Alternative Definitions of Passing Critical Gaps

Tomer Toledo and Haneen Farah

A substantial proportion of the road network in most countries consists of two-lane highways. Available gaps for passing are a fundamental element in the operation of such highways. Providing passing opportunities is important for reducing the formation of vehicle platoons in the traffic flow, increasing the level of service, and improving safety. Passing opportunities also affect fuel consumption and emissions. Despite the importance of passing on two-lane highways, few studies have focused on exploring passing gap definitions when modeling passing behavior. Research was done to investigate various definitions of passing gaps, and these definitions were used to develop passing gap acceptance models. Data on passing maneuvers collected with a driving simulator were used to develop and calibrate three models. The generic structure of these models was composed of the drivers' desire to pass and their gap acceptance decisions. The impact of traffic characteristics, road geometry, and driver characteristics was included in these models. The results show that the passing gap definition has a significant impact on the models' ability to explain passing behavior. Moreover, the estimation results show that modeling a driver's desire to pass the vehicle ahead has a statistically significant contribution in explaining passing behavior. Variables that capture the impact of the traffic conditions, geometric characteristics of the road section, driver characteristics, and the unobserved heterogeneity in the driver population were found to have a significant impact on drivers' desire to pass and their gap acceptance decisions.

Two-lane highways make up a substantial proportion of the road network in most of the world. About 60% of all fatal crashes in member states of the Organisation for Economic Co-operation and Development occur on these roads (*1*). Thirty five percent to 50% of deaths on these roads are directly related to passing maneuvers (*2*). Passing is a mentally complex task that substantially affects highway performance (*3*). A reduction in passing opportunities leads to the formation of vehicle platoons in the traffic flow, which in turn cause a decrease in the level of service and negatively affect safety, fuel consumption, and emissions. The *Highway Capacity Manual* refers to the formation of platoons as an important phenomenon in determining traffic performance on two-lane highways (*4*). Potential improvements to the design of two-lane highways include construction of additional lanes or passing sections, 2+1 lane designs, and widening of existing lanes and shoulders. However, these solutions are costly and require careful design and evaluation before implementation. Thus, a better understanding of passing behavior is essential.

T. Toledo, Faculty of Civil and Environmental Engineering, Technion–Israel Institute of Technology, Haifa 32000, Israel. H. Farah, Department of Transport Sciences, Royal Institute of Technology, Teknikringen 72, SE-100 44 Stockholm, Sweden. Corresponding author: H. Farah, fhanin@kth.se.

Transportation Research Record: Journal of the Transportation Research Board, No. 2260, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 76–82.
DOI: 10.3141/2260-09

Despite the importance of the problem, few studies have attempted to model passing behavior. Several studies developed analytical models based on equations of motion to determine required sight distances (*5–9*). Other studies focused on prediction of numbers and frequencies of passing maneuvers depending on macroscopic traffic characteristics (*10*) or the impact of impatience on critical passing gaps (*11*). Early studies done to estimate critical passing gaps distributions did not model the variables that affect mean critical gaps (*12–15*). Clarke et al. indicated that passing is a complex maneuver that can fail in a number of ways, such as through errors in judgment of the distance required to complete the maneuver, misjudging the speed of the leader (or possibly the acceleration of the driver's own vehicle) or the speed of the oncoming vehicle, insufficient clear sight distance, or single-vehicle crashes resulting from the dynamics of the passing maneuver itself (*16*).

