

Investigation of Influential Variables to Predict Passing Rate at Short Passing Zones on Two-Lane Rural Highways

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1 **Investigation of Influential Variables to Predict Passing Rate at Short**
2 **Passing Zones on Two-Lane Rural Highways**

3

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16

17 **Abstract**

18 The passing zone (PZ) is that part of two-lane highways in which drivers can safely overtake
19 slower vehicles. Several studies have presented passing rate models in the PZ. However, there is
20 no model to predict the passing rate in PZs shorter than 350 m. Furthermore, the effect of variables
21 such as lane width, and the proportion of motorcycles on the passing rate were not investigated in
22 previous works. This study assessed the effects of these variables on the passing rate and present
23 a prediction passing model for short PZs. Data were collected from seven PZs using a drone on
24 three different two-lane rural highway segments in Iran. The results showed that the passing rate
25 depends on the lane width, absolute vertical grade, the flow rate in both directions, directional
26 split, the proportion of heavy vehicles in the subject direction, and the proportion of motorcycles
27 in the subject direction. Short PZ length values did not have a significant effect on the passing rate.
28 The passing capacity occurred at a flow rate of 680 veh/h in both directions irrespective of the
29 directional split.

30

31 **Keywords:** passing rate, short passing zone, two-lane rural highway, lane width, the proportion of
32 motorcycles.

33 **1. Introduction**

34 On two-lane highways, faster vehicles are forced to follow slow vehicles until they reach a stretch
35 of road which provides a passing opportunity, which depends on a gap in oncoming traffic and
36 sight distance. The passing zone (PZ) provides a sight distance value which is sufficient for passing
37 maneuvers. Where many passing maneuvers are possible, the traffic operation performance will
38 improve. Passing demands and passing capacity (maximum passing rate) have a considerable
39 impact on operation and driver perception of service. The passing rate indicates the number of
40 passing maneuvers conducted in an hour by vehicles travelling in the same direction on a two-lane
41 road.

42 *The Highway Capacity Manual (HCM) (TRB, 2010)* used the percent time spent following
43 (PTSF) as a surrogate measure for passing demand to measure the operating performance of
44 two-lane rural highways. However, HCM does not use the passing rate in the operation analysis
45 because of the lack of comprehensive studies in this area. Passing rate modelling requires accurate
46 observational field data: each individual vehicle needs to be constantly monitored while engaged
47 in passing maneuvers. Hence, field data are difficult to collect due to the considerable length of
48 PZs. For example, Mwesige, et al. (2016) used pneumatic tubes and camcorders mounted on
49 tripods placed by the roadside along the PZ. Moreno, et al. (2013) used a mobile traffic laboratory
50 which was equipped with six digital video cameras installed on an elevated platform.

51 Harwood, et al. (2008) presented two categories for the PZs: short PZs (PZ lengths shorter
52 than 240 m) and long PZs (PZ lengths equal to 300 m or more). Using traffic simulation analysis,
53 they showed that very few passing maneuvers occurred in short PZs. Their field observations also
54 showed that only 0.4% of all vehicles made passing maneuvers in short PZs while 92% of passing
55 maneuvers ended in no-passing zones (NPZ). Hence, their conclusion that short PZs contribute

56 little to operational efficiency. However, they did not develop the passing rate prediction model
57 for PZs. While a few field studies investigated the passing rate models (Mwesige, et al., 2016,
58 Moreno, et al., 2013, Hegeman, 2008), none of them considered short PZs in their analysis.
59 Furthermore, the effects of two explanatory variables - lane width and proportion of motorcycles
60 on the passing rate - were not investigated in previous works.

61 To address this gap in knowledge, this study has investigated the effects of geometry and
62 traffic-related variables, including the lane width and proportion of motorcycles, on the passing
63 rate in PZs shorter than 350 m. Videos of vehicles involved in passing maneuvers were collected
64 along short PZs using a drone. Video analyses were carried out to obtain independent variables
65 that were then used to develop a first passing rate model for those maneuvers ending in the PZ
66 (i.e., PZ-PZ and NPZ-PZ), and a second passing rate model for those which both start and end in
67 the PZ (i.e., PZ-PZ). The two models are appropriate for countries where it is legally accepted that
68 passing maneuvers may start in the NPZ and end in the PZ (NPZ-PZ), and to countries where they
69 must start and end in the PZ (PZ-PZ) (Mwesige et al., 2016).

70 The manuscript is organized as follows: Section 2 presents a literature review on passing
71 frequency along PZs; Section 3 explains how to model the passing rate statistically and also
72 introduces the study sites and data collection method; Section 4 provides the results of the study,
73 while the discussion of the results is presented in Section 5; Section 6 provides the main findings
74 and addresses implications, recommendations, and future work needs.

75

76 **2. Background**

77 Wardrop (1952) offered a theoretical model to estimate passing demand from the speed
78 distribution while assuming an ideal situation with no opposing traffic and no passing sight

79 limitations. He used eq.(1) to calculate the number of passing maneuvers per kilometer per hour
80 (P_n):

$$81 \quad P_n = 5.6 \left(\frac{V_S^2 \cdot \sigma_s}{\bar{\mu}_s^2} \right) \quad (1)$$

82 where V_S is traffic flow in the subject direction [veh/h], $\bar{\mu}_s$ is the average of space mean speeds
83 [km/h] and σ_s is the standard deviation of space mean speed [km/h].

84 Daganzo (1975) developed a theoretical negative exponential passing rate model based on
85 traffic flow in both directions to consider the reduction in passing opportunities due to oncoming
86 traffic. He assumed that traffic flow and speed values were the same in both directions.

87 McLean (1989) proposed a formula for passing opportunities which used both oncoming
88 traffic and sight distance limitations as follow:

$$89 \quad P(o.t) = P(g > 30) \times P(road) \quad (2)$$

90 where $P(o.t)$ is the probability of an overtaking opportunity, $P(g > 30)$ is the proportion of time in
91 which there is a gap larger than the critical gap (30 s), and $P(road)$ is the proportion of road length
92 which is suitable for passing. In McLean's method, a passing maneuver is possible when the
93 opposite gap is larger than 30 s (critical gap). He calculated $P(g > 30)$ as a function of the proportion
94 of following vehicles and mean free headway. McLean (1989) determined $P(road)$ as a function
95 of percentage of PZs length along the road segment, frequency of NPZs, and speed of traffic flow.

96 Dommerholt and Botma (1988) attempted to capture both passing opportunities and
97 passing demand for the development of a passing rate model. They developed the theoretical
98 passing rate as a function of the standard deviation of the speed and the density of vehicles. To
99 calculate the *expected number of overtaking maneuvers*, they reduced the theoretical passing rate
100 using the probability that the passing maneuver was possible. To verify their proposed model,

101 Dommerholt and Botma (1988) investigated six locations. Real passing rates were lower than the
 102 values obtained from the Dommerholt and Botma equation. To reduce the theoretical passing rate,
 103 they took the following two factors into account: (1) that the passing maneuver does not occur if
 104 the speed difference between the lead and following vehicles is below a threshold value, and (2)
 105 that the passing rate reduces linearly with increasing mean platoon length for traffic flows above
 106 400 veh/h.

107 More recently, Tuovinen and Enberg (2006) developed separate linear regression models
 108 for individual road segments in order to estimate passing rates. One-way traffic flows were used
 109 as the only predictor variables in the quadratic form. Hegeman (2008) studied passing maneuvers
 110 along two road segments, one of which had a passing prohibition. This prohibition was applied
 111 according to the Dutch Sustainable Safety Program (Wegman and Aarts, 2006), which suggested
 112 the prohibition of passing maneuvers as a means to improve safety. Hegeman (2008) developed a
 113 multivariate linear regression model to estimate passing rates based on subject and oncoming flow
 114 rates:

$$115 \quad OF = 1.6 \times 10^{-11} \times V_s^{1.5} (1700 - V_o)^{2.5} \quad (3)$$

116 where OF is the passing rate per kilometer per hour, V_s is traffic flow in the analysis direction
 117 [veh/h], V_o is traffic flow in the opposite direction [veh/h].

