Safety Effects of the Yellow Light Border (YPB) Pedestrian Signal: An Evaluation

or

An Empirical Study on Crossing Behavior at a Signalized Intersection with High-Volume Pedestrians

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Final Report

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16. Abstract

This study focuses on the pedestrian crossing behavior (individual or group), vehicle yielding action, and possible factors contributing to the conflict at the tourist location (signalized T-intersection) with high volume of pedestrian and traffic. Several attributes including pedestrian demographics (age, gender, etc.), crossing behavior (waiting time, crossing speed, etc.), and motorist characteristics (waiting time, yielding, etc.) are considered for the empirical analysis. The dataset contains 327 manually extracted events including 500 pedestrians recorded from the video cameras placed at signal poles to focus on the crosswalk interaction behavior. Out of these events, 246 are conflicts and the other 81 include regular and unique crossing behavior. Several models including binary logit, ordered logit and multinomial logit are formulated to analyze pedestrian crossing behavior, vehicle yielding action, and interaction process coupled with conflict, yielding, and pedestrian behavioral class. The primary findings include: (i) vehicles will more likely yield to an aggressive (violating) pedestrian; (ii) vehicle involved in a right-turning conflict will more likely yield to pedestrian during green period; (iii) vehicle will more likely yield to baggage-carrying pedestrian during pedestrian's green; (iv) longer waiting period tend to make motorists impatient and search for gap, resulting in pedestrians' yielding; (v) male pedestrians tend to be more aggressive in crossing as opposed to female pedestrians; (vi) pedestrians crossing in a group are likely to yield to turning vehicles.

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INTRODUCTION

With rapid urbanization and growing pedestrian activities, interaction between pedestrian and vehicles has increased manifold, increasing the potential conflicts and magnified the safety issue. Statistics show that majority of pedestrian-vehicle crashes occur at crosswalks since pedestrian maneuvers are significantly different from enclosed or open spaces coupled with the difference in geometry, signal control, and presence of vehicles *(1)*. For instance, in the USA about 26% of all pedestrian fatalities (1554) occurred at intersection or are intersection influence area in 2017. First half of 2018 (January to June), is also showing similar trend, where five states (Arizona, California, Florida, Georgia, and Texas) account for almost half (46%) of all pedestrian fatalities *(2)*. In a signalized intersection pedestrian safety features installed at the intersection along with priority movement ensures the necessary safety. However, increasing vehicle movement and congestion in some parts (downtown, CBD, tourist areas) often shift the emphasis on improving efficiency which in turn acts as a deterrent to pedestrian safety making them vulnerable and prone to crashes. Thus, intersections serving a high volume of pedestrian and vehicular traffic possess a challenge to analyze possible safety issues and ensure safe crossing.

Conflict studies provide a relevant way to address these safety issues, since conflict points designate the possible crash locations at an intersection. Conflict can be defined as an event where either motorist or pedestrian take necessary maneuver or yield for the right-of-way to avoid imminent crash. Some literature exploring pedestrian-vehicle conflicts focus on the microscopic vehicle behavior, such as speed profiles including acceleration and deceleration events and assumed that the pedestrian behavior is passive and not a major contributing factor *(3, 4)*. Whereas others focus on the pedestrian behavior and activity on the crosswalks, as pedestrian's acceleration, deceleration and direction change can easily lead to safety issues near conflict areas *(1, 5, 6)***.** In general, the acceleration, deceleration, distraction behavior, and speed profiles of two conflicting parties are considered in literature.

