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Advance yield markings and drivers' performance in response to multiple-threat scenarios at mid-block crosswalks

Donald Fisher[a,*] and **Lisandra Garay-Vega**[b,1]

[a] Department of Mechanical and Industrial Engineering, University of Massachusetts, Governors Drive, Amherst, MA 01003, USA

[b] Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA 01003, USA

Abstract

This study compares, on a simulator, drivers' performance (eye fixations and yielding behavior) at marked mid-block crosswalks in multi-threat scenarios when the crosswalks have advance yield markings and pedestrian crosswalk prompt signs versus their performance in such scenarios when the crosswalks have standard markings. Advance yield markings and prompt signs in multi-threat scenarios lead to changes in drivers' behaviors which are likely to reduce pedestrian–vehicle conflicts, including increases in the likelihood that the driver glances towards the pedestrian, increases in the distance at which the first glance towards the pedestrian is taken, and increases the likelihood of yielding to the pedestrian.

Keywords

Drivers' performance; Marked mid-block crosswalks; Multi-threat scenarios; Driving simulator; Pedestrian crashes; Eye movements

1. Introduction

In the United States, 69,000 pedestrians were injured in motor vehicle crashes in 2008. Approximately 4400 pedestrians were killed in motor vehicle crashes in the United States that year (NHTSA, 2008). Seventy-six percent of pedestrian fatalities occurred at non-intersection locations crossings. Although many of these fatalities take place on freeways and interstates, a small but still significant number of fatalities still occur at uncontrolled, marked mid-block crosswalks. It is crashes at these latter locations upon which we will focus. A safety risk at uncontrolled marked mid-block crosswalks emerges when driver's view of the pedestrian in the crosswalk is obscured until just seconds or fractions of a second before the crash. We refer to scenarios in which the driver's view of the pedestrian in the crosswalk is obstructed as *sight-limited scenarios*. An example of a sight-limited scenario (see Fig. 1) is when there are parking spaces adjacent to the travel lane and the driver's view of the pedestrian in the crosswalk is obstructed by these vehicles (*parking lane obstruction* scenario). A similar situation occurs when the driver's view of the pedestrian in the crosswalk is obstructed by vehicles turning from the opposite lane (*opposing-lane obstruction* scenario); in this case, the obstruction is on the left side (see Fig. 2). Sight-

* Corresponding author. Tel.: +1 413 549 1734. fisher@realmail.ecs.umass.edu, vze29yxh@verizon.net (D. Fisher)..
[1] Present address: U.S. Department of Transportation, Research and Innovative Technology Administration, Volpe National Transportation Systems Center, Cambridge, MA, USA. Tel.: +1 202 366 0413.

limited scenarios at multilane roads are also associated with a type of pedestrian–vehicle conflict defined as a *multi-threat* crash scenario (Snyder, 1972). In a multi-threat scenario, a pedestrian in a crosswalk can potentially be struck by a vehicle (first threat) traveling in the same direction as a vehicle that is yielding or stopped (second threat) for a pedestrian in the crosswalk (see Fig. 3). Vehicles yielding or stopped too close to the crosswalks often obscure the visibility for drivers traveling in the adjacent lane.

In order to identify alternative treatments for sight-limited scenarios we need to identify why it is that drivers might be colliding with pedestrians in these situations. There are two very different possibilities. In one case, we might find that drivers are indeed looking for pedestrians, but just do not have enough time to stop. Increasing the number and intensity of warnings to motorist that a pedestrian crosswalk is ahead will do little to solve this problem. In the other case, we might find that drivers are not looking for the hidden pedestrian and thus are not actually aware of the potential danger—at least do not give any indication of being aware. In this case, making drivers more aware of the hidden threat could help. A driving simulator can be used to study this problem without creating dangers for the pedestrians.