118 Moreno, et al. (2013) developed a Poisson regression model such as that in Equation (4) to
 119 predict the passing frequency in the subject direction for a 15-min period (PF):

$$120 \quad PF = \exp \left(\begin{array}{l} -4.57904 - 0.00125 \cdot V^2 - 0.0000013 \cdot L_{PZ}^2 \\ + 2.75645 \cdot D_s + 0.04093 \cdot V + 0.003455 \cdot L_{PZ} \end{array} \right) \quad (4)$$

121 where V is the two-way traffic volume for a 15-min period [veh/h], L_{PZ} is the length of PZ [m],
 122 and D_s is the directional split in the subject direction. They used two different road segments with

123 different lengths of PZ in two directions and used 114 periods of 15 min per passing zone to
124 develop their model. The maximum passing rate occurred at a two-way traffic volume between
125 600 and 700 veh/h for all PZs.

126 Mwesige, et al. (2016) proposed a model to predict the passing rate per hour (P) in the
127 subject direction at PZs based on traffic and geometric parameters as follows:

$$128 \quad P = \exp \left(\begin{array}{l} -5.089 + 1.123 \cdot L_{PZ} - 0.1948 \cdot L_{PZ}^2 + 0.09951 \cdot V_G \\ + 0.01917 \cdot V - 0.00002401 \cdot V^2 + 0.008177 \cdot S_{85} \\ + 0.0376 \cdot D_S + 0.05555 \cdot P_{HV} + 0.0008065 \cdot P_{HV}^2 \end{array} \right) \quad (5)$$

129 where L_{PZ} is the length of PZ [km], V_G is the absolute vertical grade [%], V is the total traffic
130 volume in the two travel directions [veh/h], S_{85} is the 85th percentile speed [km/h], D_S is the
131 directional split in the subject direction, and finally P_{HV} is the proportion of heavy vehicles.

132 Mwesige, et al. (2016) used a total of 96 observations to estimate their models. They found
133 that by increasing the percentage of heavy vehicles, the passing rate rose, then reached a peak of
134 35% before falling back. Based on their model, passing capacity occurred at the two-way volume
135 of 400 veh/h. Other variables including the length of PZ, absolute vertical grade, and directional
136 split in the subject direction were significant at the 95% confidence level. The 85th percentile speed
137 was significant at the 90% confidence level. Table 1 presents a list of the above-mentioned studies
138 and their corresponding contributions (e.g., explanatory variables) and shortcomings.

139 A number of field studies were conducted to find the influential variables on the passing
140 rate in PZs. No study presented a passing rate prediction model for short PZs. Furthermore, the
141 effects of both the proportion of motorcycles and lane width variables have yet to be investigated.

142

143 **3. Objectives, methodology, and data collection**

144 **3.1 Objectives**

145 This research aims to determine the effects of geometric (i.e., short PZ length, lane width) and
146 traffic-related variables (i.e., the proportion of motorcycles) on the passing rate and the passing
147 capacity. This research used field data collected with a drone to develop models for predicting the
148 passing rate in the PZs. In particular, two models were developed: (i) Model 1 estimates the number
149 of passing maneuvers in 15 minutes ending in PZ (PZ-PZ and NPZ-PZ) in the subject direction,
150 while (ii) Model 2 estimates the number of passing maneuvers in 15 minutes which both start and
151 end in the PZ in the subject direction (PZ-PZ).

152

153 **3.1. Variables**

154 **3.1.1 Dependent variable**

155 In most cases, passing maneuvers that start and end in the PZ (PZ-PZ maneuvers) have sufficient
156 sight distance (Khoury and Hobeika, 2007). Passing maneuvers that begin in the NPZ and end in
157 the PZ (NPZ-PZ maneuvers) are more likely to be initiated near the beginning of the PZ (Mwesige,
158 et al., 2016). Harwood, et al. (2008) categorized them as *jumping*. Although drivers do not have a
159 passing sight distance sufficient to complete the entire passing maneuver, it should be enough to
160 reach the abreast position, at which point they can abort the maneuver if necessary. Hence, drivers
161 have a sight distance which is sufficient for the risk evaluation of passing maneuvers ending in the
162 PZ (PZ-PZ and NPZ-PZ). However, many countries legally accept only those maneuvers that start
163 and end in the PZ (PZ-PZ), while others accept both cases (Mwesige, et al., 2016).

164 In light of the above, two dependent variables were considered: (i) the number of passing
165 maneuvers ending in the PZ in the subject direction, and (ii) the number of passing maneuvers
166 starting and ending in the PZ in the subject direction.

167

168 **3.1.2 Explanatory variables**

169 Explanatory variables were derived from both theoretical and field observation models described
170 in the Background section; however, some additional variables expected to be influential were also
171 examined.

172 Variables were categorized into two groups: (i) geometry-related variables like PZ length,
173 upstream NPZ length, absolute vertical grade, and lane width, and (ii) traffic-related variables like
174 traffic flow rate in both directions, traffic flow rate in the subject direction, traffic flow rate in the
175 opposite direction, directional split of traffic volume, proportion of heavy vehicles, proportion of
176 motorcycles, mean free-flow speed, standard deviation of free-flow speed, and 85th percentile of
177 free-flow speed.

178

179 **3.2. Statistical analysis**

180 The number of passing maneuvers takes only non-negative integer values. Thus, in this case, the
181 count data models provide an appropriate framework for estimating the number of passing
182 maneuvers. Poisson regression is the most popular method for modeling count data. In the Poisson
183 regression model, the probability of observation i -th having y_i completed passing maneuvers in
184 15-min, is given by:

$$185 \quad P(y_i) = \frac{\exp(-\lambda_i)\lambda_i^{y_i}}{y_i!} \quad (6)$$

186 where λ_i is the Poisson parameter, which is equal to the number of expected passing maneuvers
 187 for a i -th 15-min. One of the properties of a Poisson distribution is that the mean of the counting
 188 process equals its variance. The Poisson regression model is estimated by specifying λ_i as a
 189 function of explanatory variables, as shown in:

$$190 \quad \lambda_i = E[y_i] = VAR[y_i] = \exp(\beta X_i) \quad (7)$$

191 where X_i is the vector of explanatory variables, and β is the vector of estimable parameters from
 192 observed data. This model was estimated using the standard maximum likelihood method. The
 193 likelihood function computed for all observations is:

$$194 \quad L(\beta) = \prod_i \frac{\exp[-\exp(\beta X_i)] [\exp(\beta X_i)]^{y_i}}{y_i!} \quad (8)$$

195 The equality between mean and variance represents a limitation in the case of
 196 over-dispersed data (i.e., when the variance is greater than the mean). In many studies, the omitted
 197 variables are the main reason for overdispersion (Washington, et al., 2010). Overdispersion leads
 198 to inflation in estimated standard errors of estimated parameters, but it does not affect the
 199 magnitude of estimated parameters (Cameron and Trivedi, 2013). The Negative Binomial model
 200 is able to account for overdispersion, which is derived by rewriting Equation (7) into Equation (9)
 201 :

$$202 \quad \lambda_i = \exp(\beta X_i + \varepsilon_i) \quad (9)$$

203 where $\exp(\varepsilon_i)$ is the disturbance term, which has a Gamma distribution with mean one and variance
 204 α . This term makes it possible to have a variance different from the mean, as shown in:

$$205 \quad VAR[y_i] = E[y_i] + \alpha E[y_i]^2 = \lambda_i + \alpha \lambda_i^2 \quad (10)$$

206 where α is the overdispersion parameter. When α is zero, the negative binomial and Poisson models
 207 are the same, therefore the choice between these two models depends on the value of α . The
 208 Negative Binomial probability distribution is:

$$209 \quad P(y_i) = \frac{\Gamma((1/\alpha) + y_i)}{\Gamma(1/\alpha) y_i!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_i} \right)^{1/\alpha} \left(\frac{\lambda_i}{(1/\alpha) + \lambda_i} \right)^{y_i} \quad (11)$$

210 where $\Gamma(\cdot)$ is the Gamma function. The parameters of the negative binomial model were able to be
 211 estimated using again the maximum likelihood method (Cameron and Trivedi, 2013).

