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Research Article

Drivers' Yielding Behavior in Different Pedestrian Crossing Configurations: A Field Survey

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Although in recent years road victims have been reported to decrease, the growing number of pedestrians involved in road accidents still remains a social concern. This work analyzes the drivers' behavior in approach to two different configurations of pedestrian zebra crossing: marked by (1) white stripes over the pavement (named "white zebra crossing") and (2) white stripes on a red-colored pavement (named "red and white zebra crossing"). Even though the latter configuration is nowadays quite widespread on urban environment, there is no scientific evidence of its actual effectiveness in conditioning drivers' yielding behavior. This study was aimed at verifying the effectiveness of the red and white zebra crossing on improving road safety at pedestrian crossings. A set of synchronized cameras were used to record drivers' behavior while approaching the pedestrian crossings. By reconstructing the speed profile of each surveyed driver (309 in total), it was possible to analyze the driver-pedestrian interaction. Data were used to study the driver yielding behavior, to analyze how it is affected by vehicle dynamic constraints, and to identify the significant explanatory variables of a logistic regression model for predicting the drivers' likelihood of yielding the pedestrian on the different crossing configurations. As a result, significant differences in terms of yielding behavior on the two pedestrian crossing configurations were observed: a higher yielding rate (about 20% higher) and a higher tendency to yield to the pedestrian were reported for the red and white zebra crossing, especially for the most critical conditions of driver-pedestrian interaction. Moreover, the analysis of yielding behavior with respect to vehicle dynamics constraints highlighted that drivers approaching the red and white zebra crossing experienced more opportunities to yield. As a confirmation, logistic regression model showed that the yielding likelihood is significantly and positively affected by the presence of the red and white zebra crossing configuration.

1. Introduction

Road travel has become significantly safer for most road users in the recent decades, largely through the improvements made by vehicle manufacturers to protect vehicle occupants [1]. However, the same cannot be said for pedestrians who are rapidly becoming the majority of people killed and injured on our roads, particularly in urban areas. Indeed, although the period spanning from 2001 to 2017 has witnessed a 57.5% decrease of the total number of accidents in Europe, the rate of decrease has been reported to be only 36% for pedestrian fatalities [2]. Oppositely, by referring to Italy, these fatalities have seen an increase of 5.3% in 2017 [3].

In general, more than 270,000 pedestrians lose their lives due to road accidents each year. According to the WHO report [4], pedestrians constitute 22% of all road traffic fatalities, globally. In fact, as reported by Naci et al. [5], pedestrians hit by motor vehicles represent the world's largest group of road user fatalities. The age groups having the highest percentage of pedestrian deaths are children below 14 years of age and adults aged 65 years or older. Furthermore, most injuries to pedestrians occur in urban areas. Motor vehicles (cars, lorries, and buses) account for over 80% of vehicles striking pedestrians.

Frequently, accidents occur at facilities specially designed for pedestrians such as pedestrian crossings. According to ACI-ISTAT [6], more than 50% of accidents involving pedestrians are reported in pedestrian crossing. These accidents often occur as people try to cross the road, due to the driver's sight being limited by scarce light conditions or obstacles (e.g., parked vehicles) or due to unclear pedestrian behavior [1]. Therefore, several studies have addressed a more comprehensive understanding of pedestrian behavior during crossing, the crossing speed, and the acceptance of the time gap [7–13].

In turn, only few scientific contributions focusing on the driver's point of view within his interaction with the pedestrian have been published [14–19].

It is well known that accidents occurring between pedestrians and drivers generate from a refusal by the driver in yielding to the pedestrian [20, 21] and that pedestrian's safety at crossings increases as vehicle speed decreases [22–27]. Pasanen and Salmivaara [28] have found that the likelihood for a driver traveling at 50 km/h of being involved in an accident with a pedestrian is twice that of a driver who adopts lower speeds.

Most of the past studies have considered driver behavior with pedestrian being already engaged in crossing, by carrying out driver's eye-gaze and video analysis regardless of the phase of arrival of pedestrian at the sidewalk [29]. However, [27] studied the speed drivers' behavior in approach to the pedestrian crossing.

According to the literature, the vehicle-pedestrian interaction is affected by driver's characteristics (attitude to yield), pedestrian's characteristics (assertiveness and risk acceptance), and parameters related to vehicle dynamics, such as vehicle speed, distance from the conflict area, and maximum comfortable deceleration rate [30]. Vehicle dynamics play a significant role as they affect the vehicle's arrival time at the zebra crossing and, consequently, the pedestrian decision. Such a time, defined as the time left for the driver to reach the zebra crossing at the moment the pedestrian arrives at the curb, is generally referred to as Time-to-Zebra arrive (TTZ_{arr}) and is frequently used in the literature to discuss the vehicle-pedestrian interaction at zebra crossings [27].