Passing models are not commonly incorporated in microscopic traffic simulation models that are developed mainly to evaluate congested urban networks. To fill this gap, several specific simulation tools for two-lane highways that incorporate passing have been developed. These include TWOPAS (*17*), TRARR (*18*), VTISim (*19*), and RuTSim (*20*). These use simplified passing models that are based on data collected in the 1970s. Both St. John and Harwood (*17*) and Tapani (*20*) indicated the need for improved passing gap acceptance models. However, few studies have been conducted at the microscopic level (*16*). Passing maneuvers may occur anywhere on a section of road, and field studies to collect data on passing maneuvers may be expensive and inefficient. Furthermore, they offer little control over the explanatory variables and usually no information on the drivers being observed. Driving simulators have been shown to be a reliable alternative to observing driving behavior (*21, 22*). In the context of passing behavior, data collected with driving simulators have been used by several authors. Jenkins and Rilett used simulator data to develop a classification of passing maneuvers (*23*). Bar-Gera and Shinar evaluated the effect of speed difference between the lead and subject vehicle on a driver's desire to pass (*24*). However, they studied a divided highway and so did not consider vehicles in the opposing lanes and the feasibility of passing as captured, for example, by gap acceptance functions. Farah et al. developed a passing gap acceptance model that takes into account the impact of the road geometry, traffic conditions, and driver characteristics (*25*). However, this model does not consider driver motivation to pass.

Passing is commonly modeled as a binary choice in which the driver either accepts or rejects an available gap in the traffic on the opposing lane. Passing gaps are defined by either distance or time. The most common definition found in the literature uses the gaps between two consecutive vehicles on the opposing lane (*22, 26, 27*). Other researchers defined passing gaps as the distance between the passing vehicle and the vehicle on the opposing lane at the moment the passing maneuver starts (*5, 9*). In this study, various definitions of passing gaps are formulated and compared with data collected with a driving simulator.

MODEL FORMULATION

The completion of passing maneuvers is modeled in two stages: the desire to pass and the decision whether to accept or reject an available passing gap. This generic model structure is shown in Figure 1.

Drivers are first assumed to decide whether they want to pass the lead vehicle. Drivers that are interested in passing then evaluate the available passing gap and either accept it and complete the passing maneuver or reject it and do not complete the maneuver.

The desire to pass is formulated as a binary choice problem:

$$\mathrm{DP}_{nt} = \begin{cases} 1 & \text{if } U_{nt}^{\mathrm{DP}} \geq 0 \\ 0 & \text{if } U_{nt}^{\mathrm{DP}} < 0 \end{cases} \tag{1}$$

where

n and t = indices for the driver and the passing gap, respectively;
DP_{nt} = choice indicator variable with value 1 if the driver desires to pass and 0 otherwise; and
U_{nt}^{DP} = utility to the driver from desiring to pass. The utility of the other alternative, not desiring to pass, is assumed to equal 0.

The desire-to-pass utility is unobserved and modeled as a random variable, with a mean that is a function of explanatory variables,

$$U_{nt}^{\mathrm{DP}} = x_{nt}^{\mathrm{DP}}\beta^{\mathrm{DP}} + \alpha^{\mathrm{DP}}\nu_n + \epsilon_{nt}^{\mathrm{DP}} \tag{2}$$

where X_{nt}^{DP} and β^{DP} are vectors of explanatory variables and the corresponding parameters, respectively, and ν_n is an individual-specific error term that captures the effect of unobserved driver characteristics, such as aggressiveness and level of skill, on their desire to pass. It is constant for a given driver, and so introduces correlations between the observations obtained from a given driver. The model assumes that conditional on the value of this latent variable, the observations of a given driver are independent. α^{DP} is the parameter of ν_n, and $\epsilon_{nt}^{\mathrm{DP}}$ is a random error term.

Assuming that $\epsilon_{nt}^{\mathrm{DP}} \sim N(0, \sigma^{\mathrm{DP}})$, the desire to pass probability conditional on the value of ν_n is given by

$$P\left(\mathrm{DP}_{nt} = 1 \middle| \nu_n\right) = \Phi\left(\frac{X_{nt}^{\mathrm{DP}}\beta^{\mathrm{DP}} + \alpha^{\mathrm{DP}}\nu_n}{\sigma^{\mathrm{DP}}}\right) \tag{3}$$

where $\Phi(\cdot)$ is the cumulative normal distribution function. For identification of the model in estimation, σ^{DP} is normalized to 1.