Consider the first case, are drivers approaching a marked crosswalk indeed looking for pedestrians? Pradhan et al. (2005) explored this question in a driving simulator experiment with 24 novice drivers (16–17 years old), 24 young drivers (19–29 years) and 24 older drivers (60–75 years old). In one of 16 scenarios, the driver approaches a marked mid-block crosswalk (see Fig. 4). A truck is parked on the shoulder blocking the driver's view of pedestrians who might be crossing in front of the truck. The driver should look to the right as he or she approaches the crosswalk to determine whether a pedestrian in the crosswalk could emerge from in front of the truck. The results of the study indicate that even when a crosswalk is marked, drivers in general, and novice drivers in particular, fail to look for pedestrians that are crossing in front of a vehicle stopping in the travel or parking lane (sight-limited scenario). In particular, most experienced drivers do look, but certainly not all (only 57%) and the great majority of novice drivers do not look (90%) (Pradhan et al., 2005).

The above results suggest that the first case does not represent the great majority of drivers. In particular, many drivers are not looking for pedestrians. Thus, we need to consider the second case where drivers are not looking for the hidden pedestrian. In this case, there is the possibility that making drivers more aware of the hidden threat could help to reduce the likelihood of a crash. Garay-Vega et al. (2007) {also see Garay-Vega and Fisher (2005)} examined whether presenting a foreshadowing element in the scenario, which pointed to an area of future potential risk, would alert drivers to the potential threat and eliminate or even reduce the differences in glance behavior between novice and experienced drivers. The experiment included 24 novice and 24 experienced drivers. The parking-lane obstruction scenario was presented to drivers (Fig. 1) with one slight exception. In this experiment, a pedestrian entered the crosswalk three seconds before the driver traveled over the crosswalk (and possibly encountered the potential threat, a pedestrian hidden by a truck stopped on the near side of the truck in the parking lane); the *foreshadowing event* (the pedestrian crossing) is shown to the driver only once. Similar to the methods used by Pradhan et al. (2005), an ASL 5000 head mounted eye tracker was used to document the location in the virtual world that is being fixated by the driver at each point in time as he or she approaches the crosswalk. They analyzed the unconditional probability that the driver fixated the critical region as he or she approached the crosswalk (the region immediately to the left front of the truck) as well as the conditional probability that the critical region was fixated as the driver approached the crosswalk given that the foreshadowing element (the crossing pedestrian) was fixated three seconds prior to the driver traveling across the crosswalk (Table 1).

Although the performance of novice drivers was better with foreshadowing (Garay-Vega et al., 2007) than without foreshadowing (Pradhan et al., 2005), almost 40% of novice drivers fail to glance for a hidden pedestrian even when the driver had fixated a crossing pedestrian just seconds before. The results show that effective upstream cues are needed to improve drivers' glance behavior even when the presence of a potential pedestrian is foreshadowed.

Compared to standard crosswalk markings, alternative treatments to improve driver behavior at uncontrolled, marked mid-block crosswalks should provide advance alerting and longer stopping distances and, ideally, should not be more expensive than traditional markings. Previous studies have shown that the use of advance yield markings and a related "Yield Here for Pedestrian" sign increase drivers' yielding distance while reducing the number of conflicts at multilane crosswalks with uncontrolled approaches (Van Houten et al., 2001, 2002). In theory, the treatment has the potential to reduce conflicts at multi-threat and sight-limited scenarios. First, the treatment alerts the driver of pedestrians further upstream of the crosswalk. Second, it prompts the driver to stop further upstream from the crosswalk increasing the separation between the driver and the pedestrian. Thus, advance yield markings and a related "Yield Here for Pedestrian" sign provide more time for the driver to react and respond. However, it is not known whether these changes might occur solely in scenarios where the pedestrian is visible in the crosswalk. This is because there is no means to determine from the results that have been reported in the above studies whether any of the scenarios included sight-limited situations in general and multi-threat situations in particular.