In such a framework, countermeasures are required to improve both pedestrians' and drivers' safety at pedestrian crossings. In particular, countermeasures addressed at drivers mainly aim at reducing the approaching speed at pedestrian crossings. As a confirmation, a topic-related literature review has shown various applications of countermeasures to limit drivers' speed at the approach to pedestrian crossings with no signalization [31–36]. Among the most recognized driver-oriented countermeasures, the following can be listed: advanced yield lines to improve the visibility of the crossing pedestrians, removal of parking adjacent to the crossing for clearing the view of the approaching vehicles, installation of curb extensions to improve visibility, pedestrian-activated flashing beacons to warn drivers of crossing pedestrians, and in-pavement warning lights with advance sign to inform the drivers of the crossing.

Recently, countermeasures known as traffic calming interventions have been introduced, such as the pigmentation of road pavement (mainly in red, blue, or green) at the pedestrian crossings. Many Italian municipalities have adopted these white strips on colored background, especially in proximity to schools, in order to increase the safety of child crossings. Nevertheless, the application of such an intervention is currently not advised by any standard nor its effectiveness has been evaluated.

The present work aims at carrying out a comparative analysis of drivers' behavior at the approach to two different zebra crossing configurations, not regulated by traffic lights. Specifically, two pedestrian crossings having different markings and signs are selected as case studies: the first one is an uncommon layout characterized by white stripes on a red pavement (i.e., red and white zebra crossing) and the second one is a traditional white zebra crossing with simple white strips (i.e., white zebra crossing) and served as reference. The comparison between the two configurations from a driving behavior point of view allows verifying the effectiveness of the red and white zebra crossing configuration.

2. Methodology

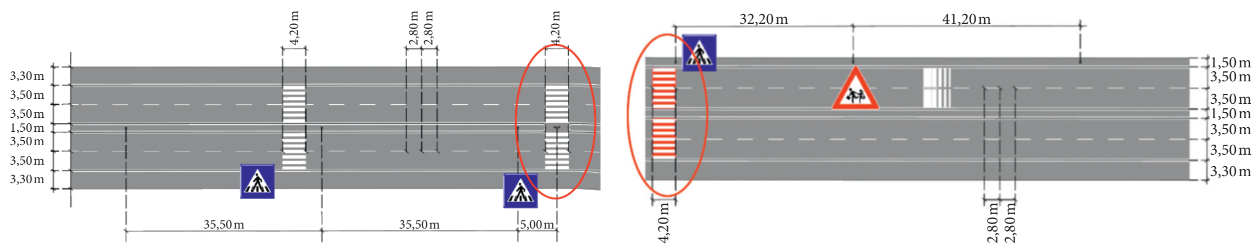
This study analyzes drivers' speed profiles collected by means of field surveys in the two crossing layouts, as the pedestrian approaches the zebra crossing. The recorded data were used to study the driver's yielding behavior by both assessing whether and to what extent it is affected by vehicle dynamic constraints and identifying the significant explanatory variables of a logistic regression model capable of predicting the likelihood of the driver to yield the pedestrian.

2.1. Case Study. Two pedestrian crossings were identified and selected in a suburban area of the Municipality of Rome, Italy, with the first being a traditional white zebra crossing with simple white stripes and the second being composed by white stripes on a red pavement (Figure 1). Since they are located in two different points of the same road, the two crossings are comparable in terms of road geometry. In fact, for both cases, the road cross section is made up of two carriageways, each including two lanes, separated by a curb. Furthermore, both configurations are located between a tangent section about 270 meters and a curve with 75 meters of radius and comparable deviation angle. From the vertical alignment point of view, the values of slopes range between 0% and 1%. Both pedestrian crossings are not regulated by traffic lights and the parking at the road sides is not permitted. Finally, traffic flows, visibility conditions, road environment, and boundary conditions are verified to be the same (Figure 1).

2.2. Pedestrian Crossing Layouts. The two layouts include different configurations of signs and markings. The first one is a white zebra crossing (Figure 2(a)), signalized by a vertical pedestrian crossing sign in correspondence of the crossing itself. Oppositely, the red and white zebra crossing (Figure 2(b)) is provided of more detailed signs and markings. In fact, in addition to the pedestrian crossing sign in correspondence of the crossing, a danger sign of children crossing is located 30 meters before the crossing. Moreover, lane markers aimed at lower drivers' speed are placed on the

(a) (b)

Figure 1: White zebra crossing (a) and red and white zebra crossing (b).



(a) (b)

Figure 2: Layouts of white zebra crossing (a) and red and white zebra crossing (b).

pavement 45 meters before the crossing. For both configurations, the speed limit is set to 50 km/h.

