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Modeling drivers' passing duration and distance in a virtual environment

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ABSTRACT

In many countries two-lane rural highways constitute a large proportion of the road network. One of the most fatal crash types is head-on collisions. Some of these head-on collisions are caused by failed passing maneuvers, when a driver does not succeed to complete the pass safely.

Detailed observation of drivers' passing behavior in reality is difficult and complex. This study uses a driving simulator to collect detailed data on drivers' passing behavior. Using this data, empirical models explaining passing duration and distance were developed and estimated. These models take into account the impact of the traffic conditions, geometric design, and drivers' socio-demographic characteristics.

The results revealed that the passing duration and distance of older drivers are significantly higher than younger drivers. The passing duration and distance are significantly affected by the traffic related variables of the subject, front, and opposing vehicles. The duration and passing distance increase when drivers initiate the passing maneuvers from a larger following distance from the front vehicle. Driver gender, road curvature, and types of front and opposing vehicles were not found to have a statistically significant impact on the passing duration and distance.

The time that takes the driver to arrive to the critical position, or the point of no return, from the moment of start passing is equal to 41.7% of the time needed to complete the passing maneuver, higher compared to the value suggested by AASHTO (33%). This has important implications on safety.

The main contribution of this paper is in the empirical models developed for passing duration and distance which highlights the factors that affect drivers' passing behavior and can be used to enhance the passing models in simulation programs.

1. Introduction

Two-lane, two-way roads constitute a major part of the road network in most countries [1]. A fast traveling vehicle overtakes a lead slower vehicle, on this type of roads, by traveling on the traffic lane designated for the opposing traffic. Thus, this maneuver involves a risk of a head-on collision with opposing traffic, and therefore has a direct impact on safety. About 20% of the fatal crashes that occurred on two-lane rural highways in the US are head-on collisions, in which passing is one main leading cause to this type of crashes [2]. In the OECD (Organization for Economic Co-operation and Development) European countries this percentage is even higher, reaching 25% [3]. This maneuver is considered as one of the most complex maneuvers on this type of roads [4] because the passing vehicle needs to adapt its speed and position so that it could complete the passing maneuver safely. A road segment which provides few opportunities for passing could lead to the causation of platoons and to a reduction in road capacity and its level of service. This has also implications on fuel consumption. Therefore, the design of passing sight distances is a very important element of two-lane highways. This topic has been dealt with extensively by safety and traffic operational researchers as discussed in the following paragraphs.

According to AASHTO [1] the passing sight distance is composed of four elements: the distance the passing driver travels during the perception and reaction time and the initial acceleration to the point of encroachment on the left lane (d_1), the distance traveled on the opposing lane (d_2), the distance at the end of the passing maneuver between the passing and opposing vehicle (d_3), and the distance traveled by the opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane (d_4). Many other analytical models for passing sight distance were developed in the last four decades. Harwood et al. [5] conducted a comprehensive review of passing sight distance models developed between 1971 and 1998 summarized in a report for the National Cooperative Highway Research Program (NCHRP). The main purpose was to examine the adequacy of the AASHTO Green Book models knowing that they are based on old

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data and have not been revised for many years. The authors reviewed more than 12 models and highlighted for each model the conceptual approach used, the analytical models that have been developed, the assumed values of the model parameters, and a critique of each model. The authors found that the two models developed by Glennon [6] and Hassan et al. [7] were the most appropriate alternatives to the AASHTO models. These models recognize that drivers might abort a passing maneuver at an early stage of passing, before reaching the critical position. Glennon [6] defined the critical position as the location where the sight distance needed to continue the passing is equal to the sight distance needed to abort the passing. Hassan et al. [7] proposed a broader definition of the critical position accounting for situations where the critical position, as defined by Glennon, occurs beyond the abreast position. The abreast position is defined as when the passing vehicle is at a position alongside the front vehicle. In these cases, the authors suggested that the critical position be defined as the location where the two vehicles are abreast because it is unlikely that a passing driver would abort a passing maneuver when the front bumper of his vehicle is ahead of the front bumper of the front vehicle.

Hegeman [3] analyzed 26 accelerative and 6 flying passing maneuvers on two-lane rural roads using an instrumented vehicle and found that the average duration of accelerative passing is 7.9 s with a standard deviation of 1.5 s, and the average duration of flying passing maneuvers is 6.8 s with a standard deviation of 1.4 s However, the author did not develop models that explain the duration or distance of passing maneuvers.