A recent field study did evaluate drivers' behavior in sight-limited scenarios with and without parking lane obstructions (Fig. 1) (Garay-Vega et al., 2008). Observations were made with standard crosswalk markings as well as advance yield markings and prompt signs. The methodology employed included standard videotaped observations of staged pedestrian–vehicle interactions (experimenters would step into the crosswalk, but remain stationary unless the approaching vehicle slowed and stopped) as well as separate in-vehicle evaluations of eye movement data as a surrogate measure for hazard anticipation. Advance yield markings increased the likelihood that a driver yielded for a pedestrian when there was an adequate sight distance, confirming previous results (Van Houten et al., 2001). However, when the sight distance was not adequate (i.e., a vehicle was parked on the near side of the crosswalk in the parking lane and obscured the staged pedestrian), there was no change in the likelihood that a driver yielded to the pedestrian. Interestingly, among those who did yield in the sight-limited scenarios, the advance yield markings and prompt signs lead to increases in both the distance between the stopped vehicle and the crossing pedestrian and the number of glances to the right for a potential pedestrian. The results indicate that adding advance yield markings without improving sight distance will not result in significant improvements in yielding behavior, but among those who do yield the advance yield markings will result in increases in safety related behaviors. A mathematical model was developed better to determine why more drivers did not yield when the advance yield markings were present in the sight-limited scenarios. The model suggested that it was the failure to see the pedestrian, not the failure to see the advance yield markings and prompt sign, that explained why there was no improvement in yielding behavior in the sight-limited parking lane obstruction scenarios. The data suggest that parking must be prohibited in the area between the yield line and the crosswalk.

This still leaves the question of how drivers will behave in sight-limited, multi-threat scenarios (Fig. 3), perhaps the most dangerous of all of the sight-limited scenarios because drivers are likely to be traveling faster than the other sight-limited scenarios. Specifically, to date, no studies have shown in sight-limited, multi-threat scenarios whether the use of advance yield markings and prompt signs actually increases the likelihood of drivers' glancing towards hidden pedestrians or increases how soon a driver first glances towards a pedestrian that might be hidden by a stopped vehicle in a travel lane.

2. Method

Evaluation of drivers behavior in sight-limited, multi-threat scenarios is very difficult in the field, primarily because of the inherent dangers created if the scenario is staged. A driving simulator is an ideal alternative in this case. Thus, a simulator was used in the current study to evaluate whether drivers approaching a crosswalk in a sight-limited, multi-threat scenario were more likely to look for pedestrians when advance yield markings were present than when the traditional markings were used (Hypothesis 1). We also evaluated whether drivers who looked for a pedestrian did so sooner when advance yield markings were used (as indicated by time to crosswalk measured from the moment that the driver first glanced at the pedestrian) (Hypothesis 2). And lastly, we evaluate whether drivers yielded more often for a pedestrian in the crosswalk emerging into view at the last minute when advance yield markings were used (Hypothesis 3).

2.1. Participants

Thirty-six (36) subjects participated in the study conducted in a driving simulator. Eighteen subjects were randomly assigned to the traditional markings condition and eighteen to the advance yield markings and prompt sign condition. Most subjects (72%) were male; however, the proportion of males and females was equal in both groups. The mean age for participants in the control condition was 21 years old and 22 years old for the experimental condition. The average annual mileage per driver (self-reported) was 7700 in the control and 8200 in the experimental group. Overall participants in each group were not totally unfamiliar with advance yield markings and the associated prompt sign. In particular, subjects in both groups indicated they frequently drive in downtown Amherst, Massachusetts (an area where yield markings have been installed for at least three years). Subjects were recruited from the local area using information posted around the University of Massachusetts Amherst, regional online newspapers, and local businesses. Subjects received $20 for their participation.

2.2. Stimuli

The control condition consisted of a stop bar located 10 ft before the crosswalk. The experimental condition presented advance yield markings and prompt signs (Fig. 5). Yield markings consisted of a line of solid white triangles (triangles are 24 inches wide at the base and 36 inches long) pointed towards approaching vehicles. The line of triangles extended across the approach lane; the space between each triangle was 12 inches. Yield markings were placed 30 feet upstream of the crosswalks to indicate the point at which the yield was required to be made. Dimensions and placement of the yield markings followed the guidelines of the 2003 Edition of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD, 2003). A prompt sign (MUTCD R1-5) 24 inches wide by 30 inches high was placed right next to the yield markings. Dimensions of the sign exceeded the guidelines provided in the 2003 MUTCD (i.e., 18 inches wide by18 inches high). Note: recently revisions to the MUTCD recommend 36 inches wide by 48 high inches signs (MUTCD, 2009).

2.3. Apparatus and experimental scenarios

2.3.1. Driving simulator—The fixed-base simulator included a full size Saturn sedan in which all vehicle controls were fully operative. The visual world was displayed on three screens—allowing 150° of vision in the horizontal direction and 30° in the vertical direction.

