The Extension Study on the Evaluating of the Spot Speed Distribution at Horizontal Alignment on Two-Lanes Rural Arterial Highway

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ABSTRACT

The rising number of accidents has been associated with inconsistencies in the geometric design of highways. To evaluate design inconsistency, estimation of 85th percentile speeds associated with horizontal geometric is vital important. Significant variations in the operating speeds of consecutive elements indicate inconsistencies in the alignment. Therefore, to enhance the safety of the road it is crucial to produce road design that permits and encourages operating vehicles at uniform speed. This research investigates and expands the use of operating speeds in the analysis of design consistency. Series of regression equations were developed to predict the operating speeds of passenger vehicles in Malaysian's road. The conventional method for designing is using the design speed process which ensures design consistency are involved. Once the design speed is selected, it guides the selection of values for geometric design elements. The study was carried out by analyzing the speed characteristics on daytime at 3 different segments along the Horizontal cure (i.e. Transition at entering of curve, Middle of Curve and Transition at leaving of curve) and it was discovered that vehicles travelling on transition entering curve tend to travel at higher speed than on the middle and on transition leaving curve. Based on the preliminary finding, further testing on middle of curve at night-time was carried out to find significant effect under Mesopic and Photopic visual condition. The speed data measurement is based on Spot Speed Data at specific points and location using Laser Gun Detector. It was also found that the existing speed limit of the selected road stretches is lower than the 85th percentile speed. The 85th percentile speed is a commonly used measure to decide speed limit on a road. Also, the different in the mean speed on the contrast sensitivity under mesopic and photopic condition was determine using t-test. Further discussion on the analysis will be presented in the data and result analysis.

Keywords: Speed; road geometrical design; road safety; curve road; mesopic photopic, Minimum three keywords; avoid too general and too specific keywords; CDF Letters (Please use semicolon as separator)

INTRODUCTION

The significant increase in the number of vehicles in Malaysia has led to various traffic challenges, most notably a rise in road accidents [1]. Road accidents are not just a national issue but a global concern. These incidents are seldom caused by a single factor; instead, they usually result from a combination of multiple influences that can affect both the likelihood and the severity of an accident.

To achieve the vision of "Malaysia, A Country with Zero Road Fatalities," the government has set a target to reduce road deaths by 50% by 2030, using 2019 as a baseline. As outlined in the priority areas, safer infrastructure is one of the ten focus areas to achieve this vision[2]. Improving road infrastructure design will ultimately enhance road safety. Adopting standardized road design can make roads safer and enable drivers to navigate them more securely. Regular monitoring of road conditions is crucial to ensure public safety, especially in areas prone to frequent accidents. This also involves promptly addressing road assets like guardrails, signage, and delineation posts. The engineering and layout of a road can significantly influence the severity of injuries sustained during a road accident.

BIL No	STESEN Station	KM	LOKASI Location	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
PERAK													
1	AR 101	106.6	Ipoh-Tanjung Malim (Slim River Toll house)	13,854	15,038	15,322	14,039	14,431	15,328	16,501	16,736	15,187	14,913
2	AR 204	78.9	Ipoh-Lumut	21,138	23,920	22,389	23,758	25,283	25,942	23,834	26,494	25,939	27,384
3	AR 301	35.9	Ipoh-Kampar	23,050	23,659	31,022	30,311	27,497	28,520	27,126	30,592	24,654	29,911
4	AR 303	5.6	Ipoh-Gopeng	71,205	79,513	84,135	73,487	85,819	77,195	78,210	78,136	77,483	87,006
5	AR 501	30.4	Ipoh-Kuala Kangsar (500m North of Sg. Siput Town)	18,036	19,085	19,426	22,500	19,251	20,478	18,578	19,895	19,936	20,443
6	AR 601	79.7	Ipoh-Batu Hampar-Changkat Jering	16,091	16,752	14,128	11,726	19,410	20,588	19,881	20,664	21,327	19,058
7	AR 603	82.1	Ipoh-Changkat Jering-Semanggol	10,034	7,076	10,270	18,646	12,586	12,938	12,531	12,949	13,919	9,227
8	AR 703	106.3	Ipoh-Teluk Intan-Simpang Empat	24,244	25,159	25,365	25,004	28,465	25,489	25,865	27,249	33,024	26,218
9	AR 801	96.6	Ipoh-Kuala Kangsar-Gerik	2,509	2,715	1,724	3,110	3,562	3,487	2,826	3,139	3,017	2,798
10	AR 803	2.4	Lebuh Raya Timur-Barat	2,945	3,078	3,337	3,148	3,944	3,796	3,636	3,293	3,818	3,923