Drivers who desire to pass evaluate the available passing gaps against their critical gap, which is the minimum acceptable gap. The driver passes the front vehicle if the available gap is acceptable (i.e., larger or equal to the critical gap) and does not pass if the gap is rejected:

$$A_{nt} = \begin{cases} 1 & \text{if } G_{nt} \geq G_{nt}^{\mathrm{cr}} \\ 0 & \text{if } G_{nt} < G_{nt}^{\mathrm{cr}} \end{cases} \tag{4}$$

where A_{nt} is a choice indicator variable with value 1 if the gap is accepted and 0 otherwise. G_{nt} and G_{nt}^{cr} are the available passing gap and the critical passing gap, respectively.

Critical gaps are unobserved and therefore modeled as random variables. Their means are a function of explanatory variables. Critical gaps are modeled as random variables to capture the probabilistic nature of gap acceptance decisions. A logarithmic transformation is used to guarantee that critical gaps are always positive:

$$\ln\left(G_{nt}^{\mathrm{cr}}\right) = X_{nt}^{G}\beta^{G} + \alpha^{G}\nu_n + \epsilon_{nt}^{G} \tag{5}$$

where

X_{nt}^{G} and β^{G} = vectors of explanatory variable and the corresponding parameters,
α^{G} = parameter of ν_n, and
ϵ_{nt}^{G} = random error term.

Assuming that $\epsilon_{nt}^{G} \sim N(0, \sigma^{G})$, the probability that a passing gap is acceptable, conditional on ν_n is given by

$$P_n\left(A_{nt} = 1 \middle| \nu_n\right) = \Phi\left[\frac{\ln\left(G_{nt}\right) - X_{nt}^{G}\beta^{G} + \alpha^{G}\nu_n}{\sigma^{G}}\right] \tag{6}$$

The details of the likelihood function used in estimating the parameters of this model were given by Farah and Toledo (*28*).

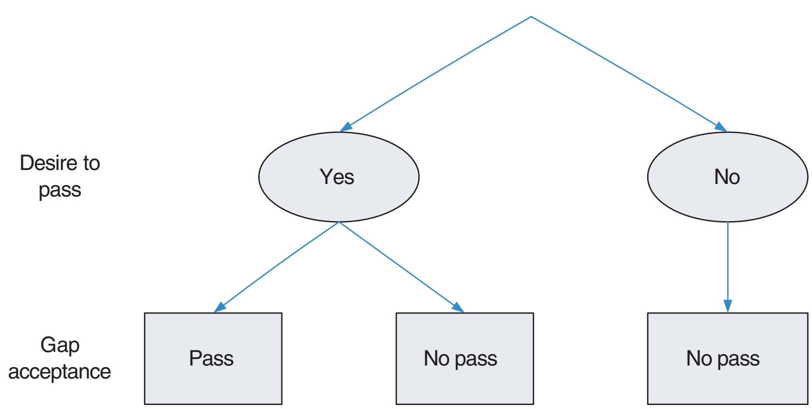

FIGURE 1 Structure of passing model.

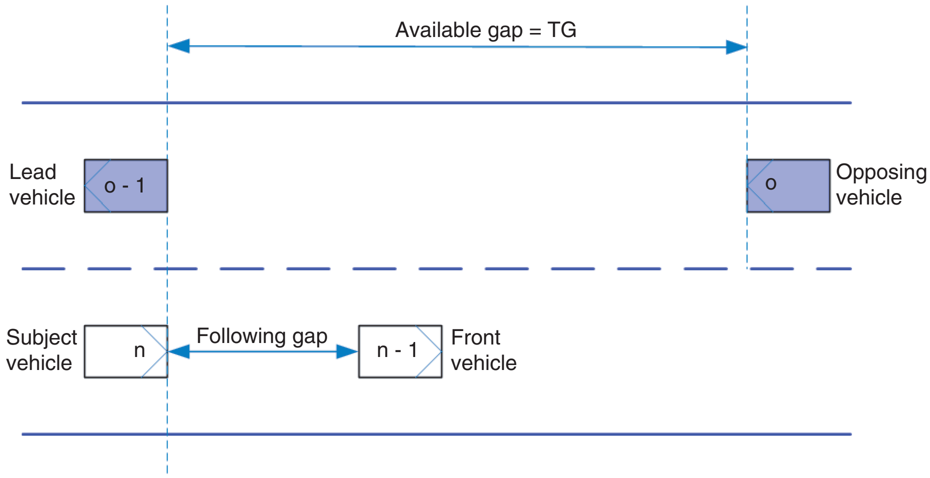

FIGURE 2 Opposing lane TG definition of passing gaps.

