Case study of safe avoidance manoeuvres on a rural road in South Africa

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Abstract— **An existing rural road with a posted speed limit of 100 km/h was assessed on typical geometric elements. The existing rural road is a surfaced single carriageway road with one lane and surfaced shoulders in each direction. The assessment concluded that the design speed is 100 km/h. Specifically, the stopping sight distance based on an object height of 0.6 m does not substantiate a design speed of 120 km/h.**

The client, South African National Roads Agency SOC Ltd. (SANRAL), requested that the geometric elements be re-assessed for performing an avoidance manoeuvre to see if this can justify a safe road condition with the preferred posted speed limit of 120 km/h. A 20 km/h difference in operating speed still represents a tolerable design, therefore a 120 km/h posted speed is acceptable. The avoidance manoeuvre is not a geometric design criterion on its own. A literature study was performed to understand how an avoidance manoeuvre is performed and what factors play a role in performing an avoidance manoeuvre. The avoidance manoeuvre was assessed for safety considering speed and road geometry. An avoidance manoeuvre is calculated using an avoidance manoeuvre time consisting of a perception-reaction time and an avoidance action time. The avoidance manoeuvre was then applied to three scenarios to illustrate simulated situations.

South African road geometric design values and standards were studied to understand the input data required in performing an avoidance manoeuvre.

Recommendations were made on how this study can impact the selection of the design speed of the road.

Keywords—geometric design; avoidance manoeuvre; design standards; evasive action; safety; posted speed.

I. Introduction

The avoidance manoeuvre is defined in American Association of State Highway and Transportation Officials (AASHTO) [1] as the manoeuvre required to negotiate an obstacle or location properly. The avoidance manoeuvre was assessed on a rural road to overcome the stopping sight distance (SSD) restrictions for 100 km/h at locations where SSD did not conform to the proposed 120 km/h design standards. The paper describes the avoidance manoeuvre as defined in design guides and literature. The paper uses a case study to show how avoidance manoeuvres are calculated empirically. The case study is located in the Free State Province on National Route 8, section 12, from Thaba'Nchu North (km 1,2) to Tweespruit (km 19,2).

The assessment of the N8 section 12 using the South African National Roads Agency SOC Ltd. (SANRAL) Geometric Design Guidelines [6] confirmed that the existing geometric elements of the road met the criteria for a design speed of 100 km/h. Specifically the SSD and object height analysis for 0.6 m showed the design speed to be 100 km/h which conforms to the existing posted speed limit and general speed limit for rural roads. A 20 km/h difference in operating speed still represents a tolerable design, therefore a 120 km/h posted speed is acceptable. In discussion with the client, SANRAL, the avoidance manoeuvre was used to determine the suitability of increasing the posted speed limit to 120 km/h.

The objective of this study was to investigate if avoidance manoeuvres can substantiate the use of a specified posted speed limit in excess of the design speed as described in the SANRAL Geometric Design Guidelines. The investigation was restricted to a specific case study with defined parameters and this solution should not be used in general, as an avoidance manoeuvre is not defined as a geometric design parameter. Most of the information was obtained from the visual assessment, concept and detailed design of the case study. The paper starts with a literature study. It then uses a case study to show how avoidance manoeuvres are calculated empirically. Conclusions and recommendations are discussed.

II. Literature Study

Understanding a driver's reaction and avoidance time is a challenge as driver habits are unpredictable. Numerous studies have been done to determine reaction time but limited studies on avoidance manoeuvre time. Reaction time is the time a driver takes to observe a situation and decide on how to react to the situation. Reaction time (often specified as perception-reaction time) in this study was taken as the sum of perception, intellection, emotion and volition times [4]. Referred to as the PIEV process:

- Perception — the time to see or discern an object or event
- Intellection — the time to understand the implications of the object's presence or event
- Emotion — the time to decide how to react
- Volition — the time to initiate the action, for example, the time to engage the brakes

Avoidance action time is the time it takes to perform the decided action. An avoidance manoeuvre time therefore comprises of firstly a driver's perception-reaction time upon seeing that there is an object in the vehicle's travel path and deciding what is required to avoid crashing into the obstacle. The avoidance action time comprises secondly the time to physically perform the selected avoidance manoeuvre.