Images were displayed with a refresh rate of 60 Hz. The simulator also employed a surround sound audio system.

2.3.2. Scenarios and procedure—The scenarios included situations where the driver approached uncontrolled, marked mid-block crosswalks with an obstruction in either the right lane or left lane (i.e., three vehicles in queue, each with its the turn signal activated). The virtual world simulated was an urban environment and the posted speed limit was 30 mph. The environment consisted of a two-way/four-lane road with vehicles traveling in the opposite direction, approaching from the right or left side at stop-controlled intersections, and entering/leaving parking lots. The simulation also included construction zones and other physical obstructions in the travel lane as well as pedestrians. Participants followed a lead vehicle to an unknown destination and were also prompted to change lanes at various points within the trials.

Two drives were presented to each subject. Each scenario (obstruction on right or left lane) was included once within a drive. Pedestrians were included in the simulation (e.g., pedestrians completing street crossings at selected intersections) to show the driver that it was possible to encounter such an event elsewhere in the simulation. However, a pedestrian was never present in the crosswalk in any of the experimental (sight-limited, multi-threat) scenarios included in the first drive but always present in the last experimental scenario of the second drive. For the last scenario in the second drive, there was an invisible trigger on the road at the same location for the standard and experimental conditions; when the driver crossed the trigger the pedestrian started walking towards and then into the crosswalk. When a pedestrian was present, its initial position and speed was carefully coordinated so as to ensure each participant driver experienced the same scenario. The scenarios were beta tested prior to conducting the experiment.

Participants were asked to drive as they normally would while following all traffic rules and regulations. Additionally, they were told that they were to follow a lead vehicle (a black SUV) while maintaining a safe following distance. Finally, they were told that their speed would be recorded at selected intervals throughout the drive.

2.3.3. Eye tracker—A portable eye tracker system (ASL Mobile Eye) was used to monitor eye movements of the driver. The eye tracker sampled the position of the eye at 30 Hz. The visual range was 50° in the horizontal direction and 40° in the vertical direction. The system's accuracy was 0.5° of visual angle. The point of gaze in the driving environment was superimposed on a video of the scene viewed by the driver. The video allowed the experimenter to determine whether a driver fixated specific areas in the driving scene.

2.4. Dependent variables and data collection

The dependent variables included: (1) whether the driver did or did not fixate predefined areas in the driving environment, (2) time-to-crosswalk once the pedestrian had been fixated, and (3) the percentage of vehicles yielding to pedestrians. We anticipated that drivers approaching a crosswalk would be more likely to look for pedestrians when the crosswalks have advance yield markings and pedestrian crosswalk prompt signs than when they are delineated by standard markings. Two sets of reference points delimited the areas of visual interest: one set defined the area of the roadway in which the driver must be operating when the fixation was scored (*launch zone*); the other defined the area of the roadway or environment at which the driver must be looking (the *target zone*). If the driver was in the launch zone when he or she fixated in the target zone, then the driver was considered to have looked at the risky situation or area of interest along the road.

The *target zone* was the area right in front of the first vehicle stopped near the crosswalk (or stopped at the advance yield makings, in the advance yield markings condition). This first vehicle was blocking the view of a potential pedestrian entering the crosswalk. The *launch zone* was defined as the area extending from the crosswalk to 150 ft in advance of the crosswalk. It was assumed that drivers predicted the risk if they fixated the area where a pedestrian may emerge. If the driver fixated this area, a hit or a correct response was recorded (value = 1), otherwise a miss was recorded (value = 0).

It was hypothesized that drivers who do look for a pedestrian will do so sooner when advance yield markings are present than when the traditional markings are used. In this case, the time-to-crosswalk at which the driver first fixated the area in front of the obscured vehicle was recorded. It was also expected that drivers would stop/yield more often for a pedestrian when advance yield markings were used. Drivers were scored as yielding if they initiated braking in advance of the crosswalk and gradually slowed before stopping. Drivers were scored as not yielding if they passed in front of the pedestrian and did not stop when the pedestrian arrived at the crosswalk.