DEFINITIONS OF PASSING GAP

Three definitions of passing gap are proposed in this study. The first, which is the one commonly used in the literature, defines the available passing gaps as the time gap (TG) between two consecutive vehicles in the opposing lane measured at the time the subject vehicle passes the lead vehicle in the opposing lane, as shown in Figure 2.

$$\mathrm{TG} = \frac{X_{o,o-1}}{V_o} \tag{7}$$

where $X_{o,o-1}$ equals the distance between the lead vehicle and the opposing vehicle and V_o equals the speed of the opposing vehicle.

The second definition uses the TG between the opposing vehicle and the vehicle in front of the subject at the time the subject vehicle and the lead vehicle in the opposing lane pass each other, as illustrated in Figure 3. This definition defines the time for maneuver completion (TFMC) before the opposing vehicle and the front vehicle pass each other.

Mathematically, the TFMC is calculated by

$$\mathrm{TFMC} = \frac{X_{o,n-1}}{V_o + V_{n-1}} \tag{8}$$

where $X_{o,n-1}$ is the distance between the front vehicle and the opposing vehicle and V_{n-1} is the speed of the front vehicle.

The third definition uses the time to collision (TTC) between the opposing vehicle and the subject vehicle at the time the subject vehicle and the lead vehicle in the opposing lane pass each other. This gap is illustrated in Figure 4. It is calculated by

$$\mathrm{TTC} = \frac{X_{o,n}}{V_o + V_n} \tag{9}$$

where $X_{o,n}$ is the distance between the subject vehicle and the opposing vehicle and V_n is the speed of the subject vehicle.

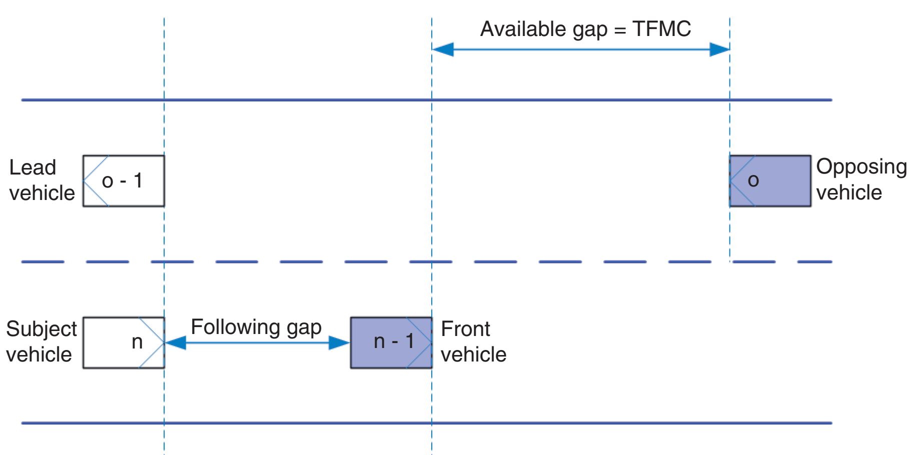

FIGURE 3 Time for maneuver completion (TFMC) definition of passing gaps.

