhead	Presence and type of overhead structures (e.g., Bridges, Flyovers, Tunnels, Electric Cables)	Categorical
23.	Road_edge	Type of road edge (e.g., Concrete Curb, Painted Edge-Line, Grass Shoulder, Drainage Ditch)	Categorical
24.	Roadside_features	Features along the roadside (e.g., Electrical Utility Box, Garbage Pile, Temporary Structure, Vegetation)	Categorical
25.	Roadside_images	Image references were taken of roadside features for a visual record.	Categorical
26.	Controlled_straightaway_track_layout	Whether a controlled straightaway layout exists (Yes/No).	Categorical
27.	Light_source	Type of artificial lighting present (e.g., LED Streetlight, Solar-Powered Streetlight, Floodlights)	Categorical
28.	Dark_low_contrast_background	Brightness level of background at night (e.g., Bright, Low, Moderate, Poor)	Categorical
29.	Street_light_presence	Presence and distribution of streetlights (e.g., Both Sides, One Side, Few/Scattered, None)	Categorical
30.	Condition_of_street_light_at_night	Operational condition of streetlights at night (e.g., Fully Functional, Some Lights Not Working, None)	Categorical
31.	Visibility_during_night_time	Visibility level during night (e.g., Clear, Moderate, Poor, Very Poor)	Categorical
32.	Reflective_elements_presence	Presence of reflective safety elements (e.g., Road Studs, Reflective Signboards, None)	Categorical
33.	Reflective_elements_presence_description	Additional notes on reflective element types, placement, and condition	Categorical
34.	Peak_braking_coefficient	Type of road surface condition for braking analysis (e.g., Dry Asphalt, Wet Asphalt, Gravel)	Categorical
35.	Traffic_light_type	Type of traffic signal present (e.g., Standard, Pedestrian, Bicycle, None)	Categorical
36.	Traffic_light_description	Visibility, functionality, or other characteristics of traffic lights	Categorical
37.	Tcl_0700_1000	Level of congestion from 0700 to 1000	Categorical
38.	Tcl_1000_1300	Level of congestion from 1000 to 1300	Categorical
39.	Tcl_1300_1600	Level of congestion from 1300 to 1600	Categorical
40.	Tcl_1600_1900	Level of congestion from 1600 to 1900	Categorical
41.	Tcl_1900_2200	Level of congestion from 1900 to 2200	Categorical
42.	Delay_0700_1000	Delay by minutes from 0700 to 1000	Numeric
43.	Delay_1000_1300	Delay by minutes from 1000 to 1300	Numeric
44.	Delay_1300_1600	Delay by minutes from 1300 to 1600	Numeric
45.	Delay_1600_1900	Delay by minutes from 1600 to 1900	Numeric
46.	Delay_1900_2200	Delay by minutes from 1900 to 2200	Numeric
47.	Heavy_0700_1000	Number of heavy vehicles (lorries, buses, trucks) recorded between 0700 and 1000	Numeric
48.	Car_0700_1000	Number of four-wheeled vehicles (cars/vans) recorded between 0700 and 1000	Numeric

49.	Bike_0700_1000	Number of two-wheeled vehicles (motorcycles/bicycles) recorded between 0700 and 1000	Numeric
50.	Heavy_1000_1300	Number of heavy vehicles (lorries, buses, trucks) recorded between 1000 and 1300	Numeric
51.	Car_1000_1300	Number of four-wheeled vehicles (cars/vans) recorded between 1000 and 1300	Numeric
52.	Bike_1000_1300	Number of two-wheeled vehicles (motorcycles/bicycles) recorded between 1000 and 1300	Numeric
53.	Heavy_1300_1600	Number of heavy vehicles (lorries, buses, trucks) recorded between 1300 and 1600	Numeric
54.	Car_1300_1600	Number of four-wheeled vehicles (cars/vans) recorded between 1300 and 1600	Numeric
55.	Bike_1300_1600	The number of two-wheeled vehicles (motorcycles/bicycles) recorded between 1300 and 1600	Numeric
56.	Heavy_1600_1900	Number of heavy vehicles (lorries, buses, trucks) recorded between 1600 and 1900	Numeric
57.	Car_1600_1900	Number of four-wheeled vehicles (cars/vans) recorded between 1600 and 1900	Numeric
58.	Bike_1600_1900	Number of two-wheeled vehicles (motorcycles/bicycles) recorded between 1600 and 1900	Numeric
59.	Heavy_1900_2200	Number of heavy vehicles (lorries, buses, trucks) recorded between 1900 and 2200	Numeric
60.	Car_1900_2200	Number of four-wheeled vehicles (cars/vans) recorded between 1900 and 2200	Numeric
61.	Bike_1900_2200	Number of two-wheeled vehicles (motorcycles/bicycles) recorded between 1900 and 2200	Numeric
62.	Name_of_junctions	Official or common names of junctions along the track	Categorical
63.	Roundabout_type	Classification of roundabout type (e.g., Mini, Single Lane, Turbo)	Categorical
64.	Junction_type	Classification of junction type (e.g., T-junction, Crossroad, Clover Leaf)	Categorical
65.	Roundabout_junction_surroundings	Observed surroundings near roundabout/junction (e.g., Commercial, Residential)	Categorical
66.	Roundabout_junction_surroundings_description	Additional details about the nearby surroundings	Categorical
67.	Junction_characteristics	Operational control type of junction (e.g., Signalized, Unsignalized)	Categorical
68.	Roundabout_characteristics	Lane configuration type for roundabout (e.g., Single Lane, Multi-Lane)	Categorical
69.	Roads_heading_to_roundabouts_junction	Connecting roads leading to the junction/roundabout	Categorical
70.	Distance_from_to_nearest_junction_roundabout	Measured distance to the nearest junction/roundabout in meters	Numeric
71.	Entry_and_exit_deflection_design	Assessment of lane deflection at entries/exits (e.g., Adequate, None)	Categorical
72.	Visibility_at_junctions_and_roundabouts	Visibility level for approaching junctions/roundabouts (e.g., Clear, Obstructed)	Categorical
73.	Traffic_conflict_potential	Likelihood of vehicle conflicts (e.g., Smooth, High Conflict)	Categorical
74.	Traffic_conflict_potential_description	Specific hazards or risks causing conflicts	Categorical
75.	Type_of_surrounding_land	Primary land use in the surrounding area	Categorical
76.	Weather_condition	Weather conditions during data collection	Categorical
77.	Surface_water_drainage_condition	Water drainage condition observed on site.	Categorical
78.	Noise_level	Ambient noise rating during observation	Categorical

