Evaluation of speed distribution at horizontal curve on two-lane rural arterial highway under mesopic and photopic scenario

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Abstract. Drivers travel at speed they assumed to be comfortable to achieve prevailing conditions and road geometry. The relationship between road geometrical design and speed of travelling vehicle is very prominent especially when travelling at the horizontal curve of a roadway. Crash events on horizontal curve are higher by the range of 1.5 and 4 times compared to the tangent sections. This is because speed varies according to the perception of constrains imparted to the drivers by the road geometrical design. The purpose of this study is to investigate the relationship between design speeds, operating speeds, and speed limits while drivers negotiate the horizontal curve. Furthermore, this study also investigates the behaviour of driver manoeuvre on the horizontal curve under mesopic and photopic visions. The speed data measurement was based on spot speed data at specific points and locations using the laser gun detector. The study was carried out by analysing the speed characteristics during daytime at the different segments along the horizontal curve (i.e. transition at entering of curve, middle of curve, and transition at leaving of curve). Apart from that, the difference in the mean speed on the contrast sensitivity under mesopic and photopic conditions was determined via t-test. It discovered that vehicles travelling on transition entering the curve tend to travel at higher speed than on the middle of curve and on transition leaving the 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 conditions. The research also found that the existing speed limit of the selected road stretches was lower than the 85th percentile speed. The 85th percentile speed is a commonly used measure to decide the speed limit on a road.

1. Introduction
Engineer design roads to protect people and get people to their destination in a timely manner. The roadway act as a guideline for the road users to be aware of their environment and understand what to do while driving. However, mishap happened resulting in injuries and fatalities. Fatalities due to road traffic accident are largely avoidable but for large part of the world’s population road death is the highest fatality risk. Negative road engineering factors consist of those places where area with high severe pavement deterioration directly triggers a crash, and few elements of the street surroundings mislead road users, thereby, leading to human errors.
According to the matrix developed by Dr. William Haddon Jr. in 1970 [1], there are three types of factor that contribute to road traffic accident which are human factors, vehicle factors, and roadway/environment factors. The Highway Safety Manual (HSM) of the American Association of State Highway and Transportation Officials [2] stated that only three per cent (3%) of road crashes are due to roadway factors, while thirty-four per cent (34%) of road crashes are a combination of roadway factors and other factors (Figure 1).

**Figure 1.** Contributing factors to vehicular crash [2].

Traffic growth has raised concern on the safety of the road users and collision rate. The data of average daily traffic (ADT) along the federal road (Route 76, Ipoh-Kuala Kangsar-Gerik) are shown in Figure 2. From the statistics, the ADT increased by 45% from the year 2010 to 2011, then remained fairly constant for the next 6 years. This was probably due to the recent development of Malaysia’s mega project, namely Ipoh to Padang Besar double tracking works, as a lot of cars and lorries travelled to quarries that were located along this arterial road.

**Figure 2.** Average daily traffic at 63 locations in peninsular Malaysia from 2008 to 2017 [3].

In Malaysia, road crash has become a major source of social and econometrics losses in the recent years. It is commonly recognized that road crashes are the result of one or more factors from these three main categories: driver-related, vehicle-related, and road condition-related [4]. Out of the three categories, road and highway authorities have full control on the standard and conditions of their roads through effective design, construction, maintenance policies, and enforcement.

However, crash events on horizontal curve are higher by the range of 1.5 and 4 times compared to the tangent sections. Generally, the accidents involve skid sideways and head-to-head collision. The
factors that affect the safety of the driver in negotiating the curve include traffic volume and mix between classes, geometric features of the curves, cross section, roadside hazards, stopping sight distance, combination of two alignments in the design (i.e. vertical alignment superimposed on horizontal alignment), curve distance, intersection along curve, IRI-roughness index, and skid value. There are three steps that could be taken to improve accident at horizontal curve. First, the problem site must be identified based on its crash history and roadway conditions. Second, improvement should be assessed and implemented. Third, before and after any construction attempts, studies of crash performance should be conducted to assess the effectiveness of the changes [5]. Therefore, the objective of this study include:

1. To determine and compare the 85th percentile speed and existing posted operating speed at the middle of curve in the horizontal alignment;
2. To identify and measure the existing road geometrical design elements of curved R5 arterial rural road segment and compare their conformance to JKR ATJ 8/86;
3. To analyse the speed behaviour of the drivers by the effect of drivers’ visibility under photopic and mesopic conditions; and
4. To suggest measures in achieving safe speed by the road users

2. Literature Review

2.1 Spot Speed

In moving traffic stream, vehicle travels at a different speed and varies between individuals depending to their comfort. Thus, the traffic does not have a single travelling speed value, but rather, a distribution of individual speeds. Speed is generally analyzed in three different types which include spot speed, running speed and journey speed.

Spot speed is a speed at specific point on a roadway at certain time [6], and spot speed is the instantaneous speed of a vehicle at a specified location. It can be used to design the geometry of the road such as horizontal and vertical curves, super elevation, etc. Spot speed is very much affected by the physical features of the road i.e. pavement width, curve, sight distance, gradient, pavement unevenness, intersections, and roadside development [7]. Other factors that could also influence spot speed are the environmental condition example, weather and visibility, enforcement, traffic conditions, driver, vehicle, and factor of travel.