Fig. 1. Average Daily Traffic (ADT) by MOT website for Transport Statistic Malaysia 2017

The rise in traffic has led to growing concerns about road safety and an increase in collision rates. As illustrated in Figure 1, the Average Daily Traffic (ADT) on the federal road between Ipoh, Kuala Kangsar, and Gerik (Route 76) underwent a significant change. Specifically, there was a 45% surge in ADT from 2010 to 2011, followed by a relatively steady level over the subsequent six years. This growth is likely due to the recent Ipoh to Padang Besar Double Tracking project, a significant development in Malaysia that has increased the number of cars and trucks traveling to quarries along this essential route. With this rise in traffic, road accidents have become a major source of both social and economic losses in Malaysia. It is widely recognized that these accidents stem from factors that can be categorized into three main groups: driver-related, vehicle-related, and road condition-related [3]. Importantly, road and highway authorities maintain full control over the standards and conditions of their roads through effective design, construction, and maintenance practices [4].

Problem Statements

In Malaysia, the design speed is utilized to determine the geometric elements of a road. However, there is a notable gap in the existing design standards, particularly the lack of a method for evaluating completed projects, as they do not provide a predictive model of operating speed for designers to reference. This research focuses on evaluating vehicle operating speeds and comparing vehicles on horizontal curve roads that meet Malaysia's standards with those on sub-standard roads. The identified gaps in research serve as the foundation for the subsequent chapters of this thesis, which aim to advance knowledge in this crucial area of transportation engineering.

Crash events on horizontal curves occur 1.5 to 4 times more frequently than those on straight sections of the road [5]. These accidents often involve vehicles skidding sideways or experiencing head-on collisions. The safety of drivers navigating curves is influenced by a variety of factors, including traffic volume and the mix of vehicle types, the geometric design of the curves, cross-sectional elements, and roadside hazards. Other considerations include stopping sight distance, the integration of vertical and horizontal alignments in road design, curve length, intersections along the curve, the International Roughness Index (IRI), and skid resistance. To enhance the safety of horizontal curves, a systematic approach is recommended. The first step involves identifying problem areas based on crash history and current roadway conditions. Next, potential improvements should be evaluated and implemented. Finally, before and after any construction efforts, studies on crash performance should be conducted to assess the effectiveness of the changes [6].

LITERATURE REVIEW

Spot Speed

In a moving traffic stream, vehicles travel at varying speeds, resulting in a range of individual velocities rather than a single uniform speed. To better understand and manage this variability, speed is typically categorized

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into three main types [7]. Spot speed measures a vehicle's velocity at a specific point on the road at a particular moment, capturing its instantaneous speed at that location. Running speed represents the average speed of a vehicle while it is in motion, excluding any stops or delays, and reflects the vehicle's efficiency over a stretch of road. Journey speed, on the other hand, provides the average speed of the vehicle over the entire trip, including time spent stopped at traffic signals or intersections, offering a comprehensive view of the vehicle's overall performance from start to finish. Understanding these different types of speed helps in analyzing traffic flow and improving road system management.

Spot speed is the measurement of a vehicle's speed at a specific location on the road at a given moment. It reflects the instantaneous speed at a particular point. Understanding spot speed is crucial for designing road features such as horizontal and vertical curves, superelevation, and other road geometries. Several physical aspects of the road can influence spot speed, including the width of the pavement, curves, sight distance, road gradient, pavement roughness, intersections, and adjacent development. [8] Additionally, spot speed can be affected by environmental factors such as weather and visibility, enforcement strategies, traffic conditions, and the attributes of the driver and vehicle. [7]

The timing of the study and the observer's position (e.g., a person equipped with a radar gun) are critical elements to consider. It is recommended to conduct studies between 0900 to 1200 hours, 1500 to 1800 hours, and 2000 to 2200 hours, with a study duration of one hour for a minimum of 50 vehicles/samples. [9]

Spot Speed

Researchers have noted that the geometric design of highways is largely dependent on the speed at which vehicles travel . However, some scholars argue that there is a symbiotic relationship between vehicle speed and road design, meaning they both influence each other. [10]

When evaluating the adequacy of an existing highway's geometry, the 85th percentile speed is a critical metric. If this percentile exceeds the speed limit at a particular road section, it indicates a need to reassess the geometry and make necessary corrections to enhance road safety [11]. It is important to remember that road geometry standards are fundamentally tied to highway safety [11].