The objective of this survey is to compare these two pedestrian crossing configurations in terms of driver behavior at the approach to the conflict point with a pedestrian that crosses the road. The starting point of the observation is set at 70 meters from the pedestrian crossings (Figure 2). It is worth noting that, in the first configuration (as Figure 2(a)), a second pedestrian crossing is placed into the observation section. For sake of comparability, the data surveys have been considered valid only when this second pedestrian crossing was clear.

2.3. Survey Features. The field data were captured by three synchronized GoPro Hero 3 video cameras, installed on vertical signs at the edge of the roadway. Figure 3 shows the view angle of the cameras in the two pedestrian crossings' case study. The recordings were carried out in off-peak hours.

Speed profiles were obtained by detecting the time required by the vehicle to pass through the road section starting at 70 m from the pedestrian crossing. For both cases, this observation section was divided into 13 subsections of length S_i, so that $V_{\text{section }(i)} = S_i/\Delta t_i$, where $V_{\text{section }(i)}$ is the speed of each driver within the ith subsection, S_i is the length of the ith subsection, and Δt_i is the time interval needed by the vehicle to leave the ith subsection. Thanks to the calculation of the speeds into the 13 subsections, the speed profile is plotted in detail.

Speed profiles highlight different driving behaviors of the drivers while approaching the two pedestrian crossings. Accordingly, the drivers' behaviors can be grouped into two main behavior classes:

(i) Not yielding to pedestrian (NY: not yield), in which the driver goes through the conflict zone without yielding to pedestrian and keeping the speed unchanged.

(ii) Yielding to pedestrian (Y: yield), in which the driver yields to pedestrian by adjusting the speed and slowing down. In this case, another specification must be done: the driver can yield to the pedestrian by a soft slowing down (SY: soft yield; in this event the driver slows down to a minimum speed that is higher than 10 km/h to allow the pedestrian to pass) or by a hard slowing down (HY: hard yield; in this event, the driver slows down to a minimum speed lower than 10 km/h to allow the pedestrian to pass).

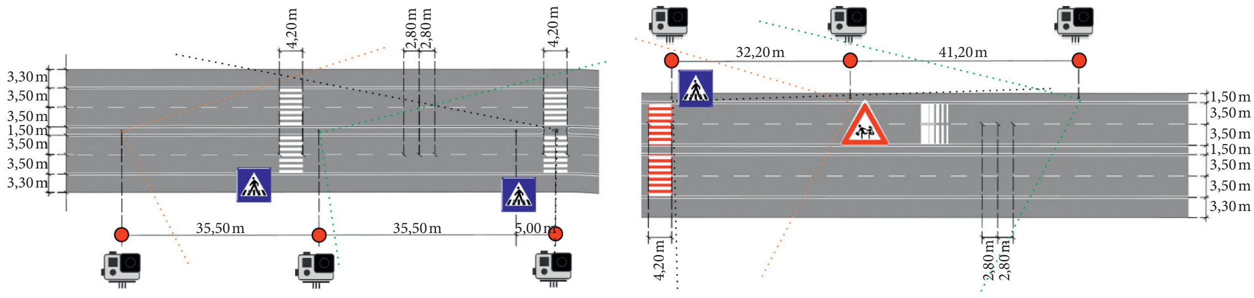
These behaviors are also confirmed by the visual analysis carried out by means of the cameras.

2.4. Data Processing. To carry out the analysis of the drivers' behavior towards the pedestrian crossing in the two different configurations, speed profiles of 309 drivers (160 for the white configuration and 149 for the red and white zebra crossing) were analyzed. Several variables have been extracted from the speed profile to describe the driver's behavior in case of yielding (Figure 4(a)) or not yielding (Figure 4(b)).

More specifically, the following variables were used for the purpose:

(i) V_0 (km/h): vehicle speed as it enters the survey section (70 m before the pedestrian crossing)

(ii) V_{i} (km/h): vehicle speed as pedestrian reaches the curb to cross



(a) (b)

FIGURE 3: Range of vision of cameras for white zebra crossing (a) and red and white zebra crossing (b).

