Evaluation of Driver Yielding Compliance at Uncontrolled Midblock Crosswalks on Divided Low-Speed Roadways

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ABSTRACT
A series of field studies were performed to compare the effectiveness of traffic control countermeasures commonly utilized at uncontrolled midblock crosswalks on divided low-speed roadways. Crosswalk treatments were evaluated at 11 low-speed midblock crosswalks located on divided roadways near two public universities. The study locations included unmarked crosswalks, in addition to continental crosswalk markings, some of which included the in-street R1-6 sign. Driver yielding compliance during staged pedestrian crossing events was used as the measure of effectiveness. To isolate the crosswalk treatment effects, several roadway and traffic characteristics were included in the analysis, including vehicular volumes, travel lane of the subject vehicle, and the subject vehicle's position in a queue. A binary logistic regression model with random effects was utilized to account for correlation in yielding rates within the same sites. The results indicated the type of crosswalk treatment has a strong influence over driver yielding compliance. While yielding compliance improves substantially when crosswalk markings are utilized, the highest compliance rates are achieved when the in-street R1-6 sign is also provided. Yielding compliance showed little sensitivity to the particular travel lane of the subject vehicle at locations where the R1-6 sign was utilized, further validating the effectiveness of this treatment.

BACKGROUND AND OBJECTIVES

Approximately 65,000 pedestrians are injured and 5,000 are killed in traffic crashes in the United States each year (*1*). Various efforts have been implemented to address this public health dilemma, including "Safe Routes to School" programs, "Complete Streets" policies, and other initiatives. However, it is expected that such programs have also facilitated increases in pedestrian traffic and may lead to an increased potential for crashes involving these non-motorized users.

Pedestrian crashes frequently occur within urban and suburban areas and on college campuses as these areas generally experience the highest levels of pedestrian activity and traffic volumes. Pedestrian safety concerns are pronounced at non-intersection (i.e., midblock) locations where drivers are less expectant of pedestrians and where pedestrians are often less conspicuous. Recent data from Michigan indicate more than 50 percent of pedestrian crashes occur at unsignalized midblock locations, and the rate of pedestrian fatalities at such locations is more than three times higher than at signalized intersections (*2*). Risks are heightened at locations with limited or no traffic control, especially where crosswalks are unmarked, where approach legs of intersections or driveways are uncontrolled, and on multilane roadways where the exposure to vehicular conflicts is higher. Divided roadways in particular are generally multilane roads with relatively higher vehicular volumes. These risks may be mitigated, in part, by the application of appropriate engineering treatments to enhance motorist awareness of approaching pedestrians.

A variety of pedestrian safety treatments are available for implementation at such locations. Resource constraints make it imperative for agencies to identify locations that are at highest risk for pedestrian-involved crashes, as well as those countermeasures that are most cost-effective in mitigating these risks. As such, there is a clear need for well-supported guidance to determine the effectiveness of specific pedestrian safety treatments under various settings.

To address this gap in the extant research literature, a series of field studies were performed across two college campuses in southern Michigan to compare the relative effectiveness of various types of traffic control devices used at uncontrolled midblock crosswalks on divided low-speed roadways, including crosswalk markings as well as the R1-6 in-street sign. Driver yielding compliance was the primary measure of effectiveness, which served as a surrogate for crash occurrence due to a limited number of pedestrian crashes on a site-by-site basis.