212 In this study, the passing rate data were obtained from seven PZs along three different
 213 two-lane rural highways. Therefore, there may be a correlation among observations in each PZ
 214 because the data from each PZ may share unobserved effects. Random effects models should be
 215 considered to account for correlations of observation in each PZ. Random effects may be
 216 considered in count data models based on:

$$217 \quad Ln(\lambda_{ij}) = \beta X_{ij} + \eta_j \quad (12)$$

218 where λ_{ij} is the expected number of completed passing maneuvers for the i -th 15-min belonging to
 219 j -th PZ, X_{ij} is a vector of explanatory variables, β is a vector of corresponding parameters, and η_j
 220 is a random effect for observations of the j -th PZ. Based on this specification, the random-effects
 221 Poisson model is:

$$222 \quad P(y_{ij} | X_{ij}, \eta_j) = \frac{\exp[-\exp(\beta X_{ij}) \exp(\eta_j)] [\exp(\beta X_{ij})]^{y_{ij}}}{y_{ij}!} \quad (13)$$

223 It is assumed that η_j is randomly distributed across groups (PZs) such that $\exp(\eta_j)$ has
 224 Gamma distribution with mean one and variance ϕ . For the random-effect Poisson model, the mean
 225 value is not equal to the variance, and the variance to mean ratio is $1 + \lambda_{ij}/(1/\phi)$. If ϕ is zero, the
 226 random-effects and pooled (Poisson) models are not significantly different. The random-effects

227 Negative Binomial model can be derived using the same approach as above for the random-effects
228 Poisson model, which was described by Hausman, et al. (1984).

229 In this paper, the presence of overdispersion and correlation among observations was
230 examined, then the appropriate model was chosen to estimate the passing rate.

231

232 **3.3. Study sites and data collection**

233 Data were collected from seven PZs on three different two-lane rural highways in Iran
234 (Jiroft-Faryab, Jiroft-Baft, and Jiroft-Kerman highways). All passing zones were along straight
235 sections and almost constant vertical grades. Table 2 presents the geometric characteristics and
236 posted speed limits for PZs. PZ length varied from 164 to 345 meters. Lane width was between 3
237 and 3.75 m, and the absolute vertical grade was between 0.5 to 9.5%. PZ n.7 (Table 1) is the only
238 one with a shoulder, which is paved. Figure 1 shows diagrams of the horizontal and vertical
239 alignment around the investigated sections.

240 Data were collected using a Phantom 4 Pro drone (Figure 2) equipped with a 1-inch
241 20-megapixel sensor capable of shooting 4K/60fps video and a 3-axis gimbal to stabilize the
242 camera oscillation. During video recording, the minimum altitude of the drone was 150 m to avoid
243 any impact on driver behavior. Data were collected during 38 flights lasting 15-20 minutes each.
244 The weather conditions during data collecting were clear and good.

245 Using road markings at the beginning of the PZs (their lengths were measured in the field)
246 and the timestamps of vehicles determined by using the open-source video analysis software
247 Kinovea (Charmant, 2016), vehicle speeds and time headways were calculated. The vehicle type
248 was visually recorded. Free-flow speeds were determined for passenger cars that were found to
249 operate in free-flow conditions based on at least 6 s headway (Al-Kaisy and Karjala, 2008).

250 Geometry variables such as lane width, vertical grade, and PZ length were measured in the field.

251 The hourly flow rate was calculated as the volume of vehicles in 15 minutes multiplied by four.

252

253 **4. Results**

254 Table 3 presents a summary of the observed variables at the PZs. The average number of passing

255 maneuvers ending in the PZ in the subject direction (N_{PZ}) was 5.0 passes per 15 minutes, reaching

256 a maximum value of 33 passes per 15 minutes. The average and maximum values of the number

257 of passing maneuvers starting and ending in PZ in the subject direction (N_{PPZ}) were 2.3 and 21,

258 respectively. The average of N_{PZ} was more than two times that of N_{PPZ} , which means that more

259 than half of the drivers ending their maneuver in PZ, started it from NPZ. The flow rate in both

260 directions had a range between 212 and 840 veh/h, with a directional split up to 80%, which

261 provides a suitable combination for analysis. The directional split equals 30% means ($V_S = 0.3V$,

262 and $V_O = 0.7V$). The proportion of motorcycles in the subject direction had a maximum value of

263 14%, which was a considerable one for rural highways. Mean free-flow speed for every 15 minutes

264 had an average of 85.3 km/h with an average standard deviation of 16.0 km/h. Based on the

265 explanatory variables presented in Table 3, the N_{PZ} and N_{PPZ} are estimated using count data models.

266 Table 4 presents a summary of the estimation of Models 1 (to estimate the N_{PZ}) and 2 (to
267 estimate the N_{PPZ}). To find a suitable model for estimating the passing rate, overdispersion in the
268 data and correlations among observations in each PZs were analyzed. Table 4 shows the results of
269 the likelihood ratio test for the overdispersion parameter (α): it illustrates that α is statistically
270 highly insignificant for both Model 1 (p -value = 0.500) and Model 2 (p -value = 0.379). This means
271 that α is equal to zero, i.e., there is no difference between the Negative Binomial and Poisson
272 models. Table 4 also shows that the random-effects parameter (ϕ) is highly insignificant for both
273 Model 1 (p -value = 1.00) and Model 2 (p -value = 1.00). These results imply that the parameter of
274 ϕ is statistically equal to zero, and there is no difference between the random-effects and pooled
275 (Poisson) models. Hence, the Poisson model was chosen to estimate the passing rate in this study.
276 The passing rate models were estimated using the *STATA* statistical software (StataCorp, 2017).
277 Different model forms using variables that were listed in Table 3 were estimated. In the following,
278 the results of model estimation for Models 1 and 2 are carefully described.

279

280 **4.1. Estimating N_{PZ} (Model 1)**

281 The overall significance of Model 1 was evaluated using the likelihood ratio test, which was
282 significant at the 95% confidence level ($\chi^2 = 226.73$, p -value < 0.0001). Deviance and Pearson
283 tests were conducted to assess the goodness-of-fit of the model. The insignificant test statistics
284 (p -value > 0.05) indicate that the model fits the data well. As additional descriptive measures of
285 goodness-of-fit, Cragg-Uhler R^2 (Cragg and Uhler, 1970) and McFadden's R^2 (McFadden, 1973)
286 were calculated (values equal to 0.950 and 0.418 respectively). These two statistics confirm that
287 the model fits the data well. Wald tests were carried out to identify significant variables which
288 were retained in the model.

289 Variables of the PZ length, upstream NPZ length, 85th Percentile free-flow speed, and
290 standard deviation of free-flow speed were statistically not significant at the confidence level of
291 90% and, therefore, removed from the model. However, the signs of the coefficients for these
292 variables were consistent with a priori expectation. The lane width was found to be highly
293 significant (p -value < 0.001). Its positive sign implies that an increase in lane width leads to an
294 increase in the passing rate. Table 5 shows that the average marginal effect of lane width on passing
295 rate at 15 min is equal to 7.47, which means that if the lane width increases by 0.2 m, N_{PZ} increases
296 by 6 passes per hour on average. The marginal effect of lane width increases by increasing its
297 value. The absolute vertical grade was statistically significant at the 95% confidence level (p -value
298 < 0.01). Based on its marginal effect reported in Table 5, each 1% increase in the absolute vertical
299 grade, the N_{PZ} increases by the hourly passing rate of 1.56 passes on average.