3. Results

First, we tested the null hypothesis that drivers in the two groups (i.e., advance yield markings condition and traditional markings condition) looked for pedestrians equally often. Overall (across all subjects and both drives) participants in the advance yield markings' group looked for pedestrians 76% of the time and drivers in traditional markings' group looked for pedestrians 60% of the time (see Table 2). The difference (16%) is statistically significant using a one tail t-test, $t(18) = 1.734$, $p < 0.05$.

Next, we examined whether the benefits decreased with successive exposure to the treatment, perhaps, due to novelty at the start (in the first drive). In particular, we were interested in whether the percentage of drivers exposed to the advance yield markings looking towards the target zone was much higher in the first drive than it was in the second drive (only the first scenario in the second drive was used because a pedestrian is materialized in the second scenario in the second drive). Table 3 shows the separate results for the first and second drives. For the advance yield markings, the mean for the first drive is 69% and increases to 83% for the second drive. Thus, novelty by itself cannot explain the effect.

A repeated measure ANOVA was undertaken in order to determine whether the fact that the scenarios were presented twice (i.e., once in drive 1 and once in drive 2) had an effect on the average proportion of correct responses for the two conditions. The within-subject variable '*drive*' had a significant effect ($F = 7.68$, $p < 0.01$) on overall performance which indicated that drivers became more cautious from the first to the second drive. However, there was no interaction between drive and treatment condition. Thus, drivers in both conditions were becoming more cautious by about the same amount. This is important when interpreting the results from the second scenario in the second drive where a pedestrian is actually materialized.

Next, we explored whether advance yield markings were more effective when the obstruction was on the right than when it was on the left. A mixed ANOVA was undertaken using the data from the first experimental drive only (see Table 4). The location of the obstruction (left versus right) did not affect the probability that a driver would look for a pedestrian.

Finally, in the last scenario in the second drive, a pedestrian actually emerges in front of a stopped vehicle in the travel lane (see Table 5). Recall that there was an invisible trigger on the road and the pedestrian starts walking when the driver crossed this trigger. We tested the hypothesis that drivers in the advance yield marking condition and drivers in the traditional marking condition looked for the pedestrian equally often. Overall, drivers looked for pedestrians equally often (83%) in each condition. We also tested the null hypothesis that the time-to-crosswalk at which a driver's first fixation to a pedestrian was made is the same in both conditions (see Table 5). The time-to-crosswalk at which a subject first looked for a pedestrian was 2.2 s for the advance yield markings condition and 1.0 s for the standard markings condition, a difference which was statistically significant ($Z = 1.96$, $p = <0.01$). Finally, the proportion of drivers yielding for a pedestrian was recorded (see Table 5). None of the participants yielded for the pedestrian in the control group. However, when advance yield markings were used, 61% of the participants yielded or stopped for the pedestrian; the difference (61%) was statistically significant [Fisher's Exact Test (p-value <0.001)]. Thirty-six (36) percent of the subjects that yielded completed an evasive maneuver to avoid a collision (e.g., steering left or sudden deceleration). This abrupt response is an unintended consequence that deserves further investigation since it may result in an increase in rear-end, vehicle-to-vehicle crashes.

4. Discussion

It is known from several different field studies in which drivers’ behavior is observed from outside the vehicle that advance yield markings and prompt signs encourage drivers to yield sooner and more often when there is no obvious obstruction between the driver and pedestrians entering the crosswalk (Huybers and Van Houten, 2004; Van Houten et al., 2001; Garay-Vega et al., 2008). And it is known from one study done in the field where drivers’ eyes were tracked that in sight-limited scenarios with obstructions in the parking lane drivers actually look towards the side of the crosswalk with advance yield markings and prompt signs sooner than they do with standard yield markings and prompt signs.

Although the evidence to date as cited above suggests that drivers will behave more safely in sight-limited scenarios where there are multiple threats (Fig. 3), it is not known that such is definitely the case since this specific scenario has not been studied. Studying such scenarios in the field is all but impossible since they are inherently among the most dangerous. This study, conducted in a driving simulator, made it possible to study these scenarios. It was demonstrated that advance yield markings and prompt signs in sight-limited, multi-threat scenarios lead to changes in drivers’ behaviors which are likely to reduce pedestrian–vehicle conflicts: increasing the likelihood of glances towards the pedestrian, increasing the distance at which the first glance is taken, and increasing the likelihood of yielding. The safer behaviors observed by drivers exposed to the advance yield markings when pedestrians were not present in the crosswalk could not be attributed to the relative novelty of these markings. If anything, drivers became more cautious as their exposure to such markings increased. And the safer behaviors observed by drivers exposed to the advance yield markings when pedestrians were materialized could not be attributed to a treatment specific increase in cautiousness since this increase in caution across drives was observed for the drivers exposed to the traditional markings as well.