Polus et al. [8] studied completed passing maneuvers to determine the required sight distances for diverse combinations of design speeds and traffic conditions based on estimates of passing distances. They found that passing distances depend on the speed of the vehicle in front. The mean passing distance was found to be 254 m with a standard deviation of 80.9 m.

Harwood et al. [5], in the same report prepared for the NCHRP, also present their results of a field study on passing maneuvers on two-lane highways at seven sites in Missouri including 12 passing zones, and eight sites in Pennsylvania including 16 passing zones. The data collection was conducted under daytime and off-peak conditions. They analyzed 153 passing maneuvers in Missouri and 149 in Pennsylvania, in long passing zones (300 m. or more), and 45 passing maneuvers in Missouri and 20 in Pennsylvania, in short passing zones (between 120 and 240 m.). They also analyzed 7 aborted passing maneuvers. The authors reached several conclusions that have direct implications on the design criteria according to AASHTO. For example, AASHTO design criteria are based on the assumption that the speed differential between the subject and front vehicles is equal to 16 km/h, while the authors found that this value is closer to 19 km/h. Moreover, AASHTO assumes that the travel time on the left lane is between 9.3 and 11.3 s and that it increases with higher driving speeds, while the authors found that the mean is 9.9 s, and that there is no correlation between the travel time on the left lane and the driving speed. Therefore, the authors suggest modifying AASHTO Green Book according to their findings. They also found that the mean passing duration is 10 s with a standard deviation of 2.8 s, and the mean passing distance is 282 m with a standard deviation of 75 m.

A recent study by Llorca and Garcia [9] included detailed registration of the trajectories of passing and passed vehicles using 6 fixed video recording cameras, installed next to 4 passing sections in the surrounding of Valencia, Spain in 2010. 234 passing maneuvers were observed, however full trajectories of vehicles were complete for only 58 maneuvers. The authors developed multiple linear regression models for explaining passing time durations and distances. The explanatory variables that were found to have a significant impact on the time of travel on the left lane included the type of the impeding vehicle, the passing zone length, and the speed differential between the passing and the impeding vehicle. The distance traveled on the left lane on the other hand was found to be a function of the vehicle type, the passing zone length and the speed of the impeding vehicle.

As can be seen most of the models developed for passing sight distance were analytical models based on equations of motion, or studies that collected field data on passing maneuvers and analyzed their duration and distance as a function of mainly traffic related variables. Very few studies modeled passing duration and distance as a function of traffic, geometric, and drivers' characteristics simultaneously.

The rest of the paper is organized as follows; Section 2 presents the research methodology which describes the experiment, data collection and model formulation. This is followed by Section 3 which presents the results, and finally Section 4 concludes the study, presents the limitations and suggests further directions for research.

2. Research methodology

The main objective of this study is to model the passing duration and passing distance on two-lane highways as a function of driver, geometric and traffic characteristics. The following paragraphs describe the research methodology adopted in this study.

2.1. Experiment design

Collecting detailed data of passing maneuvers, including the trajectories of the passing, passed, and opposing vehicles, in real life is a difficult, complex, and tedious task. Also, it would require a relatively long period of time to capture enough observations for a firm analysis to be conducted. There are multiple advantages for using simulators in driving behavior research, mainly, the safe environment and the ability to control the factors that can affect the study results. Driving simulators enable the investigation of effects of non-existent road elements, and risky situations, and drivers can be repeatedly confronted with events that infrequently occur in reality. In the context of passing behavior, data collected with driving simulators have been used by several authors. For example, Jenkins and Rilett [10] used simulator data to develop a classification of passing maneuvers, Bar-Gera and Shinar [11] evaluated the impact of speed difference between the lead and subject vehicle on drivers' desire to pass, Farah et al. [12] developed a passing gap acceptance model that takes into account the impact of the road geometry, traffic conditions and drivers' characteristics, Bella and D'Agostini [13] used interactive fixed-base driving simulator to analyze rear-end collision risk under various traffic and road geometric conditions, and Vlahogianni and Golias [14] studied the overtaking behavior of

Fig. 1. Snapshot from the driving simulator scenario.