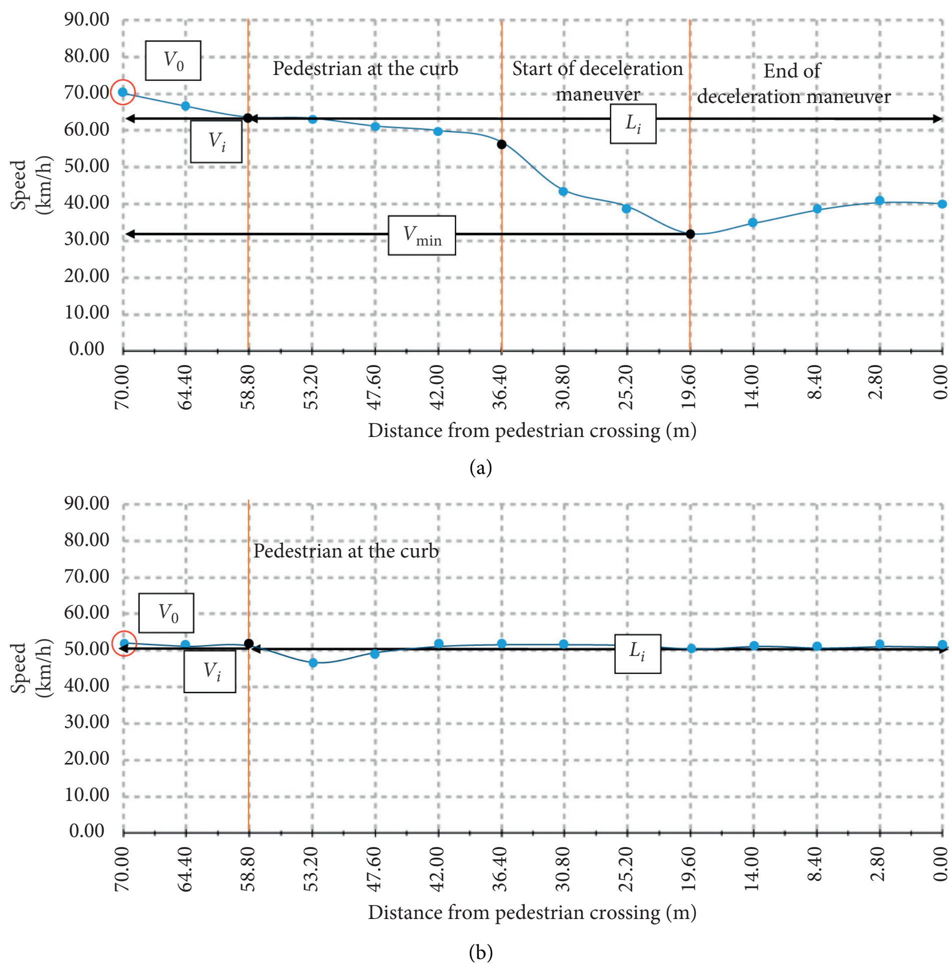


FIGURE 4: Dependent variables extracted from speed profiles: (a) yield to pedestrian event; (b) not yield to pedestrian event.

(iii) L_i (m): distance between vehicle and pedestrian crossing as pedestrian has just reached the curb. In this position, V_{i} is registered

(iv) $V_{\min}$ (km/h): the minimum speed adopted by driver to yield to pedestrian

(v) $\mathrm{TTZ}_{\mathrm{arr}}$ (s): equal to L_i/V_i, represents the time left for the vehicle to get to the zebra crossing as the pedestrian reaches the curb

It should be noted that, in case of not yielding to the pedestrian, the variable $V_{\min}$ was not achievable, since the driver did not slow down to yield to pedestrian.

3. Data Analysis and Results

Data obtained from the speed profiles have been analyzed in order to point out the difference in drivers' behavior in the two different zebra crossing configurations. The carried out analyzes are described and discussed in this section.

The first analysis was aimed at evaluating the differences in terms of yielding behavior on the two pedestrian crossing configurations. Then, a further analysis was oriented to evaluate whether the yielding behavior is affected by potentially different vehicle dynamics constraints on the two configurations. Finally, a standard logistic regression model was developed for the purpose of identifying the significant explanatory variables to predict the likelihood to yield to the pedestrian on the two pedestrian crossing configurations and to establish whether the configuration of zebra crossing is among those.

3.1. Driver's Yielding Behavior in Different Configurations. A one-way ANOVA ascertained that the difference between the mean speeds of V_0 recorded on white ($V_0 = 54.1$ km/h) and red and white ($V_0 = 52.1$ km/h) zebra crossing configurations was not statistically significant ($F_{(1,\ 307)} = 2.329$, $P = 0.128$).

This finding implies that differences in driving behavior at the approaching sections are not due to the different entering speeds but are caused exclusively by the driver's conditioning at the approach to the crossings (last 70 meters).

In turn, the yielding rate data show significant differences between the two pedestrian crossing layouts (Table 1). The percentage of yielding to the pedestrian (Y) out of the total cases is found to be about 20% higher in case of red and white zebra crossing than the standard configuration (34.4% for white zebra crossing against 53.7% for red and white zebra crossing). According to the Kolmogorov–Smirnov test, the two distributions are statistically different ($P = 0.006$).

Furthermore, the yielding events for the white configuration returned about 75% (74.5%) of soft yielding (SY) and 25% (25.5%) of hard yielding (HY), whereas these percentages resulted to be about 79% (78.7%) and 21% (21.3%), respectively, in case of white zebra crossing. This highlights a slight difference, not statistically significant, between the two configurations, which, however, indicates that the driver mainly adopts a soft yielding maneuver rather than a hard one.