There are many other factors that potentially have effects on the pedestrian crossing behavior. A handful of studies looked at the pedestrian crossing behavior at signalized *(7, 8)* and unsignalized *(9, 10)* intersections from a different perspective. They collected demographic information about pedestrians such as age and gender, together with the crossing speed, waiting time etc. to generate models describing pedestrian crossing behavior. Some have focused on the impact of crosswalk geometry and signal timing parameters on pedestrian crossing decision and speed; concluding that pedestrian maneuvers vary widely and affected by control type (signal timing and indication), crosswalk length, presence of conflicting vehicles, etc. *(11, 12)*. Some studies analyzed the crossing behavior considering different parameters such as crossing choice, waiting time, initial reaction time, walking speed, violations and difference between individuals and groups *(13-15)*. Specific conflict with left turning traffic at signalized intersections is also analyzed considering gap acceptance and speed profiles *(16-18)*. Pedestrians' gestures and smile, as well as advance yield markings and low-cost engineering improvements, are also found impacting on the yielding behavior among conflicting parties *(19-22)*. Using modeling effort several studies explored pedestrian behavior at signalized intersections including compliance with safety rules, unsafe crossing, crossing choice and pedestrian safety level over crosswalks *(23-27)* The application methodologies for these studies include multivariate regression, structural equation modeling (SEM), binary logit (BL), Multinomial logit (MNL), bi-level multivariate, binomial logistic, Dynamic Bayesian Network (DBN). However, most of the studies have focused on multiple intersections to analyze the generic pattern of pedestrian crossing behavior and the effect of geometric features, thus there is a research scope for unique settings with high volume of pedestrian and traffic.

The motivating features of the study intersection is the effect of high pedestrian volume on the level of service of the crosswalk as well as on the throughput of the intersection. Since, higher number of conflicts are obvious with the high volume of pedestrians, implicitly the grouping behavior becomes a major criterion. This is because pedestrians in a medium (<10) or large (>10) group tend to walk either slowly during pedestrian green phase or aggressively during red period. This in turn increases the safety risk and adds to the waiting time for yielding vehicles specifically during right-turn as noted from real-world observation. Moreover, gap acceptance behavior of the yielding vehicle is observed during the bi-directional crossing events consisting of pedestrian groups.

This study focuses on the pedestrian crossing behavior (individual or group), based on the pedestrian characteristics and vehicle actions including pedestrian demographics (age, gender, etc.), crossing behavior (waiting time, crossing speed, etc.), and motorist attributes (waiting time, yielding, etc.). The specific objectives are enumerated as follows: (i) examine the vehicle yielding behavior and the factors affecting pedestrian interaction level based on conflict types; (ii) determine the factors governing pedestrian behavioral classification (safe, partially safe, and aggressive) while crossing over the crosswalks.

DATA EXPLORATION

The study location includes two marked crosswalks at the signalized T-intersection formed by Coast Hwy (SR-1) / Broadway Street at Laguna Beach, Orange County, California. The crosswalks are equipped with push button signal feature. The intersection connects with the state highway (SR-1) thus, the traffic volume is high compared to local urban streets. Moreover, being a tourist attraction point, the two crosswalks serve a high volume of pedestrians. The geometric setup of the SR-1 Hwy approach consists of four lanes in one direction and five lanes in the other including a protected left-turn for the traversing traffic. The Broadway street consist of five lanes with a protected left-turn. A gas station is located at the northwest corner of the intersection and the other two corners consist of restaurants, and the tourist attraction point, Laguna beach. The intersection approaches and the crosswalk corners are coded in a specific way as noted in (**Figure 1)**. A wireless setup is used to record video data, where the cameras are mounted on the mast of the traffic signal pole and powered through the additional power-unit from the external light source. The pedestrian and traffic movement are recorded on August 3, 2018 from 6:00 am to 10:00 pm. From that resource, an array of pedestrian demographic and crossing attributes are recorded during the morning (6am-9am) and afternoon (1pm-3pm) period.

Based on the entering time at the crosswalk pedestrian crossing behavior is classified into four states: (i) Early Walker (EW); (ii) Green Walker (GW); (iii) Late Walker (LW); (iv) Risk Walker (RW) *(28, 29)*. EW enters the crosswalk just before (<6 sec) the pedestrian green time, during the vehicle- pedestrian phase change interval. GW enters the crosswalk during pedestrian green time. LW enters the crosswalk during pedestrian clearance interval (flashing green) and reach the other side at red phase. Risk Walkers (RW) enter the crosswalk during pedestrian red period. Since the study location is a tourist attraction, pedestrian groups of different sizes are observed during the recording period. The pedestrian groups are classified into four categories: (i) Large (L); (ii) Medium (M); and (iii) Small (S). Based on appearance and walking style, each pedestrian is divided into three age groups (ii) Young (A); (ii) Middle-Aged (B); (iii) Elderly (C). However, mix of pedestrians of different age in a group is recorded as Mixed (M) within the age-group category. Presence of children in the group mix is also recorded as a categorical variable. Pedestrian waiting time is computed, starting from pressing the push button until entering the crosswalk. The crossing time is recorded from entering the crosswalk and crossing over to the sidewalk. Crossing Speed (ft/s) for individual pedestrian is computed from the crosswalk length and crossing time. However, for groups, the speed is computed by averaging the speed of at least three pedestrians positioned in the front, middle, and end of the groups. Pedestrian baggage level is recorded in eight categories: (i) Small (S); (ii) Medium (M); (iii) Large (L); (iv) Medium and Large (ML); (v) Medium and Small (MS); (vi) Small and Large (SL). Erratic or risky behaviors from individual or groups are also recorded in several categories based on the crossing pattern of pedestrian. For instance, crossing outside the crosswalk and diagonal to the intersection is denoted as O, and D, respectively. Similarly, pedestrians crossing very slowly in presence of a yielding vehicle without any definite reasons (handicapper, large baggage, children etc.) are also marked in the erratic behavior category.