More generally, advance yield markings and signs have real economic advantages over almost all other treatments being considered. They are simple to install and inexpensive. And they have safety advantages not only in the three sight-limited scenarios that were discussed, but also those which do not qualify at first glance as sight-limited. For example, consider a road with two travel lanes and no parking lane. A driver approaching a vehicle stopped for a pedestrian in a marked midblock crosswalk may not realize that the stopped vehicle is waiting for a pedestrian to cross and may pull out into the opposing lane and around the stopped vehicle. This very quickly turns into a sight-limited scenario and the extra distance that advance yield markings provide should reduce the likelihood of a pedestrian–vehicle collision.

Advance yield markings and prompt signs could ultimately prove worrisome if pedestrians actually became less likely to look for threats. Perhaps they would do such because the stopped vehicles are further upstream and therefore they (the pedestrians) feel more safe. The effect of advance yield markings on pedestrians' behavior should be studied as well as the effect on drivers' behavior, something that has not yet been undertaken.

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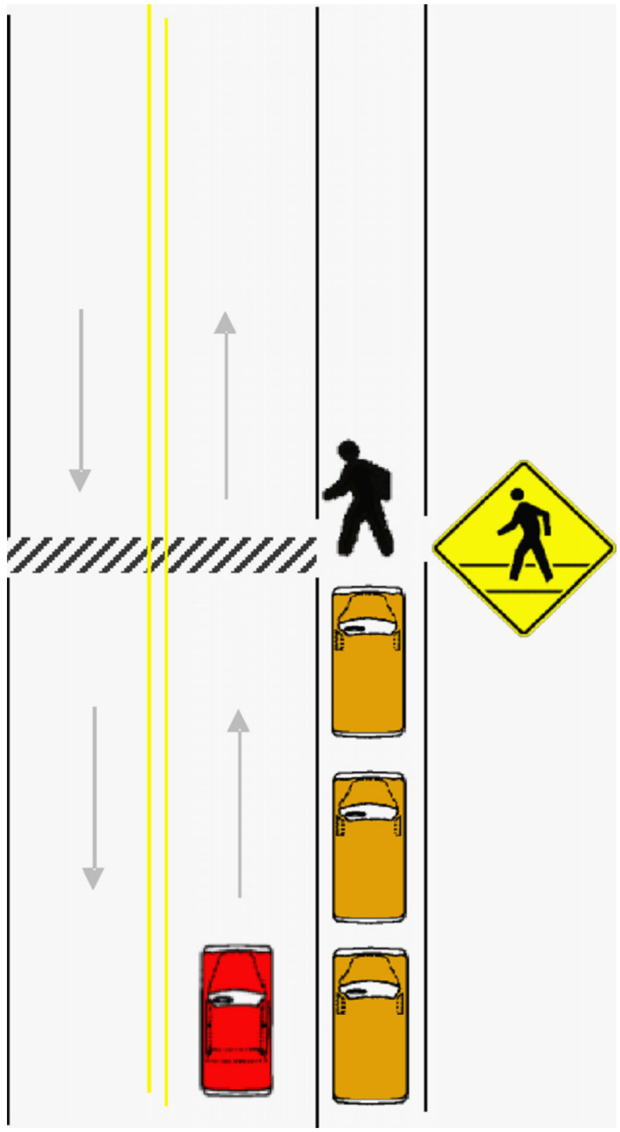

Fig. 1.
Sight-limited scenario: parking lane obstruction.