In order to deepen the analysis of the yielding behavior on the two configurations, the percentage of Not Yielding (NY) and Yielding (Y) events has been observed with respect to the criticality of the driver-pedestrian interaction, returned by the TTZ_{arr} parameter. Indeed, TTZ_{arr} represents the time left for the vehicle to reach the zebra crossing at the moment the pedestrian arrives at the curb and indicates a higher risk related to the maneuver as its value decreases. Five classes (ranging from 0 to 4.5 s) of TTZ_{arr} values were considered (Table 2).

As expected, by analyzing the percentage of yielding (Y) as divided into TTZ_{arr} classes, it is observed that, for both configurations, the tendency of yielding to the pedestrian is greater as TTZ_{arr} increases.

However, it is worth noting that only few Y events have been observed for classes of TTZ_{arr} lower than 4.5 s in case of white zebra crossing, as about 64% of Y events were reported within highest class ($TTZ_{arr} > 4.5$ s). Conversely, in case of red and white zebra crossing, high values of Y events have been recorded also in classes with TTZ_{arr} lower than 4.5 s. This implies that, in presence of a red and white zebra crossing, the driver was observed to be able to yield to the pedestrian also in case of critical interactions with the pedestrian (i.e., TTZ_{arr} lower than a 4.5 s). As a confirmation, according to the Kolmogorov–Smirnov test, the two distributions of Y events into TTZ_{arr} classes were statistically different ($P = 0.001$).

3.2. Yielding Behavior and Vehicle Dynamics Constraints. According to Schroeder and Rouphail [37], the driver's behavior in the interaction with a pedestrian while approaching a crossing is comparable to that observed in approach to a yellow phase of a signalized intersection. In this condition, the ability of driver to stop is a function of the reaction time, the maximum deceleration value rate that allows a comfortable braking maneuver, and the vehicle dynamics constraints, such as the driver's speed (V_i) and the correspondent distance from the crossing (L_i) when the pedestrian is ready to cross.

Therefore, the braking maneuver is allowed only when the time required for stopping the vehicle to yield to the pedestrian (total stopping time (TST), function of reaction time, speed, and maximum deceleration rate) is lower than the driver's time to reach the crossing at the moment the pedestrian is ready to cross ($TTZ_{arr} = L_i/V_i$). It is worth noting that, for low values of TTZ_{arr}, the driver is either close to the crossing or fast to brake. The above condition is expressed as follows:

$$\mathrm{TST} = t + \frac{V_i}{2d_{\max}} < \mathrm{TTZ}_{\mathrm{arr}} = \frac{L_i}{V_i}, \quad (1)$$

where t is the driver perception and reaction time, typically 1.0 s for an expected event; d_{max} is the maximum comfortable deceleration rate of the vehicle, fixed as 4.5 m/s^2 [38]; V_i and L_i are mentioned before.

Figure 5 shows the relationship between TST and TTZ_{arr} with respect to all the recorded events for the two crossings. Points above the bisector represent drivers that, due to dynamic constraints, cannot stop without exceeding the max deceleration rate before reaching the pedestrian crossing, as the time needed to stop (TST) is higher than TTZ_{arr}, while points below the bisector are drivers who can stop comfortably.

It is interesting to note that events with $TST > TTZ_{arr}$ (points above the bisector in Figure 5) were actually NY events, whereas the points below the bisector show both events where the driver yielded to the pedestrian and not yielding events. In these last events, the driver did not yield, despite the fact that they had the opportunity to do so for kinematic reasons, thus showing a low propensity to yield. The figure shows that the points below the bisector were 105 out of 149 (70%) for the red and white zebra crossing configuration, whereas the same events were only 93 out of 160 (58%) for the white configuration.

Table 1: Recorded events in two configurations.

Classes	Events	Y	NY	SY	HY	Y/tot. events (%)	SY/Y	HY/Y
White zebra crossing								
Tot	160	55	105	41	14	34.4%	74.5%	25.5%
Red and white zebra crossing								
Classes	Events	Y	NY	SY	HY	Y/tot. events (%)	SY/Y	HY/Y
Tot	149	80	69	63	17	53.7	78.7	21.3

Table 2: Analysis of yielding referred to TTZ_{arr} classes of the white and red and white zebra crossing.