Several vehicle attributes are recorded including waiting time, yielding time, turning maneuver, gap acceptance, etc. The recorded vehicle waiting time is different for left-turning and right-turning movement. This is because, the right-turning vehicle waits for a while before the maneuver without any dedicated signal guidance; whereas left-turning vehicles make a permissible left maneuver guided by the traffic signal. As such the waiting time recorded for the right-turning vehicle is usually higher than that of left-turning vehicle recorded during the green of left-turn signal. Gap behavior of vehicle is recorded as a surrogate for aggressive driving from the motorist, where, the yielding car navigates through the gap (time headway) between two groups of bi-directional pedestrians over the crosswalk. Part of such gap interactions involve yielding of the incoming group of pedestrians (orthogonal to vehicle) to the aggressive motorist. The interaction or yielding behavior between pedestrian and vehicle over the crosswalk is defined into four stratum A, B, C, F, where Level A defines the conflict situation where the vehicle yields to GW; Level B records GW yield to traffic; and Level C includes two sublevels C1 and C2 to record the yielding of EW/LW/RW and motorist, respectively. The extra level F is added to define safe crossing situation without any possible conflict. In this case, vehicles within the intersection influence zone abide by the traffic rules and the GW cross without any conflict with the surrounding traffic. By traffic rules, it is meant that the vehicles are stopping at the signal and waiting for the appropriate turn to perform the designated maneuver without adhering to gap finding or aggressive behavior. The data including pedestrian and vehicle attributes to describe and analyze pedestrian crossing behavior is extracted manually.