Given these considerations, it becomes clear that road geometry must be designed with speed as a central factor, as the layout and features of the road can significantly influence how fast vehicles travel. Variations in speed are influenced by several key factors. General variables such as the time of day, specific dates, weather conditions, the classification of the highway, and the level of lighting can all affect vehicle speeds [12]. Additionally, the characteristics of road users, including their driving habits, the purpose of their journey, and their mode of travel, play a crucial role in determining how quickly vehicles move.

Furthermore, the type, make, model year, condition, and features of the vehicles themselves contribute to speed differences. Vehicles with different performance capabilities will handle speeds differently. The road environment also plays a significant role; elements such as traffic control measures, prevailing traffic conditions, the skid resistance of the road surface, and any existing pavement defects can all impact vehicle speeds.[13]. By incorporating these factors into the design of road geometry, planners can more effectively manage and predict vehicle speeds, thereby enhancing road safety and efficiency.

Highway Functional Classification

Highways are organized into categories based on their purpose and the type of service they provide, distinguishing between rural and urban roads depending on their location. There are four main classes of highways:

Limited-access facilities are designed to offer uninterrupted travel, featuring minimal access points to maintain high-speed efficiency. These include freeways and expressways, which facilitate long-distance travel with minimal interruptions. According to the American Association of State Highway and Transportation Officials [14], limited-access facilities are specifically engineered to minimize access points, ensuring that high-speed

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travel is maintained effectively across long distances. The Federal Highway Administration [15] also emphasizes the critical role of limited access in maintaining the efficiency and safety of these roadways.

Arterials are categorized into principal and minor roads. Principal arterials are major routes that connect significant destinations across cities and regions, handling large volumes of traffic and supporting high-speed travel. [14] classifies principal arterials as key components in the transportation network, providing essential connections across regions. Minor arterials, on the other hand, complement principal arterials by linking them to local roads, providing a critical connection for medium to high-speed travel within more localized areas [15]. The FHWA outlines the importance of these minor arterials in bridging the gap between major thoroughfares and local streets [16].

Collectors come in two types: major and minor. Major collectors play a key role in channeling traffic from local roads to arterial routes, acting as intermediaries that direct traffic flow within larger areas. As defined in [14], major collectors are crucial for managing traffic distribution within urban and rural areas. Minor collectors focus on connecting neighborhoods and smaller areas to major collectors, facilitating access within local communities [15]. The FHWA's guidelines further elaborate on the role of minor collectors in linking neighborhoods to the broader transportation network [16].

Local roads and streets serve the purpose of providing direct access to individual properties and neighborhoods. These roads are designed for lower speeds and shorter trips, serving as the final link in the transportation network by connecting local areas to the broader network of collector roads and arterials. The AASHTO Green Book specifies that local roads are primarily intended for access to residential, commercial, and industrial properties, with minimal through traffic [14]. The FHWA's functional classification also highlights the role of local roads in ensuring accessibility within communities [15].

Understanding these classifications helps in planning and designing road networks that effectively cater to different transportation needs, ensuring a well-structured and efficient roadway system. For the purposes of this study, the focus is on literature related to the arterial system.

Spot Terminology

Table 1 below explains the key terminologies related to this research.