LITERATURE REVIEW

Safety Performance at Midblock Crossing Areas

The Highway Safety Manual (HSM) includes various methods for estimating pedestrian crashes on urban and suburban arterials, with separate methodologies provided for road segments, signalized intersections, and stop-controlled intersections (*3*). For signalized intersections, the predictive method in the HSM is based on a pedestrian-specific safety performance function (SPF) that is estimated based on the number of intersection legs, as well as pedestrian and motor vehicle traffic volumes. A series of crash modification factors (CMFs) are then applied to the base SPF to account for the effects of bus stops, schools, and alcohol establishments in the immediate vicinity. In contrast, the method for estimating pedestrian crashes along segments or corridors is rather simplistic in nature, with pedestrian crashes estimated as a proportion of motor vehicle crashes based upon only the posted speed limit. Unfortunately, the HSM provides no predictive methods for predicting the frequency of pedestrian crashes at midblock crossing locations, which is largely reflective of the relative infrequency of crashes at such locations. Nonetheless, CMFs have been estimated for various pedestrian crossing treatments in the research literature, including: raised pedestrian crosswalks (*4*); raised medians (*5-6*); high-visibility crosswalks (*7*); and pedestrian hybrid beacons (*8*). The limited number of pedestrian crashes experienced on a site-by-site basis has prompted the use of surrogate measures to assess pedestrian safety at midblock crossing areas. While previous research suggests that providing raised medians reduces crash risk for pedestrian (*5-6*), a recent study found divided roadways are associated with lower levels of driver yielding compliance on low-speed roads, possibly due to sight obstructions (*9*).

Surrogate Measures of Pedestrian Safety

To be effective, surrogate measures should be correlated with observed crash frequencies and should also fully capture the effects of the treatment (*10*). A recent naturalistic driving study provided the most extensive investigation into the relationship between crashes and near-crashes (i.e., conflicts), which were defined as rapid evasive maneuvers by the study vehicle (*11*). Analysis of these data showed a strong positive correlation, suggesting that near-crashes are an acceptable surrogate measure for crashes at locations where crashes are rare (*12*).

However, just as crashes are rare events, vehicle-pedestrian conflicts are also rare, which may lead to an under-prediction of crashes when relying on conflicts as a surrogate measure (*13*). To overcome this limitation, driver yielding compliance has often been utilized as a surrogate measure for crashes, with higher compliance rates being indicative of safer (i.e., low-crash) locations (*14-16*). One concern that arises in the analysis of compliance data for vehicle-pedestrian interactions is the significant degree of heterogeneity in pedestrian behavior both within and across locations. In order to reduce potential bias, staged crossing attempts are generally performed as a part of these studies. This approach results in crossings that occur in a uniform and consistent manner by trained data collectors. During each staged crossing event, the observer indicates the desire to cross by placing one foot in the crosswalk when the vehicle has reached a pre-defined upstream location, typically determined based on stopping sight distance. This method is consistent with right-of-way laws in most states. Driver yielding or non-yielding behavior (i.e., compliance) is assessed during each crossing attempt. A comparison of yielding behavior between staged and unstaged crossings showed no significant difference in results, supporting the use of staged pedestrians for assessment of yielding compliance (*15*).

Midblock Crosswalk Treatments

Prior research has indicated that simply converting an unmarked midblock crossing area to a marked crosswalk with no additional treatment will not improve safety (*6*). Furthermore, marked crosswalks are specifically not recommended on high-volume multilane roadways without a refuge island or median (*6*). Given the limited effectiveness of marked crosswalks as a stand-alone measure, various innovative pedestrian safety treatments have been applied. These include the pedestrian hybrid beacon (PHB), rectangular rapid-flashing beacon (RRFB), and in-street pedestrian signs, each of which have been implemented nationwide and include numerous evaluations as to their effectiveness under various settings (*8, 17-22*). The prior research has generally focused on evaluating the effectiveness of such treatments with respect to a baseline condition (i.e., marked crosswalk-only), typically utilizing yielding compliance rates as the primary performance measure.