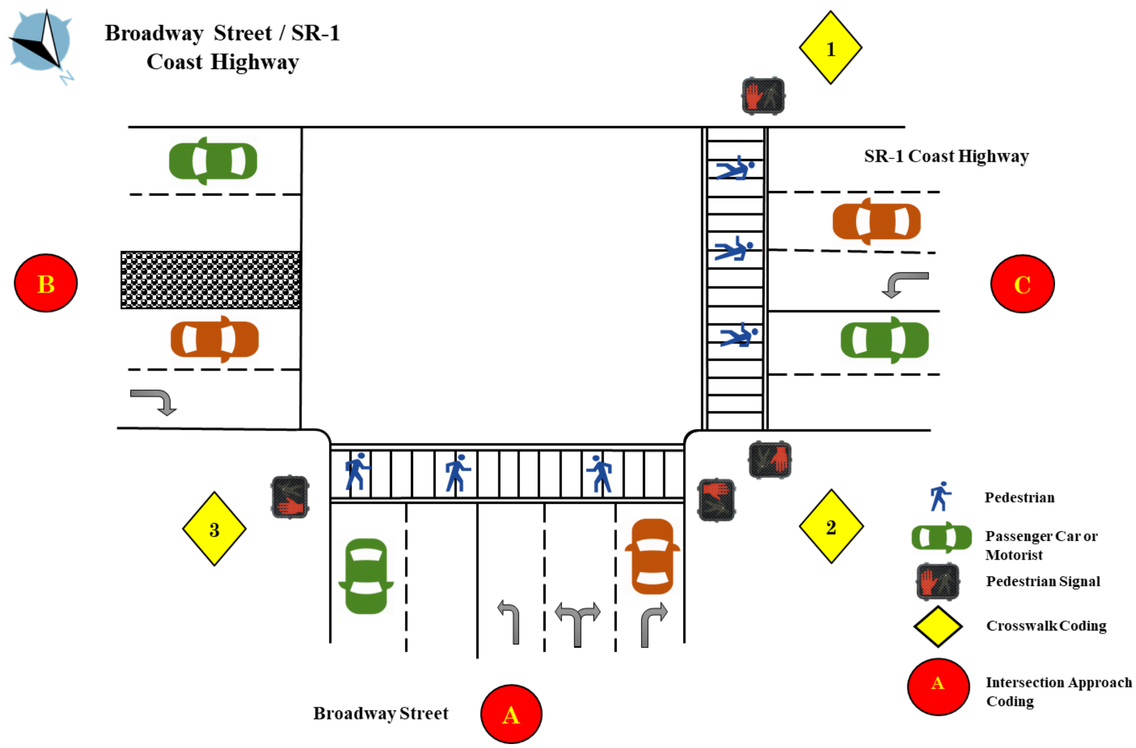

Figure 1: Broadway Street and SR-1 Coast Highway Intersection

This study focuses on the conflicts relevant to the pedestrians and classifies the conflicts in parts considering the movement direction of the motorist, (i) right-turn conflict; (ii) left-turn conflict. Yielding is the consequence of the conflict situation, where any of the interacting entities either pedestrian or motorist must stop and give the right-of-way to avoid imminent crash. Thus, yielding data for this study was recorded in two parts, (i) pedestrian yielding; (ii) motorist yielding. The directional headway for the pedestrians is defined as the time interval in seconds between individual or group of pedestrians arriving at the crosswalk from the same direction. Crosswalk coding in (*Figure 1*) shows the movement direction of pedestrians.

Table 1: Statistical Description of the Sample Data

Variable	**Classification (Coding)**	**Frequency (Proportions)**	**Statistical Distribution**				
			Minimum	**Mean**	**Median**	**Maximum**	**Standard Deviation**
Pedestrian Demographics							
Age Group	A	141 (43.1%)					
	B	54 (16.5%)					
	C	13 (16.51%)					
	M	119 (4%)					
Children Presence	Y (1)	50 (15.29%)					
	N (0)	277 (84.71%)					
Gender	Male (M)	83 (25.4%)					
	Female (F)	66 (20.2 %)					
	Both in group (B)	178 (54.4%)					
Pedestrian Volume	Male Count	257 (51.4%)	0	2.061	1	13	2.147
	Female Count	243 (48.6%)	0	2.064	1	11	2.208
Pedestrian Crossing Behavior							
Group Class	L (>10)	30 (19%)					
	M (>5)	60 (38%)					
	S (>2)	68 (43%)					
Pedestrian Class	EW	3 (0.917%)					
	GW	268 (81.96%)					
	LW	32 (9.79%)					
	RW	24 (7.34%)					
Baggage Level	S	73 (59.35%)					
	M	18 (14.63%)					
	L	13 (10.56%)					
	SL	4 (3.25%)					
	SM	15 (12.195%)					
Pet Presence	Y (1)	2 (0.612%)					
	N (0)	325 (99.4%)					
Pedestrian Yield Time (s)		246	0	0.411	0	10	1.342
Crossing Time (s)		321	5	14.757	15	25	3.086
Average Crossing Speed (ft/s)		321	2.333	4.293	4	11.20	1.205
Baggage Pedestrian		128 (39.14%)	1	1.6086	1	7	0.9397
Pedestrian Erratic Behavior	Risky (R)	27 (52.94%)					
	Outside (O)	5 (9.81%)					
	Diagonal (D)	7 (13.73%)					
	Very Slow (S)	12 (23.53%)					
Group Erratic Pedestrian		13 (2.6%)	1	2.3077	2	6	1.3156
Pedestrian Movement Direction	12	87 (26.6 %)					
	21	92 (28.13 %)					
	23	67 (20.49 %)					
	32	81 (24.77 %)					
Pedestrian Directional Headway (s)		327	1	182.367	139	1802	188.1609
Vehicle Attributes							
Vehicle Yield Time (s)		246	0	12.234	11	34	8.6