Table 1 Terminologies of Speed

Type of Speed	**Terminology**
Operating Speed	The highest overall speed at which a driver can travel on a given road under favorable weather and prevailing traffic conditions, without exceeding the design speed for any road section .[17], [18]
Design Speed	A speed selected to establish specific minimum geometric design elements for a particular highway section, including vertical and horizontal alignment, sight distance, and related features [17].
85th Percentile Speed	The speed at or below which 85% of vehicles travel under free-flowing conditions. This speed is often used as a benchmark for setting speed limits and designing road geometry .[19]

OBJECTIVE AND RESEARCH METHODOLOGY

Objective

The first objective is to determine and compare the 85th percentile speed with the existing posted operating speed at the midpoint of the curve's horizontal alignment. This involves evaluating how the 85th percentile speed aligns with the current speed limits set for that specific road segment.

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The second objective focuses on identifying and measuring the geometric design elements of the curved R5 arterial rural road segments. This will include a detailed comparison of these elements against the standards specified in JKR ATJ 8/86 to assess their compliance.

The third objective involves analyzing driver behavior concerning speed by examining the effects of visibility conditions on driving performance. This includes evaluating how photopic (daytime) and mesopic (dusk/dawn) lighting conditions influence drivers' speed and driving patterns.

Finally, the fourth objective is to propose measures aimed at helping road users adhere to the stipulated speed limit. This includes recommending strategies and interventions to improve compliance with speed regulations.

Background of Study Area

The study area is a stretch of an arterial road known as Ipoh-Kuala Kangsar-Gerik. This road, built by the Public Works Department (PWD), links the city of Kuala Kangsar to smaller towns like Sauk and Lenggong, eventually heading towards Gerik. The selected road stretch is a single carriageway, constructed with fully flexible pavement and conforming to the R5 classification as specified in the ATJ 8/86 (Rev 2015) standards[17].

As-built drawings from PWD, along with the location of curves and a Google map view of the study area, are shown in Figures 2 and 3 below.

Fig. 2. Location of HIP (Source:Google Map)

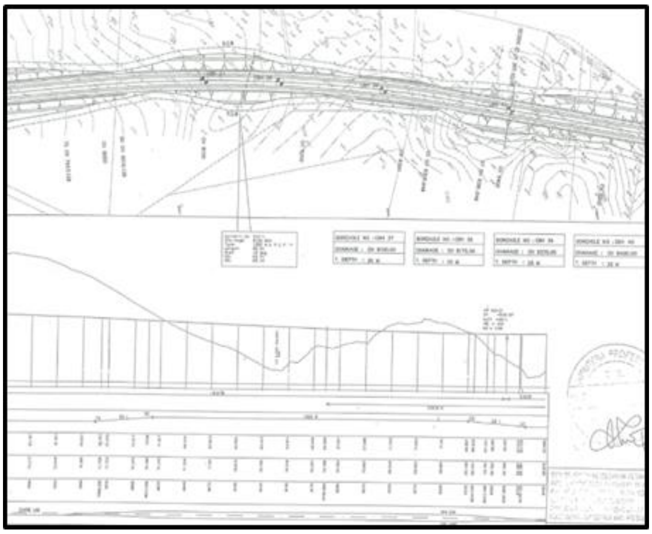

Fig. 3. Construction drawing from JKR

Geometric Design- Horizontal Vertical Curve

The geometric details came from the partial construction drawings provided by the Public Works Department (PWD). For the horizontal curves, this data includes the curve's radius, its length, and the transition lengths, all of which are illustrated in Figure 4.

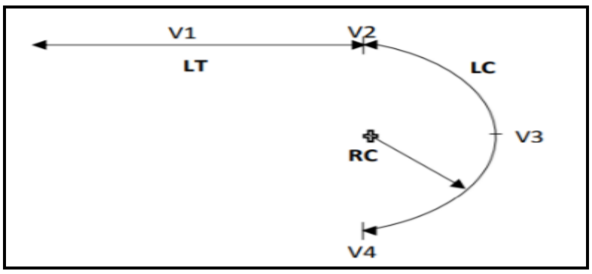

Fig. 4. Typical Horizontal Curve

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The variable V1 represents the speed of the vehicle measured before the curve or tangent, expressed in kilometers per hour (km/h).

V2 denotes the speed of the vehicle at the point where the curve begins, also measured in kilometers per hour (km/h).

V3 indicates the speed of the vehicle at the midpoint of the curve, recorded in kilometers per hour (km/h).

V4 refers to the speed of the vehicle at the point where the curve ends, again expressed in kilometers per hour (km/h).