300 The flow rate in both directions (V) and its quadratic term had a significant effect at the
301 95% confidence level (p -values < 0.05). This variable has different effects based on its value.
302 Figure 3 illustrates the average marginal effects of flow rate in both directions on N_{PZ} for different
303 values of the flow rate. This figure shows that the positive marginal effect peaked at the flow rate
304 of 400 veh/h. The figure shows a sharp fall in the marginal effect of flow rate such that it was zero
305 at the flow rate of 680 veh/h. From this value, the effect of flow rate on N_{PZ} was negative, which
306 means that at an increased flow rate (greater than 680 veh/h), the passing rate decreased. The
307 directional split of traffic volume (D_S) was also a significant variable at the level of 0.001. With
308 an increase in D_S , the traffic in the subject direction increases and the traffic in the opposite
309 direction decreases, with the former resulting in an increase in the passing demand, and the latter
310 leading to an increase in passing opportunities. Another way to capture this effect in the models is
311 to use the two variables of the flow rate in the subject and flow rate in the opposite direction.

312 However, using flow rate and directional split variables presented better model results. The results
313 show that with a 10% increase in directional split for subject direction, the N_{PZ} increased by 6.8
314 passes per hour on average.

315 The proportions of heavy vehicles (P_{HVS}) and motorcycles (P_{MCS}) to traffic volume in the
316 subject direction were significant at the 95% and 90% confidence levels, respectively. The
317 marginal effect of the P_{MCS} is almost twice that of the P_{HVS} . A five percent increase in P_{HVS}
318 increased the N_{PZ} by 2 passes per hour on average. A five percent increase in P_{MCS} increases the
319 passing rate by 4.2 passes per hour.

320

321 **4.2. Estimating N_{PPZ} (Model 2)**

322 Model 2 was significant at the 95% confidence level ($\chi^2 = 84.488$, p -value < 0.0001). The results
323 of the Pearson goodness-of-fit test suggest the model performed well ($\chi^2 = 226.73$,
324 p -value = 0.099). However, the Deviance statistic was significant ($\chi^2 = 90.559$, p -value = 0.042).

325 The length of the PZ had a statistically significant effect on N_{PPZ} at the 95% confidence
326 level (p -value < 0.01). Table 6 indicates that the average marginal effects of the PZ length on N_{PPZ}
327 were 0.018, which means if the L_{PZ} increased 100 m, the N_{PPZ} increased by 7.2 passes per hour.
328 The variables L_W , V_G , and D_S were also statistically significant as they were for Model 1. Their
329 average marginal effects are presented in Table 6. Unlike Model 1, the two variables of P_{HVS} and
330 P_{MCS} were statistically insignificant at the 95% confidence level.

331

332 **5. Discussion**

333 The upstream NPZ length did not have a significant effect on the passing rate. Mwesige, et al.
334 (2016) reached a similar result on the effectiveness of the upstream NPZ length. They presented

335 four factors that could explain this result. The two variables of 85th percentile free-flow speed and
 336 standard deviation of free-flow speed, like the study of Mwesige, et al. (2016), were statistically
 337 not significant at the 95% confidence level.

338 According to previous works, PZ length is statistically significant (Mwesige, et al., 2016,
 339 Moreno, et al., 2013). However, in this study, the PZ length had a strongly insignificant effect on
 340 passing maneuvers ending in the PZ (N_{PZ}). The PZs that previous works studied were within the
 341 range of 290-2990 m (Mwesige, et al., 2016) and 256-1270 m (Moreno, et al., 2013), respectively.
 342 The PZs in this study ranged from 164 to 345 m, with most of them on the short side. The suspect
 343 is that almost all drivers were familiar with the highways; hence they were aware of the short
 344 length of the PZs and anticipated their maneuvers to complete them safely. The results presented
 345 in Table 3 show that the average number of NPZ-PZ maneuvers was higher than that for the PZ-PZ
 346 ones. However, if only the N_{PPZ} were considered, the PZ length was significant. It may be
 347 concluded that drivers (most of whom were familiar with the road) adjust the starting point of their
 348 passing maneuver so as to complete it safely before the NPZ.

349 A sensitivity analysis of Model 1 explanatory variables was conducted to see how an
 350 explanatory variable affected the passing rate. To present the 15-min passing frequency as an
 351 hourly passing rate, N_{PZ} and N_{PPZ} are multiplied by four as equation (14) and (15) illustrate:

$$352 \quad P_{PZ} = 4 \cdot N_{PZ} = 4 \cdot \exp \left(\begin{array}{l} -8.4586 + 1.4989 \cdot L_W + 0.0779 \cdot V_G + 0.00852 \cdot V - 6.28 \times 10^{-6} \cdot V^2 \\ + 0.03381 \cdot D_S + 0.02044 \cdot P_{HVS} + 0.04307 \cdot P_{MCS} \end{array} \right) \quad (14)$$

$$353 \quad P_{PPZ} = 4 \cdot N_{PPZ} = 4 \cdot \exp \left(\begin{array}{l} -12.31318 + 0.00786 \cdot L_{PZ} + 1.71082 \cdot L_W + 0.06994 \cdot V_G \\ + 0.01218 \cdot V - 10.2 \times 10^{-6} \cdot V^2 + 0.02636 \cdot D_S \end{array} \right) \quad (15)$$

354 Figure 4 produces for $V_G = 3.5\%$, $P_{HVS} = 8.56\%$, $D_S = 50$, $L_W = 3.45$, and $P_{MCS} = 0\%$ in
 355 equation (14), except the variables that change in each figure.

356 Figure 4a provides information on the change in the passing rate of maneuvers ending in
357 the PZ (P_{PZ}) for different values of the lane width at four different levels of the traffic flow rate
358 (200, 400, 600, and 800 veh/h). The results show that by increasing the lane width, the passing rate
359 increased. The marginal effect of lane width increased as the base value increased. For example,
360 adding 0.1 m to a lane with 3.6 m width (base value) has more effect on the passing rate than
361 adding 0.1 m to a lane with 3 m width. A wider lane width results in drivers taking more risks
362 because it provides more room for passing and helps to prevent opposing vehicles from colliding.
363 Furthermore, the marginal effect of lane width with respect to the flow rate is maximized at the
364 traffic flow rate equal to 680 veh/h. Lane width had a highly significant effect in both Model 1 and
365 Model 2. This variable was not evaluated in previous works because their PZs had the same lane
366 width.

367 Figure 4b shows the effect(s) of absolute vertical grade on P_{PZ} at traffic flow rate levels of
368 200, 400, 600, and 800 veh/h. Unlike previous studies (Mwesige, et al., 2016, Moreno, et al., 2013,
369 Hegeman, 2008) where sites were located on flat terrain, in this study the absolute vertical grade
370 had a wide range from 0.58 to 9.5%. The results show that absolute vertical grade had a positive
371 impact on the passing rate, and the impact had a peak respect to the traffic flow rate. The vertical
372 grade reduces the speed of heavy vehicles, which causes the platoons. To consider this impact,
373 HCM used an adjusted factor to calculate the demand flow rate (TRB, 2010).