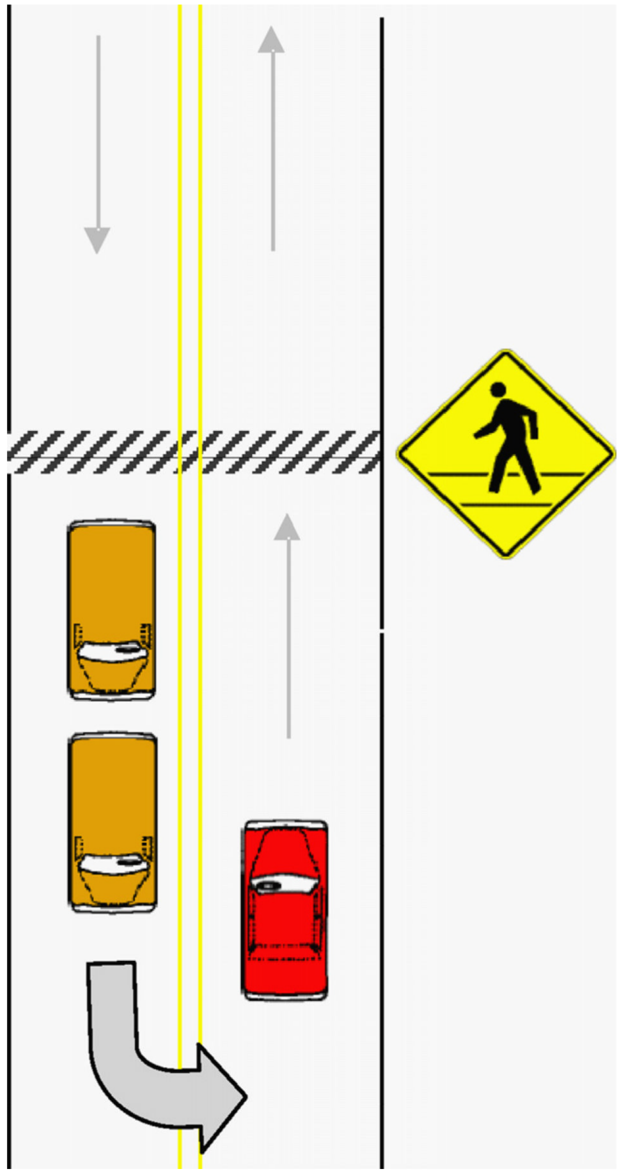

Fig. 2.
Sight-limited scenario: turning obstruction.

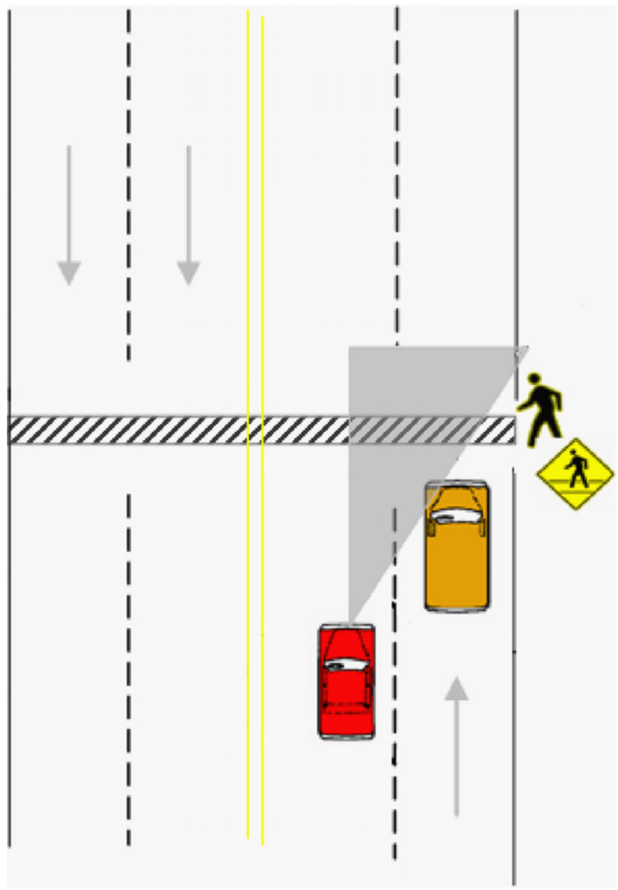

Fig. 3.
Sight-limited scenario: multi-threat.