While the PHB and RRFB are commonly utilized to improve pedestrian safety, installation costs of approximately $100,000 and $20,000 for PHBs and RRFBs, respectively, limits the application of these devices. Conversely, the in-street pedestrian sign (R1-6) provides a very low-cost pedestrian safety treatment that has shown favorable motorist compliance rates when used under certain settings and in various configurations. A single R1-6 sign placed on the centerline within an uncontrolled crosswalk at three low-speed two-lane roadways in Washington produced average compliance rates of 87 percent (*18*). Lower yielding compliance rates of 57 percent were observed with a single R1-6 in place on two low-speed multilane roadways in Michigan (*17*). However, upgrading to a series of three R1-6 signs in the “gateway” configuration at these same Michigan locations improved motorist compliance to 81 percent, likely due to a combination of the message and the lane narrowing effect provided by the signs. Furthermore, the addition of a single R1-6 to the center of a crosswalk at two Michigan locations with an existing PHB increased motorist compliance from 77 percent to 90 percent (*17*).

FIELD STUDY

Site Selection

During the early stages of this study, a total of 11 uncontrolled midblock crossing locations on divided roads were identified from two Michigan cities that are home to large public universities. A cross-sectional study design was utilized as there was no provision for modification of the pedestrian crosswalk treatments during the course of the study. Although a cross-sectional study introduces some challenges in discerning the effects of specific treatments, sites were selected such that the sample comprised a diverse range of roadway and traffic characteristics. Furthermore, the data analysis framework allowed for a robust comparison of how various treatments impacted compliance rates in consideration of these other factors. In addition, the cross-sectional study design provides a distinct advantage within the context of this study because the treatments had existed at each location for a minimum of one year. Consequently, it is expected that any novelty effects associated with any particular treatment would be less of a concern as compared to a before-and-after study design.

The study sites were selected to provide diversity among existing crosswalk treatments and roadway characteristics, in addition to a broad range of motor vehicle and pedestrian volumes. To ensure adequate pedestrian activity, the locations were selected from two college campuses across southern Michigan. A total of five sites were selected from the midtown area of Detroit (Wayne State University) and six sites were located in East Lansing (Michigan State University). The relevant site characteristics, including crosswalk treatment, roadway cross-section, and crossing width, were initially collected using Google Earth satellite imagery, and were later verified in the field. The posted speed limit was 25 mph at all locations.

Field Data Collection

Field data related to the behavior of motorists and pedestrians during pedestrian crossing events were collected at the 11 midblock crossing locations on divided roads between August and October of 2015. The data were collected during midday periods and under fair weather conditions for durations of two to four hours per site. High-definition video cameras were covertly positioned on telescoping poles that were temporarily installed at each location to record the staged pedestrian crossing attempts along with vehicle and pedestrian volumes. The videos were later reviewed to extract motorist yielding compliance during the staged crossing events. Using video recordings provided two primary advantages over using on-site human observers: 1) the number of necessary field personnel at each site was reduced and 2) permanent record of the interactions was provided, which improved training and quality assurance procedures. Volumes of vehicles, bicycles, and naturalistic (i.e., non-staged) pedestrian crossings were also collected from the videos at each study location during the study period and converted to an equivalent hourly volume. Figure 1 displays an example of the video camera setup and field-of-view.

FIGURE 1 Typical video camera setup for recording motorist yielding behavior.

Staged Pedestrian Crossings

A series of staged pedestrian crossing events were utilized for the assessment of driver yielding compliance at each study location. The staged crossings were performed by male undergraduate and graduate research assistants who were trained to follow a uniform crossing protocol for each approaching vehicle. The protocol was developed to provide consistency in terms of positioning, stance, gesture, eye contact, and aggressiveness while entering the crosswalk. This also allowed for control over external biases such as clothing style and conspicuity. The method also ensured a sufficient sample size at each location, which improved data collection efficiency at locations with lower pedestrian crossing volumes. The staged crossing events followed protocols established in prior research (*17-18*), which are summarized as follows:

- The staged pedestrian approached the crossing when approaching vehicles were within sight of the crossing. Staged crossing attempts were not attempted while other pedestrians were attempting to cross the same crosswalk.
- The staged pedestrian indicated an intention to cross by standing at the curb or roadway edge with one foot in the crosswalk and facing oncoming traffic. This action occurred as the subject vehicle closed to within 110 ft of the crosswalk, which was determined based on the standard kinematic equation for the timing of an amber interval at a traffic signal for a speed limit of 25 mph. By consistently initiating the staged crossing event prior to this point, motorists were afforded ample distance to comfortably stop for the staged pedestrian. Vehicles already past this point were considered too close to stop comfortably and were not considered.
- The staged pedestrian began to cross when the motorist in the nearest lane had begun to yield and maintained eye contact with the motorist at all times.
- If additional vehicles were approaching from other lanes, the staged pedestrian crossed halfway into the lane where a motorist had already stopped or yielded and waited until the intention of the approaching motorist was determined. This process was completed as many times as necessary to reach the curb.
- After concluding the midblock crossing, the procedure was then repeated from the opposite direction at the same crosswalk.

A yielding event was classified as a motorist that was initially positioned upstream of the boundary point at the start of the staged crossing event that slowed or stopped to allow the pedestrian to safely cross. For motorists in the nearest lane to the pedestrian, the yielding assessment was made on the basis of the initial intention to cross the roadway. For motorists in the additional lanes, if present, this assessment was made once the pedestrian had crossed to within a half-lane distance of their position. Opposing directions of traffic on divided roadways were considered separately. These procedures are consistent with the crosswalk right-of-way requirements included within the *Uniform Traffic Code for Cities, Townships, and Villages* that has been adopted as a local ordinance by many Michigan municipalities (*23*).

Data Summary

Driver yielding compliance data were extracted from the 11 sites where staged pedestrians were utilized, resulting in a total of 580 observations, which were either scored as "yielded" or "did not yield." These data are summarized in Table 1. Sites with in-street R1-6 sign utilized the continental style (i.e., markings parallel to the traffic direction) crosswalk. Utilization of R1-6 signs were limited to a single sign placed on the centerline within the crosswalk, and the three sign "gateway" application of this sign was not used in this study.

TABLE 1. Summary of Site Characteristics for Midblock Yielding Compliance Assessment

Categorical Factors					
Factor	**Level or Unit**	**Proportion of Observations**	**Number of Sites**		
Driver action	Yield	0.62			
	Did not yield	0.38			
Vehicle lane position	Near (curb) lane	0.70			
	Center or far lanes	0.30			
Position of vehicle in queue	Unqueued vehicle	0.72			
	Queue leader	0.20			
	Queue follower	0.08			
Crosswalk treatment	Unmarked	0.14	1		
	Continental only	0.70	8		
	In-street R1-6 sign	0.17	2		
Continuous Factors					
Factor	**Level or Unit**	**Mean**	**SD**	**Min**	**Max**
Crossing width	ft	64	10.01	22	49
Vehicle volume at crosswalk	vehicles/h	367.10	129.43	220.7	614.5
Pedestrian crossing volume	pedestrians/h	97.15	122.49	14.33	371

Data Analysis

As driver yielding compliance is a binary (yes/no) outcome, logistic regression provides an appropriate framework for determining those vehicle, pedestrian, and roadway factors associated with driver yielding behavior. Within the context of this study, the logistic regression model takes the general form:

$$\ln\left[\frac{p_i}{1-p_i}\right] = \alpha + \beta X_i, \quad (1)$$

where p_i is the response probability of driver i yielding to a pedestrian, α is an intercept term, β' is a vector of estimable parameters, and X_i is a vector of predictor variables (e.g., crosswalk treatment, pedestrian/vehicular volumes).

One concern that arises within the context of this study is the potential correlation in compliance rates within individual locations due to common, unobserved factors (i.e., unobserved heterogeneity). Failure to account for such correlation may lead to biased or inefficient parameter estimates. To account for this concern, a site-specific random effect is added for each location j, resulting in:

$$\ln\left[\frac{p_i}{1-p_i}\right] = \alpha_j + \beta X_i, \quad (2)$$

This approach allows for the constant term to vary across locations, but maintain the same value for all crossing events observed at an individual location. The variables from Table 1 were considered as predictors when estimating this mixed effects logistic regression model.