374 Figure 4c shows the rise in the passing rate in the subject direction (P_{PZ}) caused by an
375 increase in the proportion of heavy vehicles in the subject direction (P_{HVS}). Mwesige, et al. (2016)
376 used the proportion of heavy vehicles in both directions (P_{HV}); however, this variable did not have
377 a significant effect on the P_{PZ} . As the percentage of heavy vehicles in the subject direction
378 increases, the number of platoons and their length grow, which increases the frustration and desire

379 of drivers behind to pass (Penmetsa, et al., 2015, Polus and Cohen, 2009). Hence, P_{HVS} better
380 explains the effect of the proportion of heavy vehicles on the passing rate in the subject direction
381 than the P_{HV} . By increasing the P_{HVS} , the platooning and PTSF will increase, which leads to an
382 increase in the demand for passing maneuvers. Drivers caught in a platoon behind slow vehicles
383 (heavy vehicles for example) will attempt to conduct more passing maneuvers. The ability to pass
384 is provided by the PZs if and when drivers find a gap in the opposite direction. Mwesige, et al.
385 (2016) showed that the passing rate increases with the P_{HV} to a peak at 35% and then decreases. In
386 this study, the highest levels of P_{HV} and P_{HVS} are 30.2 and 37.9%, respectively, and the results
387 show an increase in the passing rate with an increase in P_{HVS} consistently with Mwesige, et al.
388 (2016). The P_{HVS} did not have a significant effect on the number of passing maneuvers that start
389 and end in the NPZ (P_{PPZ}). It is for this reason that, as observed in the recorded videos, the platoon
390 discharges before the PZs, hence, most of the vehicles in the platoon start passing maneuvers in
391 the NPZ.

392 Figure 4d illustrates the effect of the proportion of motorcycles in the subject direction
393 (P_{MCS}) on the P_{PZ} . The figure indicates that the P_{PZ} increased as the proportion of motorcycles in
394 the subject direction increased. The reason for the increase in the passing rate is that the vehicles
395 needed shorter gaps to pass. Furthermore, motorcycles had lower speed (51 km/h on average) and
396 width and drove close to the road edge (for roads without shoulders) or to the shoulders, which
397 made it easier for drivers to pass them.

398 It should be noted that high-speed motorcycles are forbidden in Iran. Hence, this variable
399 might prove to be insignificant in other countries. In fact, in the study conducted by Hegeman
400 (2008), motorcycles accounted for less than 2% of traffic flow, and they did not consider this
401 variable in their model. Similarly, other previous studies did not evaluate the effect of the

402 proportion of motorcycles on the passing rate. Figure 5 illustrates the graphs of the passing rate in
403 the subject direction and the traffic flow rate in both directions. Figures 4 was produced for $V_G =$
404 3.5% , $P_{HVS} = 30\%$, $L_W = 3.5$ m, $L_{PZ} = 300$ m and $P_{MCS} = 0\%$. These values were selected so as to
405 be consistent with studies conducted by Mwesige, et al. (2016) and Moreno, et al. (2013) and make
406 it possible for comparing. The graphs of P_{PZ} were plotted at five directional split levels of 20, 50,
407 60, 70, and 80%.

408 The results show that the directional split has a significant effect on the passing rate as shown by
409 the fact that an increase in the directional split in the subject direction results in a similar increase
410 in the passing rate. The directional split also had a significant effect on the studies of Mwesige,
411 et al. (2016) and Moreno, et al. (2013). Hegeman (2008) employed both subject and opposite
412 traffic volumes in her model instead of using two-way traffic volume and directional splits. The
413 graphs of previous studies (Mwesige, et al., 2016, Moreno, et al., 2013, Hegeman, 2008) and
414 P_{PPZ} in Figure 5 were plotted for a directional split of 50%. The model of Mwesige, et al. (2016)
415 (Equation (5)) is very close to the model that predicts the P_{PZ} (Equation 14). Both models
416 predicted the passing rate of passing maneuvers that ended in the PZs and also employed most of
417 the explanatory variables for estimation compared to other previous studies, and it could be the
418 reason for the more accurate prediction of these two models. Another reason could be the
419 similarity in the traffic culture of the countries.

420 The models proposed by Hegeman (2008) and Moreno, et al. (2013) (Equation (3) and (4))
421 underestimated the passing rate. Their studies were carried out in developed countries, which
422 might explain the significant differences between passing rate values in their work and that of
423 Mwesige, et al. (2016). Another reason for the lower prediction by Hegeman (2008) is due to the
424 *Dutch Sustainable Safety Program*, which recommended that authorities design two-lane

425 highways along which passing is prohibited, even where there is sufficient sight distance. In the
426 study of Moreno, et al. (2013), the two studied PZs were too close to each other (less than 350 m),
427 hence a reduction in the passing rate was possible.

428 Figure 5 shows that the passing rate of maneuvers ending in the PZ (P_{PZ}) is nearly two
429 times that of the passing rate of maneuvers that started and ended in the PZ (P_{PPZ}). Furthermore,
430 the PZ length had an insignificant effect on P_{PZ} . All of which implies that increasing the length of
431 the short PZs does not lead to a significant increase in the passing rate and, by extension, more
432 fluid traffic operations.

433 However, the high passing rates observed demonstrate that short PZs irrespective of their
434 length have a significant effect on the operation of highways in Iran. Harwood, et al. (2008)
435 observed that only 0.4% of all vehicles passed in the short PZs, while this value was 5% on average
436 in Iran. Moreno, et al. (2016) studied the effects of PZ length (250-5000m) on the operational
437 performance of two-lane highways. Their findings showed that average PZ length had an effect on
438 traffic performance, while short PZs (250m) did not.

439 As shown in Figure 5, the passing rate for maneuvers ended in the PZ (P_{PZ}) peaked at the flow
440 rate of 680 veh/h, after this a reduction was observed. This maximum value represents the
441 passing capacity, which indicates the maximum effectiveness of PZs respect to flow rate in both
442 directions.

443 Figure 5 shows the passing capacity for maneuvers that start and end in the PZ (P_{PPZ}) at
444 the flow rate of 597 veh/h. Moreno, et al. (2013) found that the peak passing rate occurred at
445 600-700 veh/h, which is similar to the findings of this research. However, in the study conducted
446 by Mwesige, et al. (2016), the passing rate reached its capacity at the flow rate in both directions
447 at 400 veh/h. The maximum flow rate that they observed in their study was 426 veh/h. Hence,

448 they could not estimate the effect of superior levels of flow rate on the passing rate. They stated
449 that it was not possible to observe the passing capacity at 600 veh/h because the average
450 headways were too short (Mwesige, et al., 2016). However, it should be noted that by increasing
451 the flow rate, the platoons will increase and, commonly, several drivers in the platoons use a
452 single gap in the opposite direction to pass the slow vehicle together.

453

454 **6. Conclusion**

455 This study evaluated the effects of geometric characteristics and traffic-related explanatory
456 variables on the passing rate of short passing zones (PZs). The effectiveness of variables was
457 obtained by generating Poisson regression models from aerial data collected from seven PZs.

458 The main conclusions of the study were as follows:

- 459 • the length of the short PZs did not have a significant effect on the passing rate of
460 maneuvers ending in the PZ; hence, limited increases in length of the short PZs would not
461 help to improve traffic operations since, in practice, a significant proportion of drivers start
462 their passing maneuvers before reaching short PZs. Nevertheless, the results showed that
463 short PZs had an important role in improving traffic operations in Iran irrespective of their
464 length;
- 465 • the lane width had a highly significant effect on the passing rate;
- 466 • by increasing the proportion of motorcycles in the subject direction, the passing rate in the
467 subject direction witnessed a significant increase;
- 468 • the proportion of heavy vehicles in the subject direction was a significant variable when
469 estimating the passing rate in the subject direction, while the proportion of heavy vehicles
470 in both directions proved insignificant;

- 471 • the passing capacity of the PZs occurred at the flow rate of 680 veh/h, and the maximum
472 increase rate in the passing rate occurred at the flow rate of 400 veh/h.