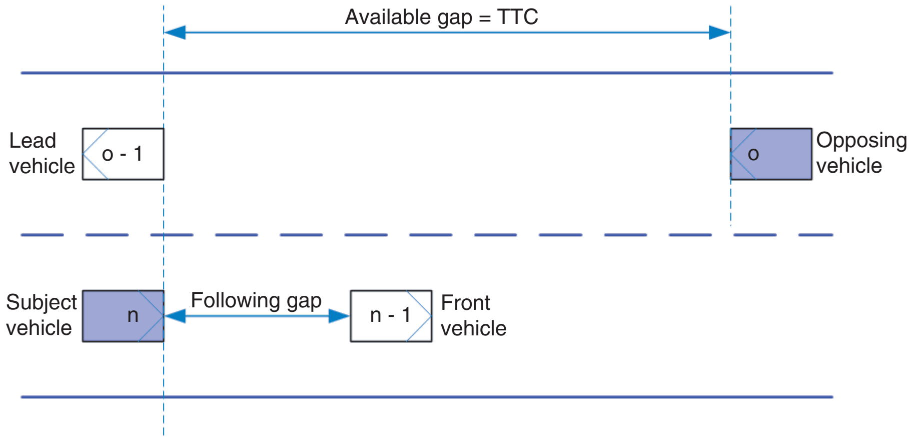

FIGURE 4 TTC definition of passing gaps.

DATA

Laboratory Experiment

A laboratory experiment that uses a driving simulator was developed to collect data on drivers' passing behavior. The simulator used in this experiment, STISIM (*29*), is a fixed-base interactive driving simulator, which has a 60° horizontal and a 40° vertical display. The changing alignment and driving scene, as observed from the driver's point of view, were projected onto a screen in front of the driver. The simulator updates the images at a rate of 30 frames per second.

To capture the impact of various infrastructure and traffic factors on passing behavior, a number of simulator scenarios were designed. The experiment design included four factors. The choice of these factors was based on previous studies that showed their impact on passing decisions. Two levels were used for each factor. The factors and their values are presented in Table 1. In addition to these factors, the type of the lead and the type of the opposing vehicle (truck or passenger car) were considered to facilitate their inclusion in the passing model. The vehicle type was randomly set for each vehicle in each scenario run, and so participants in the experiment encountered both types of vehicles.

A full factorial design with these factors, which produces 16 (2^4) scenarios, was used. Following Farah et al. (*25*), it was decided that participants would complete four scenarios, which take about 40 min. The partial confounding method was used to allocate the block of scenarios each participant would complete (*30*). This method was designed to maintain identification of the main and lower-level interaction effects of the various factors. In the design of this experiment, third-level interactions were confounded.

All scenarios in the experiment included 7.5-km two-lane highway sections with no intersections and level terrain. Daytime and good weather conditions allowed good visibility. Drivers were instructed to drive as they would normally drive in the real world. As in previous studies, drivers were given between 5 and 10 min to become familiar with the simulator (*24, 31*).

TABLE 1 Factors Included in Experimental Design

	Level	
Factor	High	Low
Geometric design[a]	Curve radius: 1,500–2,500 m	Curve radius: 300–400 m
Gaps in opposing lane[b]	Mean: 10.3 s Min: 5.0 s, max: 25.0 s	Mean: 18.0 s Min: 9.0 s, Max: 31.0 s
Speed of lead vehicle[c]	67% between 80 and 120 km/h 33% between 40 and 80 km/h	33% between 80 and 120 km/h 67% between 40 and 80 km/h
Speed of opposing vehicle[d]	67% between 80 and 120 km/h 33% between 40 and 80 km/h	33% between 80 and 120 km/h 67% between 40 and 80 km/h

[a]Lane width: 3.75 m, shoulder width: 2.25 m.
[b]Drawn from truncated negative exponential distributions.
[c]Drawn from uniform distributions.
[d]Drawn from uniform distributions.

Participants

One hundred drivers (69 men, 31 women) who had had a driving license for at least 5 years and who drove on a regular basis participated in the experiment. The age of the participants ranged between 21 and 61 years, with a mean of 32.7 years and standard deviation of 9.8 years.