Time factor and position of the observer (enumerator holding a radar gun) are important elements to be considered. It is advice that the enumerator should make themselves invisible to driver as it might influence the change in speed. The suggested times were between 0900 to 1200, 1500 to 1800, and 2000 to 2200, with a study duration of 1 hour for minimum of 50 vehicles/samples [6].

2.2 Road Geometric Design

Research stated that the required geometric design of highway depends on the speed of travelling vehicles [7 & 8]. However, other researcher provided a contrasting view, stating that the speed of travelling vehicle and the geometric design have symbiosis relationship (i.e. both depending on each other) [9].

It is important to note that, when assessing the acceptability of the geometry of an existing highway, the design standard related to the 85th percentile is relevant. If the 85th percentile is greater than the speed limit at a certain road section, then the required geometry should be assessed and correction to the geometry shall be made to enhance the safety of road users. It should always be remembered that the underlying factor for the standards of road geometry is highway safety [8].

In view of the above, road geometry shall be designed to facilitate its intention. Speed is the major element to be taken into consideration as road geometry and its design influence speed. It can be concluded that speed may vary, but it depends on many contributing factors such as follows [10]:

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i. General variable: time, date during travel, weather condition, highway classification, lighting conditions, and etcetera;
ii. Road user: driver, purpose of the journey, and travel mode;
iii. Vehicles: type, make year, condition, internal features, and external features; and
iv. Road environment: traffic control, traffic conditions, skid resistance, pavement defects, and etcetera.

2.3 Highway Functional Classification
Highways are classified according to their respective functions in terms of the characteristics of the service that they are providing. Particularly, it is described as rural road or urban road depending on the location of the road section. Highways have four major classes as follows:

i. Limited access facilities;
ii. Arterials: principle and minor arterials;
iii. Collector: major and minor collectors; and
iv. Local roads and streets.

This study only focused on literature related to the arterial system.

3. Research Methodology

3.1 Background of Study Area
The study area is a stretch of an arterial road, namely Ipoh-Kuala Kangsar-Gerik. This road was built by the Public Works Department (PWD) to link cities (from Kuala Kangsar) to small towns (Sauk, Lenggong, and etcetera), heading towards Gerik. The stretch of the selected road was single carriageway, constructed with fully flexible pavement and conformance to R5 classification in ATJ 8/86 Rev 2015 [11].

The location of curve, and Google map on the study area and as-built drawing from PWD are shown in Figures 3 and 4 respectively.

![Figure 3. Location of study area (extracted from google map).](image)
3.2 Geometric Design – Horizontal Vertical Curve
The geometric information was based on the partial construction drawing plan from the respective department in PWD. The horizontal data included the radius of circular curve, length of circular curve, and transition as shown in Figure 5.

\[ \begin{align*}
V_1 &= \text{Speed before curve / tangent (km/h)} \\
V_2 &= \text{Speed at start of curve (km/h)} \\
V_3 &= \text{Speed at middle of curve (km/h)} \\
V_4 &= \text{Speed at end of curve (km/h)} \\
LT &= \text{Length of Transition} \\
LC &= \text{Length of vertical curve (m)} \\
RC &= \text{Radius of circular curve (m)}
\end{align*} \]
3.3 Sample Size and Sampling Method

a. Existing Measurement and As-built Data
   The geometric elements were obtained during this study to include its physical aspect (i.e. horizontal curve length, width of roads, and number of lanes).

b. Spot Speed
   The spot speed data was collected on 100 vehicles passing each mentioned points at the curved road.

3.4 Method of Data Collection
(a) Spot speed characteristics include the mean, median, standard deviation, and percentile speed was analyse using Minitab and Microsoft Excel; and
(b) T-test via the Minitab software for testing the statistical difference [12].

4. Research Findings

4.1 Road Geometry
R5 road classification requires a minimum width of 3.5 m. Based on the measurement, the width of the study road area was 3.8 m, which was higher than the requirement. The summary of conformance to R5-rolling design is tabulated in Table 1. Nonetheless, the median was not provided as per the guideline of [11]. The author viewed that this was due to the minimisation of land acquisition which may lead to cost increase in the project.