473 The models presented support planners and designers in developing safety and operational
474 analyses. Traffic flow rate is an important variable in planning for a highway. Based on the
475 projected figures for passing capacity and predicted flow rate, planners could select between
476 two-lane highways and other types of infrastructure. Limited increments in length would not lead
477 to an improvement in traffic operations at short PZs. Other geometrics characteristics, e.g., the
478 lane width, could play a more significant role. However, the increment in length of short PZs could
479 significantly improve safety (Moreno, et al. (2015)). Accordingly, future research should
480 investigate the effect of short PZs on safety. From a safety perspective, increasing the flow rate
481 beyond the passing capacity serves only to decrease the passing rate and increase driver frustration
482 levels, which in turn could result in dangerous passing maneuvers. Furthermore, since in Iran,
483 motorcycles travel at a slower speed than passenger cars, the estimated models suggest that an
484 increase in the proportion of motorcycles increases the passing rate. Hence, safety experts should
485 base their evaluation of safety performance on traffic volumes, passing capacity, and the
486 proportion of motorcycles.

487 Heavy vehicles travel at a slower speed than passenger cars, and their speed decreases
488 further as the absolute vertical grade increases. The result of this work showed that an increment
489 in the proportion of heavy vehicles and/or the absolute vertical grade increases the passing rate.
490 However, the passing maneuver is a demanding and dangerous task, so planners and designers
491 should consider the safety implications of the proportion of heavy vehicles and vertical grades
492 when deciding between two-lane highways and other facility types. To achieve more homogenous

493 speeds, lower vertical grades have to be assumed at the design stage if a high percentage of heavy
494 vehicles is expected.

495 Some variables such as shoulder width, pavement surface quality, and weather conditions
496 need to be evaluated in future studies. Llorca, et al. (2013) concluded that the passing driver's
497 behavior was different at night. Hence, an investigation into the passing rate at nighttime is needed.
498 The posted speed limit could also affect the passing rate. In this study, there was not enough
499 variation in this variable for analysis. Moreover, the strategies to enforce the speed limit could be
500 important, and this aspect also requires field study in PZs. A simulation study conducted by Ghods
501 and Saccomanno (2016) showed that differential speed strategies had a significant effect on the
502 passing rate of passenger cars when overtaking heavy vehicles.

503 This study focused on short PZs, with length values between 164 and 345 m (Table 1). A
504 wider range of PZ lengths could help to find cases where the length of PZ has a significant effect
505 on the passing rate. To generalize the proposed models across different countries, future studies
506 need to be carried out.

507

508 **Data Availability Statement**

509 Some or all data, models, or code that support the findings of this study are available from the
510 corresponding author upon reasonable request.

511

512 **Acknowledgment**

513 This research was funded by Tarbiat Modares University.

514 **Notation list**

515 D_S = directional split of traffic volume

- 516 L_{PZ} = passing zone length
- 517 L_W = lane width
- 518 N_{PPZ} = number of passing maneuvers per 15 minutes starting and ending in PZ in subject
- 519 direction
- 520 NPZ = no-passing zone
- 521 N_{PZ} = number of passing maneuvers per 15 minutes ending in the passing zone (PZ) in the
- 522 subject direction
- 523 P_{HV} = proportion of heavy vehicles in both directions
- 524 P_{HVS} = proportion of heavy vehicles in the subject direction
- 525 P_{MCS} = proportion of motorcycles in the subject direction
- 526 P_{PPZ} = number of passing maneuvers per hour starting and ending in PZ in subject direction
- 527 P_{PZ} = number of passing maneuvers per hour ending in the passing zone (PZ) in the subject
- 528 direction
- 529 PTSF = percent time spent following
- 530 PZ = passing zone
- 531 V = flow rate in both directions
- 532 V_G = absolute vertical grade
- 533 V_O = flow rate in the opposite direction
- 534 V_S = flow rate in the subject direction

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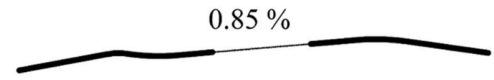
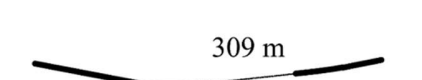
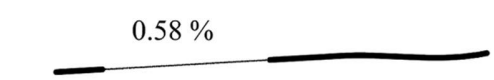
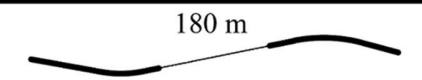
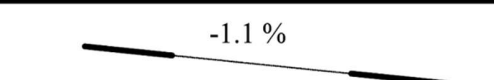
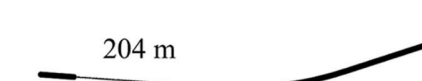

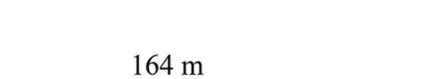





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598

599 List of Figures:

PZ ID	Alignment	Profile
1	 <p>225 m</p>	 <p>0.85 %</p>
2	 <p>309 m</p>	 <p>0.58 %</p>
3	 <p>180 m</p>	 <p>-1.1 %</p>
4	 <p>204 m</p>	 <p>-2.5 %</p>
5	 <p>164 m</p>	 <p>-5.5 %</p>
6	 <p>231 m</p>	 <p>-3.5 %</p>
7	 <p>345 m</p>	 <p>9.5 %</p>

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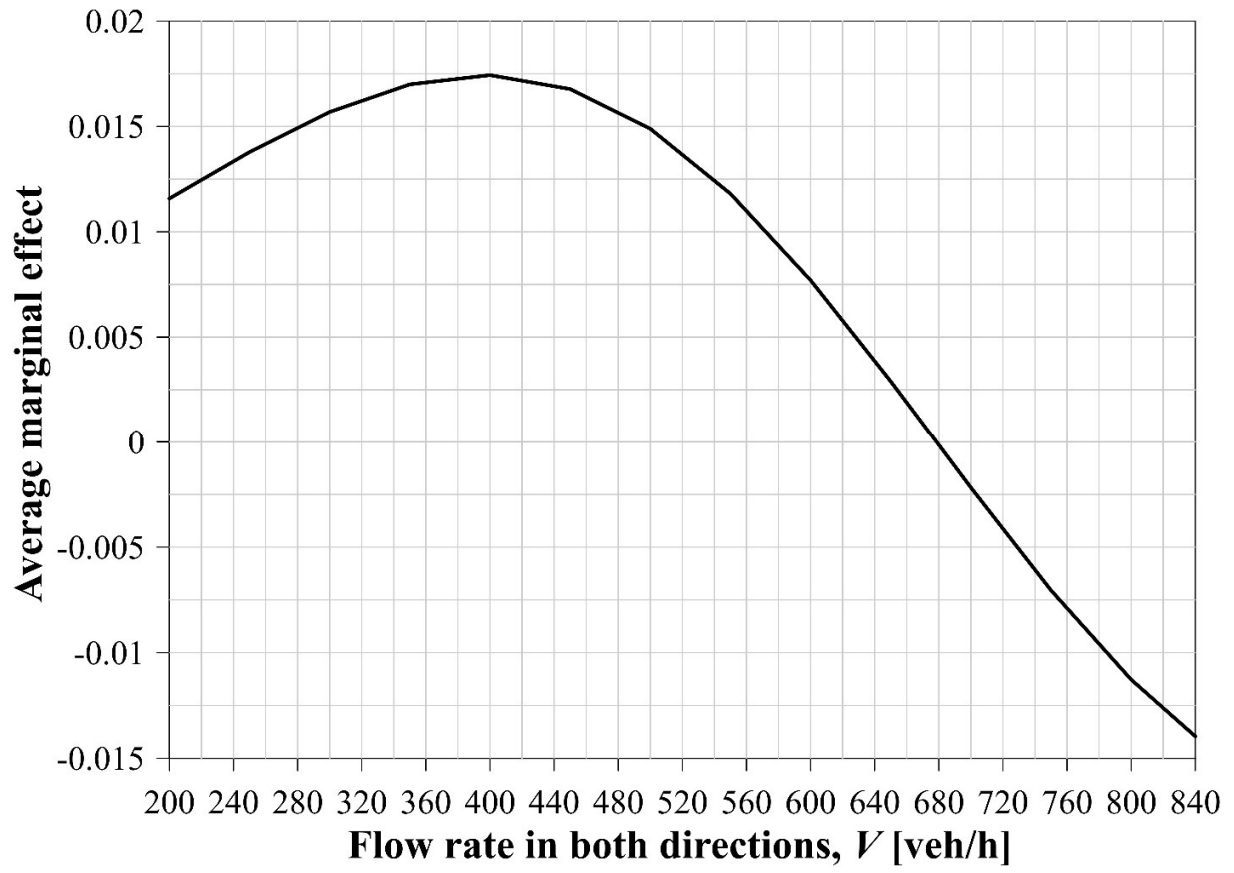
601 **Figure 1: Diagrams of the horizontal and vertical alignment around the PZs**