Data Collection

The simulator collected data on the longitudinal and lateral position, speed, and acceleration of the subject vehicle and all other vehicles in the scenario at a resolution of 0.1 s. From these raw data, other variables of interest, such as the time and location of passing maneuvers, distances between vehicles, and relative speeds, were calculated. The resulting data set included a total of 14,654 passing gap observations. In 696 (4.7%) of these gaps, the drivers completed passing maneuvers.

TABLE 2 Estimation Results for Two-Stage Passing Gap Acceptance Models

	TG Model		TFMC Model		TTC Model	
	Coeff.	*t*-Test	Coeff.	*t*-Test	Coeff.	*t*-Test
Null log likelihood	−2,056.75		−2,056.75		−2,056.75	
Maximum log likelihood	−1,300.54		−1,323.08		−1,298.45	
Desire to Pass Function						
Constant	−0.534	−4.41	−0.379	−2.84	−0.534	−4.47
(Desired speed – front speed) (m/s)	0.065	7.94	0.068	6.42	0.065	7.89
Following gap (m)	−0.016	−17.6	−0.015	−15.5	−0.016	−17.6
Cumulative distance (km)	0.014	2.29	0.021	2.87	0.015	2.42
α^{DP}	0.497	6.84	0.387	3.49	0.472	6.53
Gap Acceptance Function						
Constant	3.726	37.0	3.053	23.2	2.990	30.2
σ^G	−1.261	−19.1	−0.870	−16.7	−1.289	−18.7
α^G	−0.196	−5.25	−0.274	−4.90	−0.206	−5.87
Subject speed (m/s)	−0.018	−4.37	−0.032	−6.84	−0.039	−9.98
Lead vehicle speed (m/s)	0.036	6.19	0.029	3.92	0.032	5.57
Opposing vehicle speed (m/s)	−0.036	−13.0	−0.006	−1.89	−0.007	−3.09
Road curvature (1/km)	0.108	11.2	0.115	9.93	0.104	10.9
Type of lead vehicle (1 = truck, 0 = private)	0.094	2.31	0.070	1.44	0.072	1.82
Age between 21 and 25	−0.142	−2.10	−0.333	−2.13	−0.156	−2.29

NOTE: Coeff. = coefficient.

RESULTS

Table 2 presents the estimation results of three passing gap acceptance models based on the three definitions of the available passing gaps described earlier.

All three models showed similar impact for the explanatory variables in signs and relative magnitudes. The TTC model had the best fit to the data, as indicated by its having the highest maximum log likelihood value. To compare the alternative models, a test of nonnested hypothesis developed by Horowitz was conducted (*32*). Ben-Akiva and Swait showed that when comparing two competing models, under the null hypothesis that the model with the lower fit is the correct one, the probability of wrongly choosing the other model based on its higher fit is asymptotically (*33*)

$$\Pr\left(\bar{\rho}_B^2 - \bar{\rho}_A^2 > z\right) \le \Phi\left\{-\left[-2z\mathrm{L}\left(0\right) + \left(K_B - K_A\right)\right]^{\frac{1}{2}}\right\} \qquad z > 0 \qquad (10)$$

where

$\bar{\rho}_A^2$ and $\bar{\rho}_B^2$ = adjusted likelihood ratio indices for the models with higher and lower fit, respectively;
K_A and K_B = numbers of parameters in the two models;
L(0) = null log likelihood value; and
Φ = standard normal cumulative distribution function.

The probability that the adjusted likelihood ratio index of Model A is greater by some $z > 0$ than that of Model B, given that the latter is the true model, is asymptotically bounded above by the right-hand side of Equation 10. Table 3 summarizes the results of the comparison between the models. The number of parameters in all models is 14. The model that uses the TTC definition outperforms the other two models. The difference in likelihood value and goodness of fit with the TG model, which is based on the gap definition commonly used in the literature, is not large. Nevertheless, the calculated probability of making a mistake in choosing the TTC model as the best model among the three is very low.