Classes	Events	Events/tot. (%)	Y	NY	Y/tot. Y (%)	Y/tot. events (%)
White zebra crossing						
$0\,s < TTZ_{arr} < 1.5\,s$	37	23.1	0	37	0.0	0.0%
$1.5\,s < TTZ_{arr} < 2.5\,s$	31	19.4	5	26	9.1	3.1%
$2.5\,s < TTZ_{arr} < 3.5\,s$	20	12.5	6	14	10.9	3.8%
$3.5\,s < TTZ_{arr} < 4.5\,s$	27	16.9	9	18	16.4	5.6%
$TTZ_{arr} > 4.5\,s$	45	28.1	35	10	63.6	21.9%
Tot.	160	100	55	105	100	34.4%
Red and white zebra crossing						
Classes	Events	Events/tot. (%)	Y	NY	Y/tot. Y (%)	Y/tot. events (%)
$0\,s < TTZ_{arr} < 1.5\,s$	32	21.5	0	32	0.0	0.0%
$1.5\,s < TTZ_{arr} < 2.5\,s$	14	9.4	2	12	2.5	1.3%
$2.5\,s < TTZ_{arr} < 3.5\,s$	42	28.2	30	12	37.5	20.1%
$3.5\,s < TTZ_{arr} < 4.5\,s$	31	20.8	24	7	30.0	16.1%
$TTZ_{arr} > 4.5\,s$	30	20.1	24	6	30.0	16.1%
Tot.	149	100	80	69	100	53.7

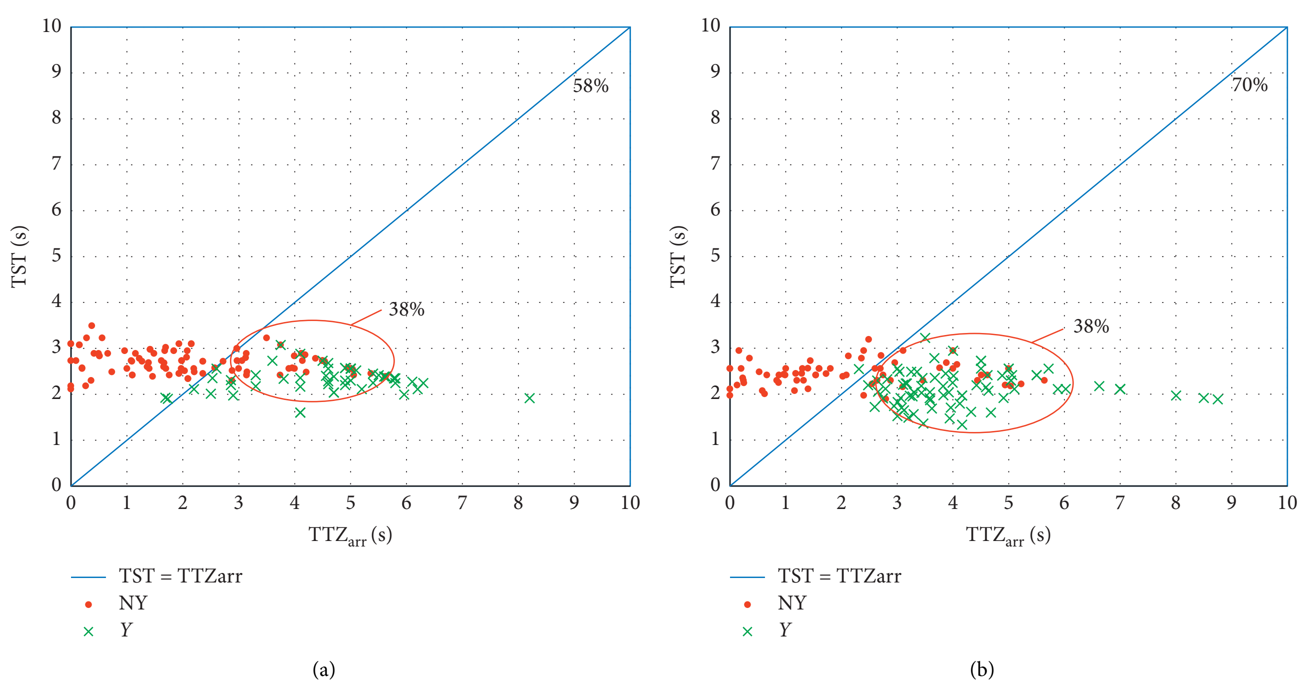


Figure 5: Total Stopping Time (TST): time to arrive (TT_{arr}) relationship for (a) white zebra crossing and (b) red and white zebra crossing.

This highlights that drivers approaching the red and white zebra crossing have experienced more opportunities to yield in terms of kinematic vehicle condition. In other words, this finding reveals bigger effectiveness of the red and white zebra crossing configuration in allowing the adoption of proper yielding behavior. It is worth mentioning that, for both configurations, 38% of the total NY events (40 out of 105 in white zebra crossing configuration and 26 out of 69 in red and white zebra crossing) were observed below the bisector line, indicating that the driver decided not to yield to pedestrians although they could ($TST < TTZ_{arr}$). This finding stresses out the same drivers' tendency to yield to the pedestrian and provides reasonable evidence that the results of the study were affected by the intrinsic characteristics of the drivers in the same extent for the two crossing configurations.