VCL stands for the length of the vertical curve, measured in meters (m). This measurement captures the extent of the vertical curvature along the road segment.

Instrumentation

The instrument that was used during the site assessment and data recording is shown Figure 5 below:

Fig. 5. Various Instrumentation

Sample Size and Sampling Method

a. Existing Measurement and As-built Data

The geometric elements were obtained during this study, including physical aspects such as horizontal curve length, road width, number of lanes, and overall road width.

b. Spot Speed

The spot speed survey was conducted on 100 vehicles passing at a point on the curved road.

Method of Data Collection

a. Existing Measurement and As-built Data

Photos were taken to represent data on the road's physical aspects using a camera. The width of the road (both paved and unpaved) was measured using a tape measure and recorded for reference.

b. Spot Speed

A radar gun was placed at appropriate points along the curvature stretch (i.e., transition and curve) and was targeted at each vehicle to conduct the spot speed study.

Method of Data Analysis

a. Spot Speed Characteristics

Statistical analyses, including mean, median, standard deviation, and percentile speed, were performed using Minitab [20] and Excel software.

b. T-test

A T-test was conducted to assess the statistical differences in the data using Minitab software.

RESEARCH FINDINGS

Road Geometry

For roads classified under the R5 category, a minimum width of 3.5 meters is required. Based on measurements, the study area's road has a width of 3.8 meters, which exceeds this requirement. A summary of the conformance to the R5-rolling design is provided in Table 2 below:

Table 2 Comparison of existing road measurements and conformance to ATJ 8/86

Road Geometry	Existing Horizontal Curve	(ATJ 8/86 Rev 2015)
Width of Road	3.8-4 m	3.5 m
No. of Lanes Available	1	N/A
Road Surface	Asphaltic concrete	N/A
Width of Road Shoulder	2.0 m	2.5-3.0 m
Super Elevation	0.38	0.8
Median	Not found	Min 3.0 m

It should be noted that the median was not provided as per the guidelines of ATJ 8/86 Rev 2015. In my view, this is likely due to efforts to minimize land acquisition costs, which could increase project expenses.

Spot Speed Analysis

The spot speed measurements were conducted along a curved section of the road, with data collected from a sample of 100 vehicles traveling in each direction. The posted speed limit for this section of the road is 90 km/h, as indicated by the speed limit signs. Analysis of the cumulative frequency graph revealed that the 85th percentile speed is 105 km/h, as illustrated in Figure 6 below. This 85th percentile speed, which exceeds the posted speed limit, is considered to represent the highest speed at which it is safe for most drivers to travel on this segment of the road. Consequently, it can be used as a basis for establishing an appropriate speed limit for the area. Additionally, the 15th percentile speed, recorded at 70 km/h, characterizes the slower-moving vehicles that might create disruptions within the traffic flow, as depicted in Table 3 and Figure 7.

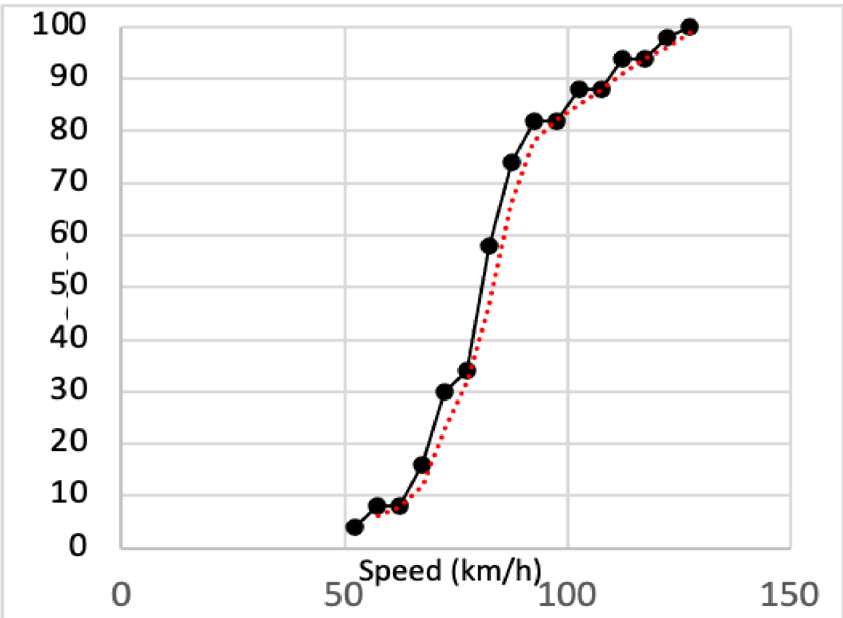

Fig. 6. Spot speed study, Descriptive Statistics: NB (Grik)