79.	Air_visibility	Visibility of the surrounding air (e.g., Clear, Hazy)	Categorical
80.	Wind_description	Observed wind conditions (e.g., Calm, Gusty)	Categorical
81.	Ambtemp_0700_1000	Recorded ambient temperature from 0700 to 1000 in °C	Numeric
82.	Ambtemp_1000_1300	Recorded ambient temperature from 1000 to 1300 in °C	Numeric
83.	Ambtemp_1300_1600	Recorded ambient temperature from 1300 to 1600 in °C	Numeric
84.	Ambtemp_1600_1900	Recorded ambient temperature from 1600 to 1900 in °C	Numeric
85.	Ambtemp_1900_2200	Recorded ambient temperature from 1900 to 2200 in °C	Numeric
86.	Pedestrian_availability	Whether pedestrians are present in the observation period	Categorical
87.	Cyclist_availability	Whether cyclists are present in the observation period	Categorical
88.	Pedestrian_users_age	Age range of observed pedestrians	Categorical
89.	Pedestrian_facilities	Types of pedestrian facilities available (e.g., Sidewalks, Ramps)	Categorical
90.	Bicycle_infrastructures	Types of bicycle facilities available	Categorical
91.	Pedestrian_crossing_infrastructures	Types of pedestrian crossing infrastructure present	Categorical
92.	Pedestrian_and_cyclist_safety_measures	Safety measures protecting pedestrians/cyclists	Categorical
93.	Ppf_0700_1000	Pedestrian presence frequency from 0700 to 1000	Categorical
94.	Ppf_1000_1300	Pedestrian presence frequency from 1000 to 1300	Categorical
95.	Ppf_1300_1600	Pedestrian presence frequency from 1300 to 1600	Categorical
96.	Ppf_1600_1900	Pedestrian presence frequency from 1600 to 1900	Categorical
97.	Ppf_1900_2200	Pedestrian presence frequency from 1900 to 2200	Categorical
98.	Amenities	Types of amenities available in the area	Categorical
99.	Infrastructures	Infrastructure types available in the area	Categorical
100.	Accessibility_of_amenities	Ease of access to amenities	Categorical
101.	Visibility_of_amenities	Signage and visibility of amenities	Categorical
102.	Cleanliness_and_hygiene_facilities	The hygiene and cleanliness conditions of facilities	Categorical
103.	Seating_and_shelter_availability	Availability and condition of seating/shelters	Categorical
104.	Utility_infrastructure_support	Utilities supporting amenities (e.g., Lighting, Water)	Categorical
105.	Safety_and_security_features_around_amenities	Security features in and around amenities	Categorical
106.	User_friendliness_and_inclusivity	The degree to which facilities cater to various user groups	Categorical
107.	Wifi_and_mobile_network_connectivity	Internet and mobile connectivity strength/availability	Categorical

## Appendix 2

Table 8. Expert review rubric table

Dimension	Score 4 (Excellent)	Score 3 (Good)	Score 2 (Fair)	Score 1 (Poor)	Score 0 (Critical)
<b>Attribute Clarity</b>	Clear and well-defined; ≥90% attributes have precise labels and definitions.	Minor ambiguity: 80–89% attributes are clearly labeled and defined.	Some ambiguity: 70–79% attributes require interpretation.	Vague: 60–69% attributes lack clarity or definition.	Not described; <60% attributes labeled or defined. Major revision needed.
<b>Metadata Completeness</b>	Complete metadata (units, constraints, examples, source); ≥90% attributes complete.	Mostly complete; minor gaps (e.g., missing units); 80–89% attributes complete.	Partial; missing key elements (units or constraints); 70–79% attributes complete.	Sparse; minimal metadata; 60–69% attributes complete.	No metadata or <60% completeness. Major revision required.
<b>Relevance to Safety Testing</b>	Highly relevant; ≥95% attributes	Relevant ≥90% attributes linked to	Moderately relevant; ≥80% attributes are	Weak relevance:	Not relevant; <70% attributes

	directly support NCAP/ASEAN scenarios.	NCAP frontal or other impact scenarios.	useful but require review for key parameters.	$\geq 70\%$ attributes have indirect or limited connection.	meet the requirement. Review and redesign needed.
<b>Accuracy of Data Extraction</b>	Fully accurate; verified against source; QC passed.	Accurate with minor issues; occasional clarification needed.	Minor misinterpretation: several corrections required.	Frequent errors: major corrections needed.	Invalid or not extracted; data integrity compromised.
<b>Structural Fit in Data Model</b>	Perfect fit; normalized; correct entity relationships; no redundancy.	Well integrated; minor normalization improvements suggested.	Needs improvement; duplicates or unclear relationships present.	Poor fit; inconsistent cardinalities; causes ambiguity.	Cannot be represented; major redesign required.