Brake reaction time is typically taken as 2.5 s in design, which exceeds the 90th percentile of perception-reaction time for most drivers and this perception-reaction time was adopted for this study in line with AASHTO [1].

Arndt [2] proposes a 3.5 s evasive action time (avoidance action time) and AASHTO [1] uses a 4.5 s lane change time. This study selected lane change as the type of avoidance manoeuvre performed and a 5 s avoidance action time was adopted, incorporating a further 0.5 s safety factor.

An interesting study performed by Jansson [3] shows that the distance required to perform an avoidance manoeuvre is half that of the breaking distance required. A note should be made that this study was done in a very controlled environment which also removed the perception-reaction time. This does illustrate the advantages of taking the avoidance manoeuvre into account when choosing the posted speed limit on a road.

III. CASE STUDY

A. *Location and Background*

The road used in the case study is located in the Free State Province, on National Route 8, section 12, from Thaba'Nchu North (km 1,2) to Tweespruit (km 19,2) which forms a part of the Bloemfontein-Maseru corridor. The N8 is one of the strategic routes in the country as it serves as an important link between South Africa and Lesotho. It is also used by local users accessing towns such as Tweespruit, Thaba'Nchu, and Ladybrand.

The geometric assessment of the N8 section 12 confirmed that the existing geometric elements of the road met the SANRAL Geometric Design Guidelines [6] criteria for a design speed of 100 km/h. Specifically, the SSD analysis for an object height of 0.6 m showed the design speed to be 100 km/h [6]. The existing posted speed limit is 100 km/h, which is also the general speed limit on rural roads. The client requested that the geometric elements be analysed for the possibility of performing an avoidance manoeuvre to substantiate the preferred posted speed limit of 120 km/h.

The majority of situations where SSD is not achieved are on sharp crested vertical curves on straight or curved sections of the road alignment.

B. *Avoidance Manoeuvre*

The avoidance manoeuvre is calculated using a avoidance manoeuvre time consisting of a perception-reaction time and an avoidance action time [2]. The input data used for the avoidance manoeuvre calculation on the N8 section 12 was the following:

- Operating Speed = 120 km/h (27.77 m/s)
- Perception-Reaction Time = 2.5 s
- Eye Height = 1.05 m
- Avoidance Action Time = 5 s
- Object Height = 0.6 m
- Deceleration Rate = 3 m/s2

The following formula [2] was used to calculate the avoidance manoeuvre time:

d = distance

v = velocity

t = time

$$d = \frac{v \times t}{3.6} \qquad (1)$$

The avoidance manoeuvre time was calculated from these input values along the N8 section. Note should be taken that the geometric design data of the N8 section 12 was used in these calculations. The avoidance manoeuvre time was calculated along the entire road section and it showed that the critical avoidance manoeuvre times matched the areas with the lower SSD.

C. *Scenarios*

It was found that throughout the entire road section an object 0.6 m high is visible at least 7.5 s before the object is reached at a speed of 120 km/h.

At 7.5 s away, an object 0.6 m high is visible while the road surface at the location of the object is still not visible. A driver of a vehicle cannot yet determine if the object is in the travel path or not. This situation occurs when a driver travels along a horizontal curve in combination with a vertical crest curve. A driver cannot identify where the object is located on the road. Only at an avoidance manoeuvre time of 4 s does the road surface become visible and a driver can perceive where the object is located on the road.

For this study, three basic scenarios can now play out:

- The first scenario is if the object is not in a driver's travel path then no further action needs to be taken.
- The second scenario is if the object is in the travel path of a driver with space to manoeuvre around the object: then a driver can choose to go to the left or right of the object. 4 s is an acceptable avoidance action time for a driver to avoid the object by passing around it on the shoulder or on the left-hand side of the object if it only partially blocks the lane. A problem would arise if a driver had to choose to pass on the right-hand side and drive into oncoming traffic. AASHTO [1] specifies that a driver requires more than 4 s to choose if they could pass a vehicle on the right-hand side into oncoming traffic. The 4 s avoidance action time in this situation is not enough and a potentially dangerous situation is created if an oncoming vehicle is present. A possible solution is to increase the shoulder width to increase the probability of a driver choosing the shoulder to avoid an object. This will not completely remove the situation where a driver needs to pass to the right of the object which say could be blocking the shoulder and the lane it is in.
- The third scenario is the worst case where a driver realises that the object blocks the entire road. A driver has 4 s = 133 m to decelerate before hitting the object. A driver travelling at 120 km/h and decelerating at 3 m/s^2 would be able to reduce their speed by around 40 km/h before impact [6]. A driver will be moving at 80 km/h when hitting the object. This creates another dangerous situation.