602

603 **Figure 2: Phantom 4 Pro drone**

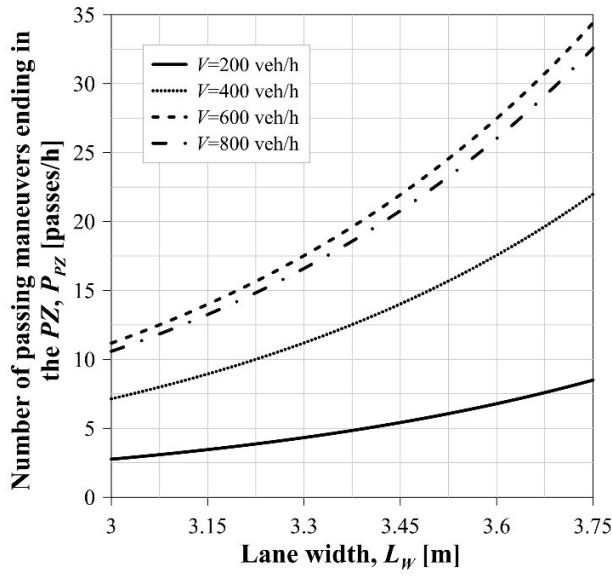
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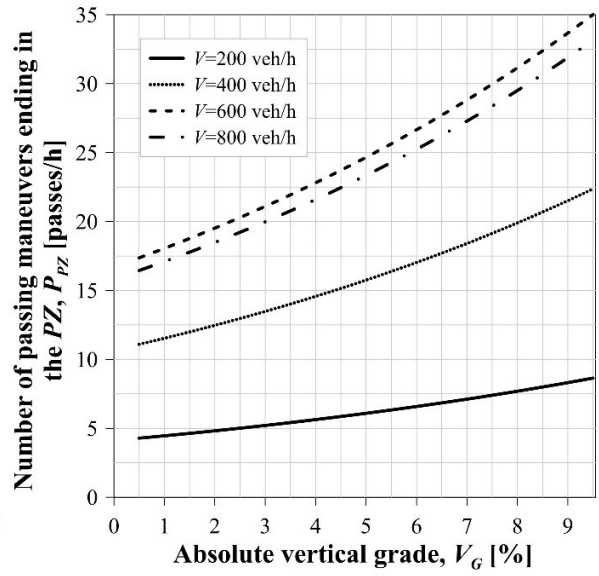
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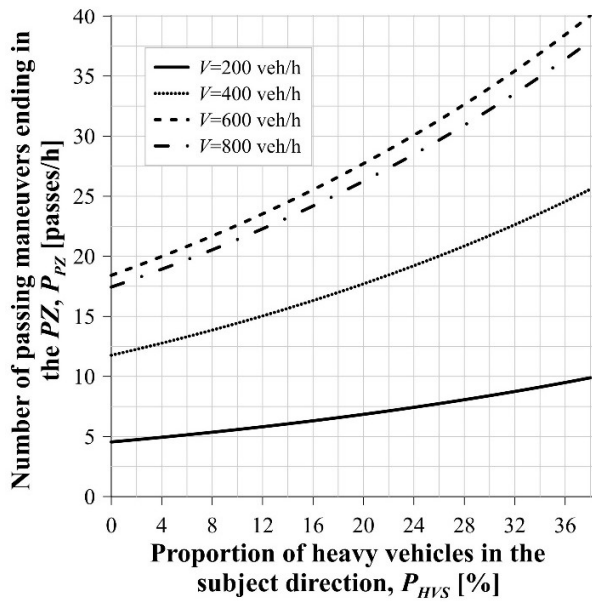
Figure 3: The average marginal effects of the flow rate in both directions on NPZ



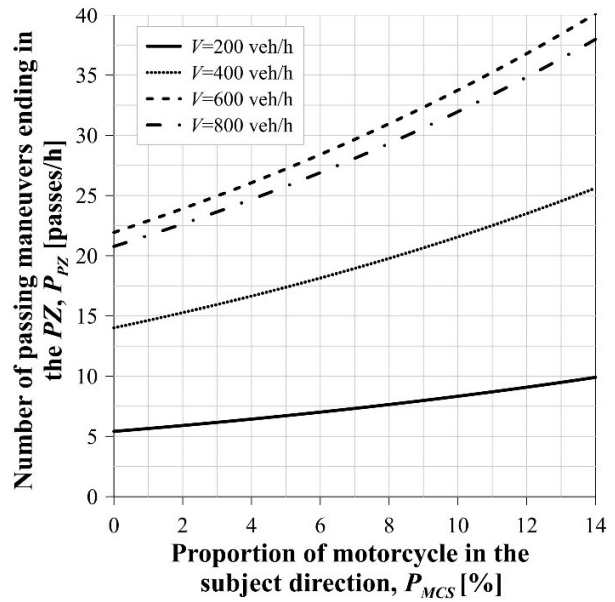
(a)



(b)



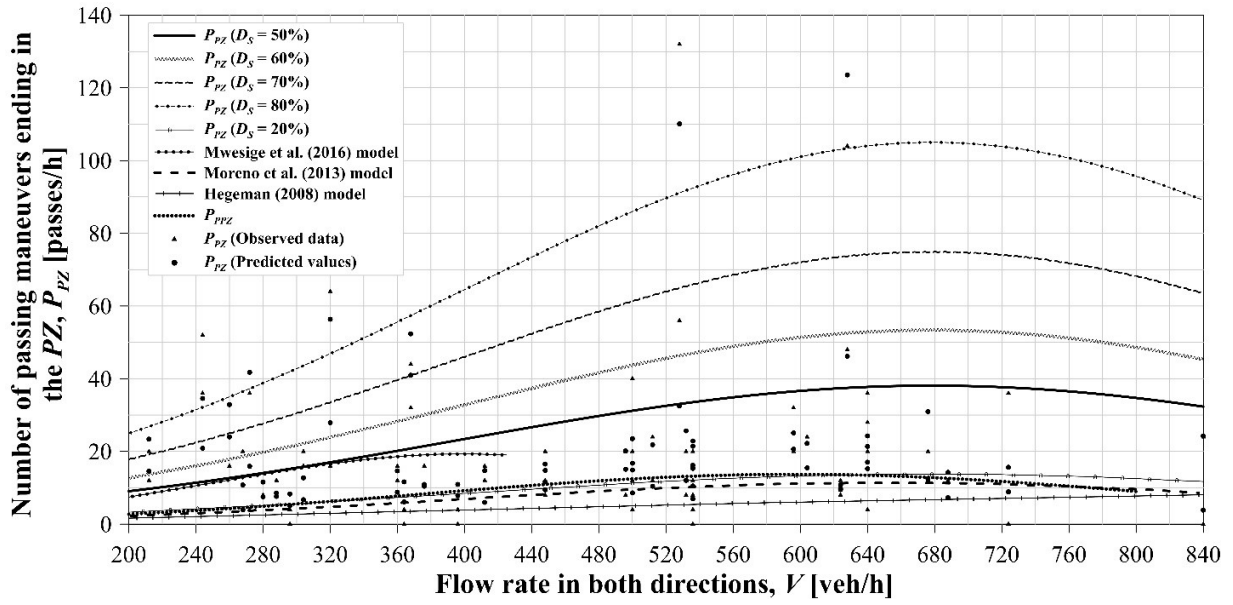
(c)