Variable	Classification (Coding)	Frequency (Proportions)	Statistical Distribution				
			Minimum	Mean	Median	Maximum	Standard Deviation
Vehicle Wait Before Yield (s)		246	0	23.68	6	88	27.4147
Gap Behavior	Y (1)	3 (0.09%)					
	N (0)	324 (99.1%)					
Gap Time (s)		3 (0.09%)	4	8.333	10	11	3.786
Crosswalk Attributes							
Crosswalk Length	56	179 (54.7%)					
	65	148 (65%)					
Road Functional Class	Major (1)	179 (54.74%)					
	Minor (0)	148 (45.26%)					
Interaction Attributes							
Interaction Level	A	180 (55.04%)					
	B	20 (6.11%)					
	C1	43 (13.14%)					
	C2	4 (1.22%)					
	F	80 (24.46%)					
Yielding	Vehicle	224 (91.05 %)					
	Pedestrian	22 (8.95 %)					
Conflict	Yes (1)	246 (75.23%)					
	No (0)	81 (24.77%)					
Conflict Type	Left turn (1)	26 (10.6%)					
	Right turn (2)	220 (89.4%)					

The sample size recorded for this study is 327, among which 246 are conflict event and 74 are safe crossing events of GW without any interaction with the surrounding traffic. The remaining 6 observations recorded miscellaneous events. Preliminary investigation of the dataset shows a high volume of right-turn conflict (220) relative to left-turn conflict (26).

BEHAVIORAL MODELING

Vehicle Yielding Behavior

Since two types of vehicle action, yielding and nonyielding, are observed during a pedestrian crossing event at the signalized intersection, a logit model is used to predict the binary response based on the categorical and continuous predictor variables. According to dichotomous nature of vehicle yielding behavior, a binary logit model is adopted, with one is vehicle is yielding or zero otherwise. The binary logit model for vehicle yielding is defined as follows.

$$P(y_n) = \frac{e^x}{1+e^x} \quad (1)$$

$$X = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_N x_N \quad (2)$$

Where, $P(y_n)$ is the probability of n vehicle yielding before the crosswalk, x denotes the predictive variables which determine the probability of a discrete outcome for n, β_N estimating parameters, N defines the number of independent parameters, and X represent the linear function of multiple explanatory variables . The odd ratio (OR) is obtained from the exponential of the logit model coefficients. OR denotes the odds that an outcome will occur given an exposure, compared with the odds of the outcome happening in the absence of that exposure. For instance, the number of exposed cases and non-cases for crosswalk usage are p and q respectively, and the number of unexposed cases and non-cases for crosswalk usage are r and s, respectively, then the OR value is calculated as follows. In case the OR is greater than 1, the exposure is associated with higher odds of the outcome and the group is more likely to comply with signal; otherwise, the group may show a lesser tendency to comply with signal *(23)*.

$$OR = \frac{p/r}{q/s} = \frac{ps}{qr} \tag{3}$$

Table 2: Logit Model for Vehicle Yielding

		Estimate (Standard Error)	**Odd ratio**	**Estimate (Standard Error)**	**Odd Ratio**	**Estimate (Standard Error)**	**Odd Ratio**
Average Crossing Speed		-2.701 c (1.446)	0.067 c	0.502422 (0.440523)	1.653	0.500172 (0.440302)	1.649
Average Waiting Time		-0.009 (0.026)	0.991	-0.003729 (0.013325)	0.996	-0.003704 (0.013347)	0.996
Vehicle Wait Before Yield		0.095 b (0.041)	1.099 b	0.090748 c (0.046843)	1.095 c	0.089527 c (0.046798)	1.094 c
Pedestrian Volume		-0.141 (0.266)	0.868	-0.067870 (0.121991)	0.934	-0.067276 (0.122494)	0.935
Pedestrian Directional Headway		0.006 (0.007)	1.006	0.004611 (0.003418)	1.005	0.004605 (0.003424)	1.005
Group Class (M)	L	-1.667 (1.488)	0.189				
	S	-2.630 (2.694)	0.072				
Grouping (0)	1			-1.258714 (0.864656)	0.284	-1.252974 (0.864305)	0.286
Pedestrian Class (LW)	GW					-0.452261 (1.056892)	0.636
	RW					-0.022617 (1.404567)	0.978
Pedestrian Compliance (0)	1	3.024 (2.037)	20.57	-0.444242 (0.925020)	0.641		
Presence of Children (0)	1	0.281 (1.180)	1.325	0.796476 (0.945928)	2.218	0.778675 (0.950113)	2.179
Gender Male (0)	1	0.438 (1.255)	1.550	1.052394 (0.820498)	2.865	1.049379 (0.820636)	2.856
Gender Female (0)	1	-17.396 (250)	0.0001	0.948088 (0.915144)	2.581	0.939662 (0.916364)	2.559
Directional Class (0)	1	0.059 (1.1)	1.061	1.074033 (0.757333)	2.927	1.083067 (0.768098)	2.954
Baggage Presence (0)	1	0.586 (1.005)	1.797	0.694158 (0.673869)	2.002	0.690230 (0.676929)	1.994
Age Group (A)	M	0.532 (1.515)	1.702	1.124158 (0.792345)	3.078	1.118569 (0.794130)	3.060
	B	0.049 (1.068)	1.050	1.451005 (0.899255)	4.267	1.440442 (0.908321)	4.223
Sample:		136		237		235	
Null deviance (dof):		90.167 (135)		146.48 (236)		146.09 (234)	