Table 1. Conformance to ATJ 8/86 [11] comparison of existing road measurement

| Road Geometry                  | Existing Horizontal Curve | (ATJ 8/86 Rev 2015) |
|--------------------------------|----------------------------|----------------------|
| Width of road                  | 3.8 m–4 m                  | 3.5 m                |
| Number of lanes available      | 1                          | n/a                  |
| Road surface                   | Asphaltic concrete         | n/a                  |
| Width of road shoulder         | 2 m                        | 2.5 m–3.0 m          |
| Super elevation                | 0.38                       | 0.8                  |
| Median                         | Not found                  | Min 3.0 m            |

4.2 Spot Speed Analysis
The spot speed was measured at curved stretch, while the sample size was 100 for both bounds. The speed limit of 90 km/h was found exhibited on the speed board. From the cumulative frequency graph, the 85th percentile was identified as 105 km/h. This figure exceeded the speed limit, but it can be used to impose speed limit as it is assumed to be the highest safe speed for the roadway section. The 15th percentile speed of 70 km/h represented the slower vehicles, whose speed may have caused interference to the traffic stream.
Table 2. Table of the spot speed study

| Type of Road   | Curve Road |
|---------------|------------|
| Number of sample | 100        |
| Mean speed    | 88.21 km/h |
| Median speed  | 85.5 km/h  |
| Standard deviation | 17.42     |
| 15th percentile | 70 km/h    |
| 85th percentile | 105 km/h   |

4.3 Photopic and Mesopic Conditions

T-test was performed on two samples at only the middle of curve to determine the contrast sensitivity under mesopic and photopic conditions. It aimed to find the existence of any significant statistical difference between the mean of two independent samples. Please note that during the study, no data were collected on spot speed for both transition/spiral at night for all types of curve (i.e. sag curve, crest curve, and horizontal curve). The hypotheses for the correlation analysis test can be stated as follows:

\[ H_0 = \text{The mean difference between two variables (photopic vision and mesopic vision) is equal to zero.} \]
\[ H_1 = \text{The mean difference between two variables (photopic vision and mesopic vision) is not equal to zero.} \]

Table 3. T-test at middle curve

| Statistical Test | p-value |
|------------------|---------|
| T-test > 0.05    | 0.606   |

The t-test showed that the p-value was larger than 0.05 (in this case it was 0.606), hence, \( H_1 \) was rejected and \( H_0 \) was accepted. This demonstrated that researchers cannot conclude that a significant difference exists. In other words, it revealed that inadequate ambient light condition does not influence the driver’s speed when negotiating the curve.

4.4 Spot Speed Analysis at Curve’s Approach, Fully Curved Area, and Leaving of the Curve

The spot speed study was also focused on the curve’s approach, fully curved area, and leaving of the horizontal curve as shown in Table 4.

Table 4. The spot speed study at three different points

| Type of Road   | Location                                          |
|---------------|---------------------------------------------------|
| V1 (SC)       | at section between spiral and curve                |
| V2 (M)        | at section in fully curved area                    |
| V3 (CS)       | at section between curve and spiral                |

A summary of the mean, median, and standard deviation is presented in table 5. Based on the data tabulated, road users were found to gradually decrease their speed when travelling and negotiating the curve area from entering and leaving of the horizontal curve.
Table 5. Comparison table on the speed at the approach, middle, and leaving of curve

| Type of Road (Road) | V1 (approach) | V2 (fully curved) | V3 (leaving) |
|--------------------|---------------|------------------|-------------|
| Number of samples  | 100           | 100              | 100         |
| Mean speed         | 93.8          | 84.44            | 83.18       |
| Median speed       | 91.5          | 83.5             | 81.5        |
| Standard deviation | 17.57         | 16.75            | 14.78       |

5. Discussion

From the spot speed analysis, vehicles were found to travel with high to lower speed from the beginning to the end of curve. The data analysis is considering to be valid because as a vehicle approaches a curve, Drivers is expected to reduce the speed of their vehicles to safe speed in order to safely negotiate the curve [13].

The statistical significance test to determine the difference between the mean speeds of two samples was carried out using t-test analysis. From the results, the p-value was 0.606, which was more than 0.05. This revealed that the speed behaviour of the drivers at the case study areas is not influenced by the environment.

In terms of the percentile speed, the literature noted that the vehicles observed in the lower 15th percentile are considered to be travelling unreasonably slow, while those observed above the 85th percentile are assumed to be exceeding a safe and reasonable speed. The 85th percentile speed along the curve was 105 km/h, therefore, the current speed imposed 90 km/h is considered slow and does not fit its purpose as to act as a warning to the driver to reduce speed at the curve area.

6. Conclusion and Recommendations

The contents and findings of this report can be used as a reference to assist the practitioners towards adopting a best practice in highway geometric design and planning. The following recommendations are drawn from this study:

a. The current speed limit imposed should be reconsidered based on the 85th percentile, but strict enforcement is mandatory for vehicles travelling at higher speed;
b. PWD is to install rumble strip/speed breaker at tangent line before entering the horizontal curve to reduce the vehicles’ speed and warn drivers about the presence of curved road ahead;
c. A minimum protection to minimise head-to-head collision, especially at the horizontal curve, should be constructed;
d. Further investigation on the skid resistance using Griptester for network assessment or localised skid surface using British pendulum shall be deployed to understand how skid affects driver behaviour;
and
e. People tend to drive faster on smooth pavement therefore, detailed IRI (roughness index) using Multi-Laser Profiler (MLP) may be performed this is because ride comfort increases when a pavement becomes smoother and simultaneously, when roughness decreases.

Researchers are highly encouraged to obtain the as-built drawing from PWD and not solely refer to the construction drawing as the construction drawing does not represent the actual construction at site.
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