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Effect of passing zone length on operation and safety of two-lane rural highways in Uganda

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ABSTRACT

This paper presents a methodology to assess the effect of the length of passing zone on the operation and safety of two-lane rural highways based on the probability and the rate of passing maneuvers ending in a no-passing zone. The methodology was applied using observed passing maneuver data collected with tripod-mounted camcorders at passing zones in Uganda. Findings show that the rate at which passing maneuvers end in a no-passing zone increases with traffic volume and unequal distribution of traffic in the two directions, absolute vertical grade, and percent of heavy vehicles in the subject direction. Additionally, the probability of passing maneuvers ending in a no-passing zone reaches 0.50 when the remaining sight distance from the beginning of the passing zone is 245 m for passenger cars or short trucks (2–3 axles), and 300 m for long trucks (4–7 axles) as the passed vehicles. These results suggest policy changes in design and marking of passing zones to enhance safety and operation of two-lane rural highways.

1. Introduction

Passing zones on two-lane rural highways provide sight distances for fast vehicles to pass slow vehicles using the opposite traffic lane. This helps to reduced travel delay and queuing of fast vehicles behind slow vehicles according to the Highway Capacity Manual 2010 [HCM 2010] [1]. Despite the apparent operational benefits, there is still limited knowledge on the quantitative effect of the length of passing zones on the operation and safety of these highways. Specifically, the extent passing maneuvers can be delayed from the beginning in order to end inside the passing zone for safety reasons is still unknown. Besides, the sight distance to complete the passing maneuver inside the passing zone decreases with increase in the delay to initiate the maneuver from the beginning of the passing zone.

The delay to initiate passing maneuvers increase the chances of the maneuvers ending in the no-passing zone, where visibility is limited to evade a potential collision with the opposite vehicle [2]. Judgement of the remaining sight distance to complete passing maneuvers inside the passing zone by design rests with the driver of the passing vehicle [3–6]. A previous study observed that drivers are unable to judge accurately the sight distance and speed of the opposite vehicles, which increases the likelihood of passing maneuvers ending in the no-passing zone [7].

The adequacy of the length of passing zones is often assessed considering the sight distance required to complete individual passing maneuvers [5,8–11]. Comparison is often made between the design passing sight distances [PSD] thresholds following '*A policy on geometric design of highways and streets[AASHTO 2001]*' [3], and the marking PSD thresholds by the Federal Highway Administration *[MUTCD 2009]* [12]. These design and marking PSD thresholds were also adopted for design and marking of two-lane highways in Uganda [6,13]. The design PSD threshold is based on a four component kinematic model consisting of distances covered during the perception-reaction and initial maneuver, occupation of the opposite lane, clearance at the end of the maneuver up to meeting the opposite vehicle [3]. Conversely, marking PSD thresholds are based on the 85th percentile speed of all vehicles using the highway under off-peak traffic conditions [12,14].

In practice, the marking PSD thresholds are nearly half of those used in design. Harwood et al. [5] argued that the design PSD thresholds are conservative, and lead to reduced passing opportunities unless the

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highway is re-aligned to create longer passing sight distances. The authors further argued that this may not be cost effective without additional justification of accrued operational and safety benefits. These arguments formed the basis for harmonizing the design and marking PSD thresholds in '*A policy on geometric design of highways and streets [AASHTO 2011]*' [4], implicitly assuming most drivers commence passing maneuvers at the beginning of the passing zone.

However, operating traffic conditions could force passing maneuvers to commence away from the beginning of the passing zone shortening the remaining sight distance to complete passing maneuvers inside the passing zone. This could result from presence of opposite vehicles close to the beginning of the passing zone, or high-speed catch-ups between the passing and passed vehicles [15]. The delay to initiate a passing maneuver contributes to a risk of crash between the passing and opposite vehicles in two ways. First, the delay reduces the remaining sight distance to complete the maneuver inside the zone where it is easier for the passing and opposite vehicles to evade a potential collision. Secondly, it increases the chances of initiating a passing maneuver with the opposite vehicle not in sight. The driver of the passing vehicle is thus unable to gauge the gap in the opposite direction at the time of initiating a passing maneuver.

Passing maneuvers ending in the no-passing zone have been reported at both short (92% for passing zone lengths shorter than 240 m), and long (21% for passing zone lengths 300 m or more) passing zones [5]. Furthermore, a study conducted in Australia (60%) and New Zealand (72%) using traffic crash data from 1999 to 2003 reported high occurrence of passing related head-on collisions in horizontal curves [16]. Therefore, it is essential to study the effect of the length of the passing zone on the chances and rate passing maneuvers end in no-passing zones. This could yield policy measures to enhance design and marking of passing zones for operational efficiency and safety.