	Estimate (Standard Error)	Odd ratio	Estimate (Standard Error)	Odd Ratio	Estimate (Standard Error)	Odd Ratio
Residual deviance (dof):	52.909 (120)		103.36 (222)		103.27 (219)	
Fisher Scoring Iterations:	17		8		8	
Log Likelihood:	-26.454		-51.678		-51.634	
AIC:	84.909		133.356		135.27	
McFadden R-Square:	0.413217		0.294404		0.293111	
Misclassification Error:	0.0244		0.0366		0.0244	
True Positive Rate (TPR)	0.6296296		0.962963		0.9714815	
False Positive Rate (FPR)	0.4		0.6		0.6	
Area under the Curve (AUC)-ROC (training 75%, testing 25%)	0.6		0.7906		0.8	

c: p<0.1; b: p<0.05; a: p<0.01 ; dof – Degree of Freedom; Akaike Information Criterion (AIC); Receiver Operating Characteristics (ROC)

Three logit models A, B, and C are tested with the sample dataset to analyze vehicle yielding behavior. Model A represents a stratified model with group classification (S, M, L) and pedestrian compliance behavior (compliant or noncompliant). Model B is different from A with the combined factored model for grouping (belong to a group or not). Finally, model C differs from model B with the inclusion of pedestrian behavioral class (GW, LW, RW). Diagnostics of the models including pseudo rho-square (McFadden R-square), AIC, TPR, FPR, and AUC-ROC are reported in (Table 1). From the sample data 75% of the data is utilized to train the vehicle yielding model and the remaining 25% data is used for prediction. The overall most successful prediction rate or TPR of vehicle yielding behavior model is observed as 98%, proving model C as the best model among three.

The logit model coefficient estimates (log odd) when positive, imply that the average impact of the that predictor variable is in the direction of vehicle yielding and vice-versa for negative value. In simple words, for every unit increase of the predictor variable the log odds of the dependent variable increase or decrease in terms of direction and magnitude. More explicit interpretation of a logit model is given in terms of odd ratio (Equation 3) (exponential of the coefficient estimates), where one-unit shift in the predictor variable would likely result in shifting the odds of yielding by that amount (odd ratio). From the estimation results of the parameters, the pedestrian age-group B shows the largest parameter value (1.44) and odds ratio (4.223). Negative magnitudes of the estimates of pedestrian volume, average waiting time, grouping, and pedestrian behavioral class indicate that all these predictor variables have an impact towards the direction of non-yielding during a crossing and conflict event. For instance, the estimated odds ratio of average waiting time shows that for a unit increase in the waiting period of pedestrians, the odds of vehicle yielding will most likely decline unlike vehicle waiting period.