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Table 3 Table on Spot Seed Study

Type of Road	Curve Road
No. of Sample	100
Mean Speed	88.21
Median Speed	85.5
Standard Deviation	17.42
15th Percentile	70 Kmph
85th Percentile	105 kmph

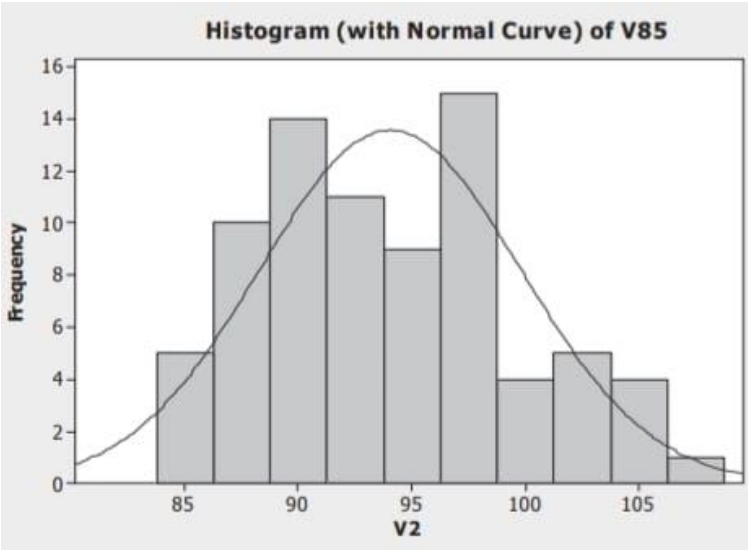

Fig. 7. Histogram for the 85th percentile operating speed on horizontal curve at mid of curve

Photopic and Mesopic Conditions

A two-sample T-test was performed to compare contrast sensitivity under photopic (daytime) and mesopic (dusk/dawn) conditions at the midpoint of the curve. This test aimed to determine if there was a statistically significant difference between the means of the two independent samples, [20] it's worth noting that no data was collected on spot speed for both transition/spiral curves at night for any type of curve (Sag Curve, Crest Curve, or Horizontal Curve).

The hypothesis for the correlation analysis was as follows:

H0: The mean difference between Photopic Vision and Mesopic Vision is zero.

H1: The mean difference between Photopic Vision and Mesopic Vision is not zero.

The T-test results showed a p-value greater than 0.05 (specifically 0.606), leading to the acceptance of H0 and rejection of H1. This suggests that there is no significant difference, meaning that inadequate ambient light conditions do not notably affect driver speed when navigating the curve.

Spot Speed Analysis at Curve Approach, Mid-Curve, and Curve Exit

The spot speed study was conducted to evaluate vehicle speeds at crucial points along the curve of the road, aiming to understand how speeds vary at different stages of the curve. Measurements were taken at three specific locations: V1 (SC), where vehicles transition from the spiral alignment into the curved section; V2 (M), within the fully curved area of the road; and V3 (CS), where the curve transitions back into the spiral alignment. By capturing speeds at these distinct phases, the study provides a comprehensive view of how vehicles adjust their speeds as they navigate through different segments of the curve, offering valuable insights into the interaction between vehicle speed and road geometry.

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Table 4 below summarizes the mean, median, and standard deviation. The data indicate that road users gradually reduced their speed as they traveled through and navigated the curve, from the point of entry to the point of exit.