RESULTS AND DISCUSSION

The final model results for driver yielding compliance are displayed in Table 2, which includes the coefficient estimate, standard error, p-value, and odds ratio for each variable included in the mixed effects logistic regression model. The base conditions for the model were included as follows: unmarked crosswalk, subject vehicle in the lane nearest to the curb, and subject vehicle not queued.

TABLE 2. Logistic Regression Results for Driver Yielding Compliance

Variable	Level or Unit	Coefficient Estimate	Standard Error	p-value	Odds Ratio
Constant		-6.5675	2.6109	0.0119	N/A
Crosswalk treatment	Unmarked	*baseline*			
	Continental only	1.0557	0.5101	0.0385	2.9
	In-street R1-6 sign	3.6715	0.6926	<0.0001	39.3
Vehicle volume	ln(veh/h)	0.9504	0.4629	0.0401	2.6
Vehicle lane position	Near (curb) lane	*baseline*			
	Other lane	0.8714	0.2481	0.0004	2.4
Vehicle position in queue	Unqueued vehicle	*baseline*			
	Queue leader	0.9059	0.2622	0.0006	2.5
	Queue follower	-1.026	0.4466	0.0216	0.4

The results of the logistic regression model revealed several interesting findings. The type of crosswalk treatment had a strong association with driver yielding compliance. Compared to unmarked crossing areas, each of the crosswalk treatments provided significant improvements in driver yielding compliance during the staged pedestrian crossing attempts. Both the continental crosswalk was shown to increase compliance over unmarked crosswalks. On average, compliance rates were 2.9 times higher for continental crosswalks. The inclusion of an R1-6 in-street sign provided substantial improvements in yielding compliance over the continental crosswalk. To further enhance discussion of the crosswalk treatment results, the raw yielding compliance summary statistics are displayed for each treatment type in Table 3.

TABLE 3. Driver Yielding Compliance by Crosswalk Treatment

Crosswalk Treatment	Number of Locations	Number of Observations	Percent of Drivers Yielding
Unmarked	1	80	25.00%
Continental only	8	404	61.14%
In-Street Sign (R1-6)	2	96	94.79%
ALL	11	580	61.72%

The raw yielding compliance rates for each type of treatment revealed several interesting findings that generally followed the model results. The sites with an R1-6 sign positioned within the crosswalk showed a yielding compliance rate of 95 percent, which was substantially higher than crosswalks with no additional treatment. Although crosswalks with R1-6 signs have shown compliance rates of up to 87 percent in prior studies (*18*), such a high level of compliance was a surprising result given the low cost of the R1-6 sign.

Turning to other variables of interest, there was significant variability in compliance based upon the lane where the subject vehicle encountered the pedestrian. Drivers traveling in the near (curb) lane were 2.4 times less likely to yield for a pedestrian compared to drivers traveling in any other lane. This effect may be reflective of differences in driver expectancy based upon pedestrian location and behavior. When crossing attempts were initiated at the near (curb) lane, approaching drivers may have either not been observed by the approaching driver or the driver may not have realized their intention to cross. In contrast, the pedestrians' intensions were likely clearer while attempting to cross the other lanes where the individual was completely within the roadway as the driver approached. The pedestrians were also likely more conspicuous to approaching drivers overall. Turning to the interaction between lane position and crosswalk treatment, the results for which are displayed in Table 4, yielding compliance was lower in the near lane across all crosswalk treatments. Near-lane yielding compliance was especially poor for unmarked crosswalks (19.6 percent), improving to 56.6 percent where continental crosswalks were used. Yielding compliance at standard crosswalks was particularly sensitive to lane position, increasing from 56.6 percent for drivers in the near lane to 75.8 percent for drivers in any other lane. Yielding compliance was far less sensitive to driver lane position at locations where the R1-6 sign was utilized, emphasizing the effectiveness of this treatment.