One interesting find for this model is the waiting time of vehicle or motorist before yielding. This predictor variable captures the waiting period of the vehicle while in queue before the interaction, with an underlying assumption that longer waiting time may generate aggressive or non-yielding interactions from motorists' perspective. However, the model shows that the estimate (0.0895) is positive and significant at 10% level, indicating that the impact of the variable is towards the direction of vehicle yielding. The odds ratio (1.094) suggests that increase in the motorist waiting period will likely result in vehicle yielding. Since the study location has high volume of traffic, the vehicle has to wait in queue for the designated turning maneuver. Moreover, after reaching the intersection, during pedestrian green period there is not enough gap for the motorist to maneuver in between the crossing pedestrian moving in groups, perceived as gap behavior. Thus, the real-world interaction indicates higher waiting period for vehicles with an additional yielding period for the pedestrian grouping behavior unlike low volume urban intersections. The average crossing speed of pedestrian either individual or in group shows a positive impact on the yielding probability, suggesting that the vehicle is likely to yield when it encounters a pedestrian crossing aggressively (fast pace) analogous to the real-world observations.

Pedestrian age groups B (middle-aged) and M (mixed) contribute in a positive way on the yielding probability, relative to young age group (A). The study location has two crosswalks one at the major approach and the other at the minor approach. Compared to the crosswalk on minor road, pedestrians crossing over the major crosswalk has a positive impact on the yielding probability, indicating that vehicle tend to yield more to the pedestrians crossing on the major approach. This is expected since majority of the right-turn vehicle yield to the crossing pedestrians on the major approach (SR-1 Coastal Highway).

For model C, pedestrian class is a critical variable since it defines the crossing behavior of the pedestrians. Since the classification level EW has a small sample (3) compared to other levels, it is excluded for this analysis. With the reference level at LW, the RW and EW class exhibit a negative impact on the yielding behavior. However, within that range the odds of yielding is higher for the RW than GW. Presence of children and baggage in a group exhibits positive impact on vehicle yielding as expected.

Model A capturers the group classification, whereas the other two models (B and C) only check for a possible grouping behavior. From model A, estimation results of the group behavior show that small and large sized group has negative impact on the yielding probability with reference to medium sized group. However, when the reference is shifted to small (S) sized group, medium (M) sized group show positive impact and large (L) size group shows negative impact on the yielding. From observation samples as the pedestrian group size changes from $S(<2)$ to $M(<10)$, the probability of yielding increases. However, when the pedestrian group size reaches $L(>10)$, the crosswalk level of service and traffic throughput deteriorates and the possibility of gap acceptance behavior from the motorist most likely increases thus, the overall yielding possibility reduces. Moreover, in some of the observed instances the traffic breakdown or congestion downstream caused the left-turning or right-turning vehicle to yield the right-of-way to the crossing pedestrians. Since the sample size of such unique incidents are very few, such behavior is not captured in the model.

Pedestrian Behavior

Previously pedestrian compliance and noncompliance behavior was modeled by combining the factor levels (29) and including predictor variables such as age, gender, group. However, the combined effect of pedestrian crossing speed, waiting time, possible conflict, baggage, presence of children has not been investigated before. Since, the classified pedestrian behavior is similar to an ordered choice (e.g. 1, 2, 3), where GW is the first, LW is second and RW is the last category, an ordinal logit model is built for the pedestrian classification. Alternatively, a multinomial logit (MNL) model is formulated with similar predictive variables to describe and compare the pedestrian behavior in ordered and unordered setting.

In order to add simplicity and increase the model predictive power, some of the classified variables are grouped into binary category variables. For instance, the group classification is rendered as the categorical variable denoting pedestrians either belong to a group (1) or individual (0). Similar approach adopted for the baggage class and pedestrian class variables. For pedestrian compliance behavior the GW represent the compliance (1), whereas the LW and RW classes are merged to represent noncompliance (0) behavior. The general Ordered Logit (OL) model (30) can be written as follows where M is the number of categories of the ordinal dependent variable.

$$p(Y_i > j) = \frac{\exp(\alpha_j + X_i\beta_j)}{1+[\exp(\alpha_j + X_i\beta_j)]}, \quad j = 1, 2, ..., M-1 \qquad (4)$$

The interpretation of magnitude and direction of OL model coefficients is detailed as follows. Notably the risk ratios of the logit coefficient allow easier interpretation which is computed from the exponential of the model estimates (Table 3). The model estimates in terms risk ratio exhibit odds of moving to the higher (risk) category for an increase in the predictive variable when the risk ratio is higher than 1. Otherwise the predictive variables indicate the odds of moving toward lower (safe) category with an increase of one unit.