Table 4 Comparison table on the speed at approach, mid-curve, and leaving the curve

Type of Road	V1 (Approach)	V2 (Mid-Curve)	V3 (Leaving Curve)
No. of Sample	50	50	50
Mean Speed	93.8	84.44	83.18
Median Speed	91.5	83.5	81.5
Standard Deviation	17.57	16.75	14.78

Figure 8 shows that upon entering the curve, most vehicles were found to be driving below the permissible speed limit of 90 km/h. However, upon exiting and 50 meters after the curve, nearly half of the vehicles were driving above 90 km/h. This indicates that drivers tend to be more cautious when approaching curves compared to when exiting them.

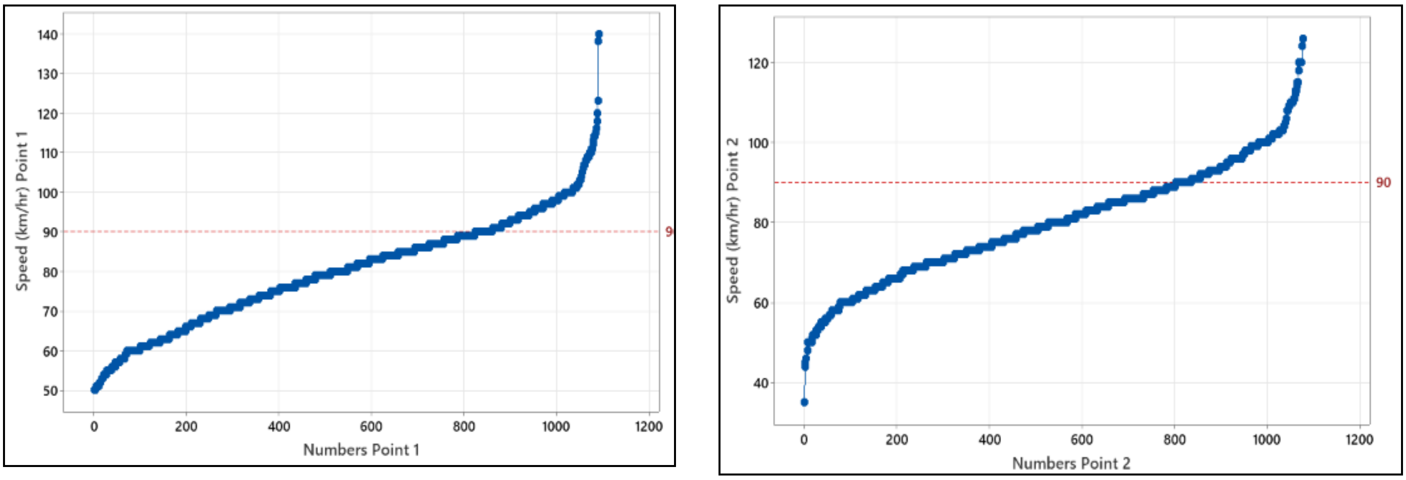

Fig. 8. Spot Speed Distribution of Vehicles within entering, point 1 and leaving the curve Point 2

The next step was to determine the 15th percentile and 85th percentile speeds. Cumulative frequency graphs were plotted using Minitab software, and the minimum speed (15th percentile) and operating speed (85th percentile) were determined. The data are shown in Figure 9 below and summarized in Table 6. The posted speed limit for this area is 90 km/h, and the operating speed of vehicles at the three locations complies with this limit. It is also noted that vehicles at Point 2 operate at lower speeds compared to the other locations, as drivers tend to be more cautious by lowering their speed when entering a smaller curve to gain better control of their vehicles. The 15th percentile speed shows that vehicles traveling at 53 km/h or below will impede traffic flow.