The results of the TTC model indicate that the desire to pass is affected by the difference between the desired speed of the subject driver and the current speed of the vehicle in front. This variable captures the extent that the front vehicle imposes a constraint on the speed of the subject vehicle. In the data, the desired speed for each driver was calculated as the mean speed of the vehicle in the sections where it was not close to the vehicle in front. As expected, the value of the coefficient of this variable is positive, which indicates that drivers are more likely to attempt to pass when the vehicle in front is slower relative to their desired speed. Similarly, the desire to pass is higher when the distance between the subject and the front vehicle decreases.

The collection of driving simulator data may lead to biases in the behavior. For example, simulator drivers may be indifferent or become tired with the experiment as it progresses and so may modify

TABLE 3 Summary of Tests of Nonnested Hypotheses

Model A	Model B	$\bar{\rho}_A^2$	$\bar{\rho}_B^2$	$\Pr(\bar{\rho}_B^2 - \bar{\rho}_A^2 > z)$	Selected Model
TG	TFMC	0.361	0.349	1e-012	TG
TTC	TG	0.362	0.361	0.0212	TTC
TTC	TFMC	0.362	0.349	1e-013	TTC

their behavior. The cumulative distance variable, which is defined as the total distance the subject has driven from the beginning of the experiment to the measurement point, aims to correct this effect. It has a small, but significant, positive effect on the desire to pass probability. Thus, the desire to pass increases as the experiment progresses, possibly so that the subject completes the task sooner. This variable intends to correct biases in the experiment and therefore should be omitted from the model when it is applied for prediction.

The passing gap acceptance decisions are most affected by variables related to the subject vehicle and the other relevant vehicles: front and opposing vehicles. These variables include the size of the available gap, the speed of the subject, and the speeds of the front and opposing vehicles. Critical gaps decrease when the speed of the subject is higher. This is intuitive because it is easier to complete the passing maneuver when the subject is driving faster as it requires less time. In contrast, critical gaps increase when the speed of the front vehicle is higher. Furthermore, the coefficients of the subject vehicle speed (−0.039) and of the front vehicle speed (0.032) are close but with opposite signs. This indicates that the critical gaps are affected by the relative speed between the subject vehicle and the front vehicle. Critical gaps decrease when the speed of the opposing vehicle increases. This appears counterintuitive. However, both the available and the critical gap is measured in time units, and so both are affected by the speed of the opposing vehicle. Everything else being equal, a higher speed of the opposing vehicle results in smaller critical gap but also reduces the available gap. Overall, the results indicate that critical gaps decrease with the speed of the opposing vehicle in time but increase in distance. The type of front vehicle also affects the critical gaps. It is larger for trucks, which obscure the field of vision and pose a higher safety risk, compared with passenger cars.

The geometric design of the road also affects passing behavior. In this model, this is captured by road curvature. As expected, critical gaps are smaller in roads with high design standards (large curve radii) compared with those with lower standards (small curve radii). Thus, the probability to accept a passing gap is higher in roads with large curve radii.

Critical passing gaps vary substantially with driver characteristics. The gaps are significantly smaller for younger drivers than for older drivers. This result is consistent with previous studies that found that young drivers tend to behave more aggressively and take more risks (*34*). Gender of drivers was not found to be statistically significant in this study.

The individual-specific error term ν_n, which captured latent driver characteristics, was statistically significant in both parts of the model. The parameters of this term were positive in the desire-to-pass model and negative in the gap acceptance model. This result is consistent with an interpretation of this term as representing aggressiveness and level of skill. Aggressive drivers (with high ν_n values) are more likely to desire to pass, and when they do they have lower critical gaps compared with timid drivers.

The usefulness of the generic model structure was examined through a comparison with a simpler model that included only a single-step gap acceptance decision. The likelihood value at convergence of this model was 1670.78 with nine parameters. The simpler model can be viewed as a restricted case of the generic model structure with the probability of the desire to pass set at 1. Therefore, a likelihood ratio test can be conducted. The test statistic is 744.66. It is distributed χ^2 with 5 degrees of freedom, which supports adopting the two-stage model and rejecting the simpler model.