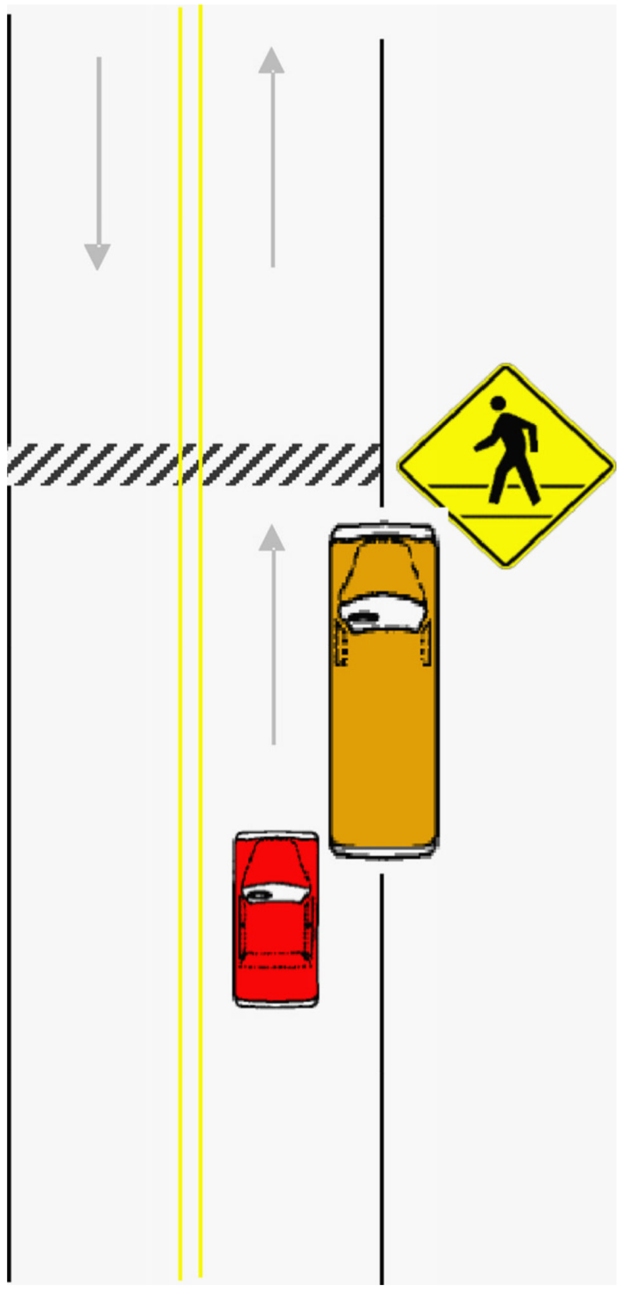

Fig. 4.
Truck parked on the shoulder obstruction blocking the driver's view of pedestrians who might be crossing in front of the truck.

Fig. 5.
Advance yield markings and sign in the virtual environment.

Table 1

Probability of fixating critical region for novice and experienced drivers (Garay-Vega et al., 2007).

	Probability of fixating critical region	Probability of fixating critical region given pedestrian was fixated
Experienced	79.2%	94.7%
Novice	52.8%	61.4%

Table 2

Percent of drivers looking to target zone, overall (2 sessions).

Condition	Mean	Std. deviation
Traditional marking	0.60	0.30
Advance yield markings	0.76	0.23

Table 3

Percent of drivers looking to target zone for each experimental session.

Condition	Drive	Mean	Std. deviation
Traditional marking	1	0.47	0.36
Advance yield markings		0.69	0.35
Traditional marking	2	0.55	0.39
Advance yield markings		0.83	0.24

Table 4

Percent of drivers looking to target zone by location of the obstruction (left vs. right).

Condition	Scenario	Mean	Std. deviation
Traditional marking	Obstruction	0.44	0.51
Advance yield markings	left	0.67	0.48
Traditional marking	Obstruction	0.50	0.51
Advance yield markings	right	0.72	0.46

Table 5

Results for last scenario, pedestrian emerges in front of obstruction.

Condition	% Drivers looking	Time-to-crosswalk (at which a driver's first fixation to a pedestrian)	% Drivers yield
Traditional marking	83%	1.1s	0%
Advance yield markings	83%	2.2 s	61%
Difference	0%	1.0 s	61%