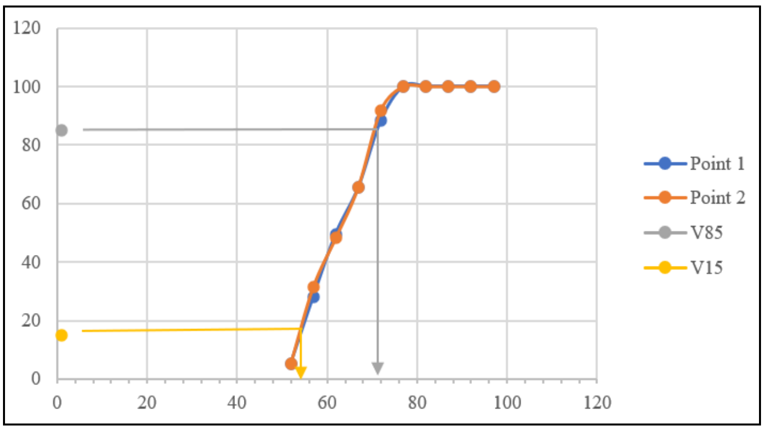

Fig. 9. S Curve

Table 6 V85th Percentile and V15th Percentile

Type of Road	Entering	Leaving	50m after the exit			
	V85	V15	V85	V15	V85	V15
Point 1	69.5	57.5	72.5	54.5	71.0	54.0
Point 2	71.0	63.5	72.0	54.0	71.0	53.5

Paired T-Test

A paired T-test was conducted to evaluate the differences between Space Mean Speed (SMS) of vehicles entering and exiting the curve for statistical significance. Table 7 below shows the findings of the paired T-test, which is statistically significant at a 95% confidence interval. The mean speed of vehicles entering the curve is lower at a mean value of 70.952 km/h, while the mean speed of vehicles exiting the curve is 76.917 km/h. The difference in speed between entering and exiting the curve is 5.965 km/h, indicating that drivers tend to accelerate when leaving the curve.

Table 7 Paired T-Test for Entering and Exiting the Curve

Variables	Mean	St. Dev	SE. Mean	P-Value
SMS Entering	70.952	2.368	0.440	0.000
SMS Leaving	76.917	2.780	0.516	
Difference	-5.965	3.565	0.662	

DISCUSSION

The non-compliance of road design often results in increased risks, including higher accident rates and reduced driver comfort. Such design shortcomings have a considerable impact on the safety of road users, particularly vulnerable ones. Therefore, roads should be designed with the safety of all road users in mind. Regular assessments and updates of standards are crucial to accommodate evolving traffic conditions and technological advancements. Future research should further investigate the implications of geometric design compliance, emphasizing real-world applications and the long-term effects on road safety and maintenance.

The spot speed analysis found that vehicles generally slowdown from the start to the end of a curve. This is consistent with expectations, as drivers usually reduce their speed when approaching and navigating a curve for safety reasons. The t-test analysis showed a p-value of 0.606, which is above the 0.05 threshold, indicating that the drivers' speed behavior in the study areas wasn't significantly affected by the surrounding environment. According to literature on percentile speeds, vehicles in the lower 15th percentile are considered to be traveling too slowly, while those above the 85th percentile are seen as exceeding a safe speed. The 85th percentile speed on the curve was found to be 105 km/h, suggesting that the current speed limit of 90 km/h might be too conservative and could be re-evaluated.

CONCLUSION AND RECOMMENDATIONS

This study assesses the geometric design of horizontal curves in relation to compliance with Arahan Teknik Jalan (ATJ) guidelines, offering crucial insights into road design standards' safety and effectiveness. Adhering to these guidelines is essential for road safety, reducing accidents, and improving the driving experience. The report's findings can guide practitioners in implementing best practices in highway geometric design and planning. Based on this study, the following recommendations are made:

a. Reevaluate the Speed Limit: Adjust the current speed limit in light of the 85th percentile speed and enforce strict measures against excessive speeding.
b. Automated Enforcement Systems (AES): Install AES at high-accident locations to improve traffic safety.
c. Rumble Strips and Speed Breakers: The Public Works Department (PWD) should place rumble strips or speed breakers on tangent lines before horizontal curves to slow down traffic and alert drivers to upcoming curves.

d. Collision Protection: Develop measures to minimize head-on collisions, particularly at horizontal curves.
e. Skid Resistance Investigation: Conduct further studies on skid resistance using a GripTester for network assessments or localized skid surface analysis with a British Pendulum Tester to understand how skid factors affect driver behavior.
f. International Roughness Index (IRI) Evaluation: Perform a detailed analysis of the IRI using a Multi Laser Profiler (MLP). Smoother pavements may lead to increased speeds, so understanding this effect is important for safety.

Additionally, researchers are advised to obtain as-built drawings from the PWD rather than relying only on construction drawings, as these may not accurately reflect the final site due to design changes and unarchived revisions. As-built drawings should be certified by an engineer with an as-built stamp and clearly marked with "AB" for revisions.

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