An alternative approach will be to assume a higher deceleration rate. The design value of 3 m/s^2 is based on comfort criterion. The legal requirement for stopping ability of vehicles is 4.4 m/s^2 in the

National Roads Traffic Act [5]. At this deceleration rate a driver can stop in 126 m and thus avoid crashing into the object.

IV. Application to N8 Section 12

The N8 section 12 case study identified four areas as having sight obstructions resulting in avoidance manoeuvre times of less than 7.5 s. They were highlighted as zones to further investigate according to the geometric layout:

- Zone 1 from km 2.500 to km 2.900 over a length of 400 m. This zone has a sharp horizontal curve to the right combined with a vertical crest curve. The implementation of a wider surfaced shoulder, allows vehicles to be able to utilise the shoulder in an avoidance manoeuvre. Due to the short length of road the wider shoulders will greatly reduce the risk of collision in this zone. As per the client's typical cross sections and in discussion with the client, the surfaced shoulders will be widened to 3 m, therefore no further action needs to be taken. This will not however completely remove the possibility of a collision.
- Zone 2 from km 8.400 to km 8.900 over a length of 300 m and has an existing climbing lane in the easterly direction of travel. This zone has a longer horizontal curve to the right combined with a sharp vertical crest curve. It is recommended to do nothing as the existing climbing lane creates a wider cross section to perform an avoidance manoeuvre. The climbing lane adds an additional lane to use to avoid obstacles.
- Zone 3 from km 9.800 to km 11.500 over a length of 1700 m has many restrictive geometric elements such as sharp horizontal curves combined with sharp vertical crest curves. The existing climbing lane in the easterly direction of travel extends from km 8.400 to km 11.200.
    - The first possible solution would be to improve the geometric alignment of the section of road by redesigning the vertical and horizontal alignment. This will have major cost implications and thus not preferred and no further investigation will be performed.
    - A second option would be to introduce a climbing lane, which was deemed warranted, in the westerly direction of travel from km 11.500 to km 10.700. This would improve the potential width to make a safe avoidance manoeuvre within the visible sight distance presently available. A climbing lane in the westerly direction of travel from km 11.500 to km 10.700 could be investigated. This 800 m of climbing lane would improve the potential width to make a safe avoidance manoeuvre within the visible sight distance presently available for a vehicle travelling in the westerly direction. It is recommended that a basic costing of redesigning the vertical and horizontal alignment be compared to the introduction of a climbing lane.
- Zone 4 from km 13.600 to km 14.000 over a length of 400 m. This zone has a sharp horizontal curve to the right combined with a vertical crest curve. The implementation of a wider surfaced shoulder, allows vehicles to be able to utilise the shoulder in an avoidance manoeuvre. Due to the short length of road the wider shoulders will greatly reduce the risk of collision in this zone. As per the client's typical cross sections and in discussion with the client, the surfaced

shoulders will be widened to 3 m, therefore no further action needs to be taken. This will not however completely remove the possibility of a collision.

V. Conclusions

It was found that SSD restricts the posted speed limit along some sections of the road. This created the opportunity to consider avoidance manoeuvres and investigate the possibility of it overcoming the SSD restrictions.

When looking at the case study it was found that with the implementation of the client's typical cross sections the surfaced shoulders will be widened to 3 m along the entire road section. This will allow vehicles to utilise the shoulder in an avoidance manoeuvre and will avoid the substantial costs associated with regrading of the road.

VI. Recommendations

When considering avoidance manoeuvres it could be possible to overcome the SSD restrictions. Note that an isolated situation was investigated. Further investigation should be performed to better understand avoidance manoeuvres.

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