3.3. Logistic Regression Model Development. A standard binomial logistic regression analysis was carried out for the purpose of proposing a model capable of predicting the likelihood of yielding to pedestrian, by ascertaining whether, among the variables affecting the phenomenon, the configuration of the pedestrian crossing configuration plays a crucial role. The values of the dependent variable Y (i.e., driver yielding) were set to 1 for yielding ($Y = 1$) and 0 for not yielding ($Y = 0$) events. The logistic regression model that returns the log odds $((P(Y=1)/(1-P(Y=1)))$ of drivers yielding is given by

$$\text{Logit}\,[P(Y=1)] = \log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_o + \sum_{i=1}^{m} \beta_i \cdot x_i, \tag{2}$$

where β_i are the coefficients of m predictor x_{i} and β_0 is the constant term.

The probability estimates for the driver's yield response are provided by the following equation:

$$P(Y=1) = \frac{e^{\beta_o + \sum_{i=1}^{m} \beta_i \cdot x_i}}{1 + e^{\beta_o + \sum_{i=1}^{m} \beta_i \cdot x_i}}. \tag{3}$$

The model in (2) allows determining the effect of each predictor on the odds of Y. More specifically, the value of odds ratio (OR) represents the multiplicative factor of the odds of Y when the independent variable x_{i} increases by one unit, with all other factors remaining constant. In other words, the odds ratio indicates the relative amount by which the odds of the outcome increase (OR > 1) or decrease (OR < 1) when the value of the corresponding independent variable increases by 1 unit [39].

Firstly, a correlation analysis between the potential explanatory variables has been conducted. Among the potential explanatory variables, in addition to the variables V_0, V_i, L_i, and $\mathrm{TTZ}_{\mathrm{arr}}$, which were obtained from the driver's speed profiles, also the dummy variable R (type of pedestrian crossing configurations; $R = 0$ for white configuration and $R = 1$ for red and white zebra crossing configuration) was considered.

High values of Pearson correlation coefficient were found for the variables L_i and $\mathrm{TTZ}_{\mathrm{arr}}$ (0.87), as well as for the variables V_0 and V_i (0.71). Therefore, these correlated variables were not used as independent variables in the same model.

The model developed procedure provided the following best-fitting model (Table 3).

The obtained model shows that the logit of drivers yielding to the pedestrian decreases as the vehicle speed at arrival in the survey section (V_0) increases and as the driver-pedestrian interaction criticalities increase (i.e., $\mathrm{TTZ}_{\mathrm{arr}}$ decreases). Also, the variable pedestrian crossing configuration (R) had a significant effect on the logit of drivers yielding; this decreases if the driver approaches the white zebra crossing configuration ($R = 0$).

The values of odds ratio for the independent variables show the pedestrian crossing configuration (R) to have the strongest influences, followed by $\mathrm{TTZ}_{\mathrm{arr}}$ and V_0. More specifically, the odds for a yield are increased 2.738 times if the vehicle approaches the red and white zebra crossing configuration ($R = 1$), are increased 2.621 times for an increase of 1 s of $\mathrm{TTZ}_{\mathrm{arr}}$, and are reduced 0.959 times for an increase of 1 km/h of the vehicle speed at arrival in the survey section (V_0).

The following equation reports the obtained binomial logit model:

$$\begin{aligned}\text{Logit}\,(P(\mathrm{YY}=1)) = -0.042 \cdot V_0 + 0.963 \cdot \mathrm{TTZ}_{\mathrm{arr}} \\ + 1.007 \cdot RR - 1.852.\end{aligned} \tag{4}$$

The effects of variables V_0, $\mathrm{TTZ}_{\mathrm{arr}}$, and pedestrian crossing configuration (R) on the likelihood of yielding to pedestrian are reported in Figure 6. The values of probability for the driver's yield response were obtained from equation (3), for changes in the explanatory variables V_0 and $\mathrm{TTZ}_{\mathrm{arr}}$ (from 1.5 to 4.5 s) and for white zebra crossing configuration ($R = 0$) as well as for red and white zebra crossing configuration ($R = 1$). As shown in Figure 6, increasing the value of V_0, the likelihood of yielding to pedestrian decreases for each combination of the other variables $\mathrm{TTZ}_{\mathrm{arr}}$ and R. At a fixed value of V_0, increasing the value of $\mathrm{TTZ}_{\mathrm{arr}}$, the likelihood of yielding to pedestrian increases in both crossing configurations.

Lastly, at a fixed value of $\mathrm{TTZ}_{\mathrm{arr}}$, for each value of V_0, the likelihood of yielding to pedestrian in the red and white zebra crossing ($R = 1$) is always greater than that in white zebra crossing configuration.

As an example, considering $V_0 = 40$ km/h and $\mathrm{TTZ}_{\mathrm{arr}} = 2.5$ s, the likelihood of yielding is around 0.24 for white configuration and about 0.48 for red and white zebra crossing.