TABLE 4. Interaction of Lane Position with Roadway Cross-Section and Crosswalk Treatment

	Number of Observations		Yielding Compliance	
Variable	**Near Lane**	**Other Lane**	**Near Lane**	**Other Lane**
Unmarked	56	24	19.64%	37.50%
Continental only	309	95	56.63%	75.79%
In-Street Sign (R1-6)	39	57	92.31%	96.49%
ALL	404	176	54.95%	77.27%

The vehicle's position within the queue also affected the likelihood of driver yielding. The logistic regression results displayed in Table 2 suggest that queue leaders were 2.5 times more likely to yield compared to unqueued drivers and were 6.3 times more likely to yield compared to queued drivers that were not in the lead position. These results are not surprising, as queued drivers in many cases are simply following the leading vehicle, who obviously also did not yield for the pedestrian. Past research on the PHB has shown that queued drivers will tend to follow the queue leader without first checking for pedestrians attempting to cross (*24,25*) and it is likely this same phenomenon occurs with other crossing treatments.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study provide several important insights to inform subsequent decisions by road agencies as to the installation of pedestrian crosswalk treatments. A logistic regression model with random effects was estimated to account for intra-site correlation in yielding rates, as well as for the effects of unobserved heterogeneity across study locations. The results demonstrate the importance of applying robust analytical methods to examine driver-pedestrian interactions.

Ultimately, the findings provide a clear indication that the type of crosswalk treatment has a strong influence over driver yielding compliance. While yielding compliance improves substantially when crosswalk markings are utilized, much greater compliance is obtained when the in-street R1-6 sign is also provided. Yielding compliance rates for the various crosswalk treatments were shown to be in agreement with previous research performed outside of Michigan, and also showed improvements across all treatment types compared to prior studies performed within Michigan. This is an important finding, which suggests that compliance improves as drivers become more familiar with a particular treatment.

It was also found that yielding compliance is highly sensitive to lane position of the vehicle relative to the location of the crossing pedestrian. Drivers were much less likely to yield when the driver encountered the staged pedestrian at the nearside curb lane compared to any other lane. This is not a surprising result, as the pedestrian is in a less conspicuous and less vulnerable position when waiting near the curb, compared to encounters that occurred while the pedestrian was approaching any other lane. While this result is reflective of the interaction between motorists and pedestrians attempting to cross, it does indicate the necessity for yielding compliance studies to control for the driver lane position. This may be indicative of potential obstructions within the median that reduce the visibility of pedestrians waiting to cross. Perhaps most importantly, however, yielding compliance showed little sensitivity to the particular travel lane of the subject vehicle at locations the in-street R1-6 sign was utilized, further validating the effectiveness of this device.

Road agencies are advised to place crosswalks in otherwise unmarked locations where pedestrians frequently cross and, when necessary, install additional treatment. Providing marked crosswalks in locations with light to moderate vehicle volumes will result in higher yielding compliance and will typically not require additional treatment unless special circumstances (i.e., school, hospital, etc.) exist. For midblock crosswalks in locations with high vehicle and/or high pedestrian volumes, particularly at multilane locations, additional low-cost treatments such as in-street pedestrian crossing signs may further increase compliance and provide subsequent safety benefits

While the results of this study provide important insights to guide subsequent investment strategies for mid-block crossings, there are some important limitations that must be stated. First, the results are limited to low-speed, divided locations only. Yielding compliance is likely different on higher speed roadways, where pedestrian activity is typically less frequent. Furthermore, all sites selected in this study were on or near public universities in the Midwest during the early fall when school was in session. Therefore, the samples of pedestrians and drivers included in this study are a non-random sample and it is unclear how these trends would extrapolate to a broader population.

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