(d)

607

608 **Figure 4: Effects of explanatory variables of Model 1 on the P_{PZ}**



609

610 **Figure 5: Effect of the flow rate in both directions on the passing rate and comparison of this**

611 **study's models and previous works**

612

613 **Table 1: List of existing studies and their corresponding contributions (e.g., explanatory variables)**
 614 **and shortcomings**

Studies	Explanatory variables												Shortcomings	
	V_S	V_O	V	$\bar{\mu}_s$	σ_s	$P(g>30)$	$P(road)$	L_{PZ}	D_S	V_G	S_{85}	P_{HV}		k
Wardrop (1952)	*			*	*									A theoretical model
Daganzo (1975)			*											A theoretical model
McLean (1989)						*	*							A theoretical model
Dommerholt and Botma (1988)	*	*	*		*								*	A theoretical model
Tuovinen and Enberg (2006)	*													Using a linear regression model
Hegeman (2008)	*	*												Using a linear regression model
Moreno et al. (2013)			*					*	*					
Mwesige et al. (2016)			*					*	*	*	*	*		
V_S = traffic flow in the subject direction [veh/h]							$P(road)$ = proportion of road length suitable for passing							
V_O = traffic flow in the opposite direction [veh/h]							L_{PZ} = length of PZ [m]							
V = traffic flow in both direction [veh/h]							D_S = directional split in the subject direction [%]							
$\bar{\mu}_s$ = average of space mean speeds [km/h]							V_G = absolute vertical grade [%]							
σ_s = standard deviation of space mean speed [km/h]							S_{85} = 85 th percentile speed [km/h]							
$P(g>30)$ = proportion of time that there is a gap larger than the critical gap (30 s)							P_{HV} = proportion of heavy vehicles [%]							
							k = density of vehicles [pc/km]							

615

616 **Table 2: Geometric characteristics of the PZs and total number of observed passing maneuvers at**
 617 **each site for 15-min periods in each direction**

PZ ID	Highway (*)	Length	Width	Shoulder width	Absolute vertical grade	Posted speed limit	Passing maneuvers recorded	15-min period observations
		[m]	[m]	[m]	[%]	[Km/h]	[#]	[#]
1	JF	225	3.45	-	0.85	85	73	16
2	JF	309	3.45	-	0.58	85	58	14
3	JF	180	3.25	-	1.1	85	24	10
4	JF	204	3.25	-	2.5	85	17	8
5	JB	164	3.00	-	5.5	95	15	4
6	JB	231	3.00	-	3.5	95	18	8
7	JK	345	3.75	1.2	9.5	85	174	16

618 (*) JF = Jiroft-Faryab, JB = Jiroft-Baft, and JK = Jiroft-Kerman

619

620 **Table 3: Descriptive statistics of explanatory variables**

Variable (Unit)	Mean	Min.	Max.	Confidence interval (95%)
Number of passing maneuvers ending in PZ in the subject direction, N_{PZ} (Passes per 15 min)	5.0	0	33	(3.8, 6.2)
Number of passing maneuvers starting and ending in PZ in subject direction, N_{PPZ} (Passes per 15 min)	2.3	0	21	(1.5, 3.1)
PZ length, L_{PZ} (m)	254.60	164	345	(240.2, 269.0)
Upstream NPZ length, L_{UNPZ} (m)	1265.5	130	5010	(946.4, 1584.6)
Lane width, L_W (m)	3.39	3.00	3.75	(3.34, 3.45)
Absolute vertical grade, V_G (%)	3.4	0.6	9.5	(2.6, 4.1)
Flow rate in both directions, V (veh/h)	470.4	212	840	(434.6, 506.3)
Flow rate in the subject direction, V_S (veh/h)	235.2	80	648	(212.7, 257.8)
Flow rate in the opposite direction, V_O (veh/h)	235.2	80	648	(212.7, 257.8)
Directional split of traffic volume, D_S (%)	50	22.9	77.1	(47.6, 52.4)
Proportion of heavy vehicles in both directions, P_{HV} (%)	8.2	0	30.2	(6.4, 10.1)
Proportion of heavy vehicles in the subject direction, P_{HVS} (%)	8.6	0	37.9	(6.4, 10.8)
Proportion of motorcycle in the subject direction, P_{MCS} (%)	3.0	0	13.9	(2.2, 3.7)
Mean free-flow speed, M_{FFS} (km/h)	85.3	63.7	102.0	(83.7, 87.0)
Standard deviation of free-flow speed, σ_s (km/h)	16.0	9.5	27.6	(15.1, 16.9)
85 th Percentile free-flow speed, S_{85} (km/h)	101.3	71.0	129.4	(99.1, 103.4)

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622 **Table 4: Estimated Poisson model parameters (Model 1 predicts N_{PZ} , Model 2 predicts N_{PPZ})**

variables	Model 1		Model 2	
	β -Estimate	Z-value	β -Estimate	Z-value
L_{PZ}	-	-	0.00786	2.69 ^b
L_W	1.4989	3.82 ^a	1.71082	2.08 ^c
V_G	0.0779	2.99 ^b	0.06994	2.04 ^c
V	0.00852	3.39 ^b	0.01218	3.00 ^b
V^2	-6.28×10^{-6}	-2.41 ^c	-10.2×10^{-6}	-2.31 ^c
D_S	0.03381	6.19 ^a	0.02636	4.55 ^a
P_{HVS}	0.02044	2.00 ^c	-	-
P_{MCS}	0.04307	1.78 ^d	-	-
constant	-8.4586	-7.44 ^a	-12.31318	-5.20 ^a
Test	χ^2	p-value	χ^2	p-value
Overall model evaluation				
Likelihood ratio test	226.73	0.0000	208.69	0.0000
Goodness-of-fit				
Deviance test	86.925	0.061	90.559	0.042
Pearson test	74.03	0.288	84.488	0.099
	$\bar{\chi}^2$	p-value	$\bar{\chi}^2$	p-value
Overdispersion				
LR test of α	0.00000	0.500	0.09	0.379
Random-effects				
LR test of φ	0.00	1.00	0.00	1.00
Cragg-Uhler R ²	0.950		0.939	
McFadden's R ²	0.418		0.479	
Sample size	76		76	

623 (^a) significance level at 0.001. (^b) significance level at 0.01. (^c) significance level at 0.05. (^d) significance level at 0.1.

625 **Table 5: Average marginal effects of explanatory variables on the number of passing maneuvers**
 626 **ending in PZ per 15 minutes [passes/15-min/one-unit change in variable]**

Variables	Average marginal effects	Confidence interval (95%)
L_W	7.47	(3.57, 11.38)
V_G	0.39	(0.13, 0.65)
D_S	0.17	(0.11, 0.22)
P_{HVS}	0.10	(0.001, 0.20)
P_{MCS}	0.21	(-0.022, 0.45)

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628 **Table 6: Average marginal effects of explanatory variables on the number of passing maneuvers**
 629 **that start and end in PZ per 15 minutes [passes/15-min/one-unit change in variable]**

Variables	Average marginal effects	Confidence interval (95%)
L_{PZ}	0.018	(0.004, 0.031)
L_W	3.92	(0.17, 7.66)
V_G	0.16	(0.004, 0.316)
D_S	0.06	(0.033, 0.088)

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