4. Conclusions and Future Perspectives

The comparison between the drivers' behaviors at the approach to both a traditional white zebra crossing and an innovative layout of zebra crossing made up of white strips on a red pavement with vertical signs and pavement markings has allowed verifying the effectiveness of the innovative configuration on improving the road safety at pedestrian crossings.

Several analyses have been carried out in order to achieve the set of objectives and interesting results have been obtained. The data on the yielding rates show significant differences: the yielding rate that was obtained for the red and white zebra crossing was about 20% higher than that for white zebra crossing. The analysis of yielding behavior, for different conditions of driver-pedestrian interaction (i.e., different classes of $\mathrm{TTZ}_{\mathrm{arr}}$), showed a higher tendency to yield to the pedestrian in presence of a red and white zebra

Table 3: Binomial logit model.

	β	Odds ratio (exp (β))	Sig.	95% C.I. for exp (β) Lower	Upper
V_0	−0.042	0.959	0.017	0.927	0.993
TTZ_{arr}	0.963	2.621	0.000	2.033	3.378
R	1.007	2.738	0.002	1.442	5.196
Intercept	−1.852	0.157	0.108		
−2Log L (−2 log-likelihood criterion) = 274.232					
AIC (Akaike information criterion) = 282.232					
R^2 cox snell = 0.38					
R^2 nagelkerke = 0.51					
N = 309; Hosmer–Lemeshow goodness of fit chi^2 (8) = 9.071; P value = 0.336					

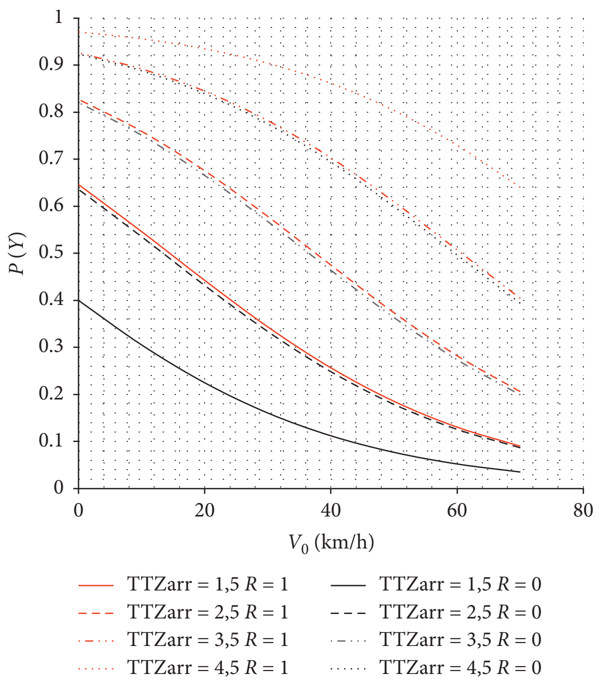


Figure 6: Effects of variables V_0, TTZ_{arr}, and pedestrian crossing configuration R on likelihood to yield ($P(Y)$).

crossing, especially for the most critical conditions of interaction (i.e., TTZ_{arr} lower than 4.5 s).

Furthermore, the analysis of yielding behavior with respect to the vehicle dynamics constraints has highlighted that drivers in approaching to the red and white zebra crossing have experienced more opportunities to yield in terms of kinematic vehicle condition.

Finally, logistic regression model showed that the yielding likelihood is significantly and positively affected by the presence of the red and white zebra crossing.

It is worth highlighting that the red and white zebra crossing configuration (and other similar solutions such as white strips on blue or green road pavement) is used on the Italian urban roads to improve pedestrian safety. However, there are currently no official guidelines or regulations concerning this zebra crossing configuration and the extent of its effectiveness is still unknown. In view of this, this study provides evidence of the effects of such configuration. More specifically, it evaluates the effects of a pedestrian crossing system made up of vertical signs and pavement markings and with a red and white strips zebra crossing. This implies that the results of this work do not allow recognizing the effect of each single element (vertical sign, pavement marking, and the white strips on red road pavement) of the system, rather attributing the increasing in yielding behavior to the entire pedestrian crossing system.

In order to identify the potential effects of each element that compose the crossing system, several experimental tests based on the driving simulator have been planned at the Road Safety Laboratory (LASS3) of the Department of Engineering at Roma Tre University. In fact, the implementation of different road scenarios and crossing layouts would allow investigating the effectiveness of a specific variable out of the various influencing factors.

Lastly, further experiments might be carried out to investigate the effects of red and white zebra crossings on different road sections, for example, one carriageway and one lane in each direction, where lower approaching speeds to pedestrian crossing are expected, and to evaluate the drivers' behavior in approach to other colored pedestrian crossing configurations.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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