SUMMARY AND CONCLUSIONS

This study investigated alternative definitions for passing gaps on two-lane highways. Three definitions of passing gaps were proposed. The first defines the available passing gaps as the TG between two consecutive vehicles in the opposing lane measured at the time the subject vehicle passes the lead vehicle in the opposing lane; the second definition uses the TG between the opposing vehicle and the vehicle in front of the subject at the time the subject vehicle and the lead vehicle in the opposing lane pass each other; and the third definition uses the TTC between the opposing vehicle and the subject vehicle at the time the subject vehicle and the lead vehicle in the opposing lane pass each other. Three passing gap acceptance models were developed and estimated on the basis of these definitions for passing gaps. These models were composed of two steps: the desire-to-pass step and the gap acceptance step. Therefore, the probability to complete a passing maneuver was modeled as the product of the probabilities of a positive decision on both these choices. To estimate these models, data on passing maneuvers were collected with an interactive driving simulator in a laboratory environment. Sixteen scenarios were used to capture the impact of factors related to the vehicles involved, the road geometry, and the driver characteristics in the model.

A comparison of the results of the three models showed that the model that uses the TTC between the opposing vehicle and the subject vehicle has the best fit to the data for maximum log likelihood value and the test of nonnested hypothesis.

In all three models, it was found that the desire-to-pass step makes a statistically significant contribution to explaining drivers' passing behavior and decisions beside the gap acceptance step. These two steps together better explain the passing procedure versus a single-step procedure, which accounts only for the gap acceptance decisions.

All three models showed similar impact for the various explanatory variables in signs and relative magnitudes. The results indicate that the variables that capture both the impact of the attributes of the specific passing gap that the driver evaluates (e.g., passing gap size, speed of the subject vehicle, and the following distance it keeps from the vehicle in front), the horizontal curvature of the specific road section and the personality characteristics of the driver (e.g., gender, age) significantly affect passing behavior. Also the individual-specific error term that captures latent driver characteristics was statistically significant in both parts of the model.

Although the results reported here are promising, this work has limitations that merit further research in several directions. Perhaps the most important limitation is that the model estimation used only data from a driving simulator. Driving simulator data may be subject to biases in the perception of the situation and risks, which may lead to biased estimates of the behavior. For example, driver perception of speeds and distances may be affected by the video resolution and the realism of the image. Furthermore, driving in a simulator does not involve the risks associated with real-world driving. Jenkins et al. pointed out differences in passing behavior in a driving simulator compared to the real world (*22*). They found that simulator drivers tend to underestimate distances. Similar results were reported by Baumberger et al. (*35*) and Farah et al. (*36*). The latter also reported that the mean remaining headway to the opposing vehicle at the end of the passing maneuver in the simulator was approximately half that observed in the field, indicating that drivers are willing to accept higher risks in the simulator. Thus, it appears plausible that the results reported here overestimate passing probabilities and underestimate critical gap values. It is therefore important to validate the results with field observations to eliminate biases resulting from the use of a simulator. Unfortunately, detailed data on passing behavior are difficult to collect because of the spatial extent of the locations where these maneuvers may take place. Aggregated data on vehicle passage times at various points in a section of road, which are more readily available, may also be used for this purpose.

The effect of the geometric design on passing behavior was captured only through the road curvature. This is partly because important design parameters, such as those related to the quality of the pavement, sight distances, or roadside features, are difficult to model and to perceive in the simulator. Again, real-world data are needed to enhance the models in this direction. In addition to an improved understanding of driver behavior, the intended practical application of the model presented in this paper is in the framework of traffic simulation models. This would require additional extensions to handle situations, such as aborted passing maneuvers and overtaking multiple vehicles in a single pass. Finally, car crashes are an important problem on two-lane highways. Safety indicators related to passing maneuvers need to be developed, and the impact of geometric, traffic, and driver characteristics on the risk and severity of car crashes in these roads need to be further studied.

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The Traffic Flow Theory and Characteristics Committee peer-reviewed this paper.