The aim of this study is therefore to assess the effect of passing zone length on operation and safety of two-lane rural highways based on the probability and the rate at which passing maneuvers end in the no-passing zone. In order to achieve this aim, models for estimating the probability and the rate at which passing maneuvers end in no-passing zones are formulated and presented in Section 2. The methods, tools, and data processing are also discussed in Section 3. Section 4 presents results of model estimation and sensitivity analyses. Section 5 discusses the results in comparison with previous studies and practice. Section 6 concludes the paper, and discusses future research directions.

2. Model formulation

This section describes theoretical concepts for the development of models to predict the probability and the rate of passing maneuvers ending in no-passing zones on two-lane rural highways.

2.1. Model formulation of the probability of passing maneuvers to end in no-passing zones

Passing maneuvers that end inside passing zones are safer by design because the sight distances are sufficient for the passing and opposite vehicles to avert potential collisions. The length of a passing zone, the extent of delay to initiate the passing maneuver, and traffic related factors influence the chances of individual passing maneuvers ending inside passing zones or outside passing zones (in the no-passing zone) as illustrated in Fig. 1.

Long passing zones provide adequate sight distances to complete passing maneuvers inside the zone [3,4]. The underlying assumption is that individual passing maneuvers commence close to the beginning of the passing zone. However, quite often passing maneuvers commence away from the beginning of the passing zone due to presence of opposite vehicles or as a result of high-speed catch-ups [15]. Thus, for a given length of a passing zone, the longer the distance up to the initiation of a passing maneuver, the higher the probability of the passing vehicle completing the passing maneuver in the no-passing zone.

The distance up to the initiation of the passing maneuver indirectly depends on the speed of the passing vehicle measured at the beginning of the passing zone, and the time up to the point of initiating a maneuver. Previous design PSD thresholds in AASHTO 2001 [3] also adopted in Uganda [6] explicitly incorporated a distance component for perception-reaction and initial maneuver to account for delays to initiate passing maneuvers. However, this component was removed in AASHTO 2011 [4] leading to short design PSD thresholds. Moreover, marking of passing zones follow even shorter PSD thresholds than those used in design [13], which increases the chance of delayed passing maneuvers ending in a no-passing zone.

The speeds of passing and passed vehicles at the beginning of the passing zone affect the position of initiation of the maneuver inside the passing zone. Additionally, the speed of the passed vehicle has been shown to influence the time it takes to complete the maneuver, also known as the passing duration [17,18]. The passing duration has also been found to depend on other traffic factors; the type of passed

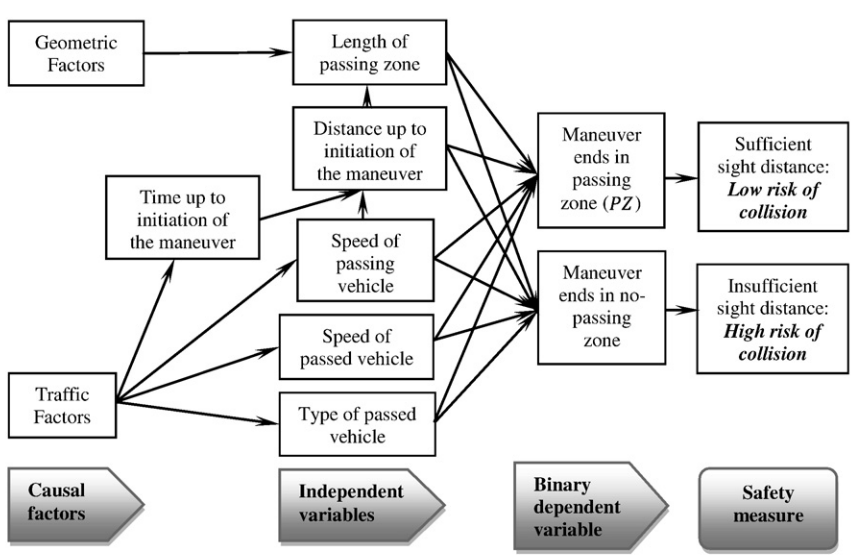

Fig. 1. Theoretical framework of underlying theoretical causal relationships.