Table 3: Ordered and Multinomial Logit Models for Pedestrian Behavior and Interaction Level

Coefficient:		**Pedestrian Behavior Classification**			**Interaction Level Classification**		
		OL	**MNL**	**MNL**	**OL**	**MNL**	**MNL**
		Estimate (Risk Ratio)	$\ln\left(\frac{GW}{LW}\right)$ **Estimate (Risk Ratio)**	$\ln\left(\frac{RW}{LW}\right)$ **Estimate (Risk Ratio)**	**Estimate (Risk Ratio)**	$\ln\left(\frac{A}{C}\right)$ **Estimate (Risk Ratio)**	$\ln\left(\frac{B}{C}\right)$ **Estimate (Risk Ratio)**
GW (A)	LW (B)	-2.0844			-4.9165		
LW (B)	RW (C)	0.1138			-39828		
Average Waiting Time		-0.11637 a (0.890)	0.108 a (1.114)	-0.584 b (0.558)	-0.073 a (0.930)	0.121 a (1.129)	0.121 a (1.129)
Average Crossing Speed		0.024478 (1.025)	0.050 (1.051)	0.027 (1.027)	-0.041 (0.960)	0.125 (1.133)	-0.347 (0.706)
Pedestrian Volume		0.14185 (1.152)	-0.066 (0.936)	-2.088 c (0.124)	0.068 (1.070)	-0.045 (0.956)	-0.068 (0.935)
Vehicle Wait before Yield		-0.001990 (0.998)	-0.022 (0.979)	-0.035 (0.966)	-0.001 (0.999)	-0.021 (0.980)	-0.075 b (0.928)
Gender Female (0)	1	0.253508 (1.289)	0.35 (0.531)	3.298 (0.261)	-0.387 (0.679)	0.119 (1.126)	0.365 (1.440)
Gender Male (0)	1	1.336675 c (3.806)	-1.595 (2.269)	1.886 (0.5)	0.228 (1.256)	-1.132 (0.322)	-2.260 (0.104)
Conflict (0)	1	-1.679230 (0.187)	-9.850 a (0.0001)	-10.211 a (0.0004)			
Conflict Type (LT)	RT				-2.434 a (0.088)	0.045 (1.046)	-3.996 a (0.018)
Grouping (0)	1	-0.136203 (0.873)	-0.113 (0.893)	3.021 (20.511)	0.073 (1.076)	0.166 (1.18)	0.894 (2.446)
Directional Headway		-0.009704 a (0.990)	0.017 a (1.018) a	0.013 a (1.013) b	-0.011 a (0.989)	0.010 a (1.010)	0.008 (1.008)
Pedestrian Age Group	B	0.316921 (0.728)	0.737 (2.090)	-0.227 (0.797)	-0.658 (0.518)	0.294 (1.342)	-16.204 a (0.0005)
	M	-2.793228 a (0.061)	2.653 b (14.190) b	-15.242 a (0.0001) a	-0.982 (0.375)	2.111 a (8.257)	2.225 (9.25)
Child Presence (1)		1.422256 (4.146)	-2.641 c (0.085) c	-16.927 a (0.0001) a	0.524 (1.688)	-2.532 b (0.079)	-3.030 c (0.048)
Baggage (1)		0.295762 (1.344)	0.270 (1.311)	1.002 (2.724)	-0.24 (0.787)	0.289 (1.335)	-0.616 (0.540)
Directional Classification (0)	1	0.668692 (1.952)	-0.468 (0.626)	-0.073 (0.930)	0.018 (1.018)	0.297 (1.345)	1.058 (2.88)
Observations		237			232		
McFadden R-square			0.51063			0.5516	
Log-Likelihood			-91.144			-75.927	

c: $p < 0.1$; b: $p < 0.05$; a: $p < 0.01$

In the OL model of pedestrian behavior, a handful of the predictive variable such as average crossing speed, pedestrian volume, gender, child presence, baggage have risk ratios greater than 1, indicating that these variables will be in a higher category with an increase in one unit or pedestrians will become aggressive. Whereas the remaining variables (age group, conflict, grouping, etc.) indicate a movement towards lower category or safe interaction behavior. The model reflects that increase in pedestrian crossing speed shifts the pedestrian behavior towards aggressive. This is expected, since violating pedestrians tend to run to cross the intersection.

Notably, from risk ratio increase in average waiting time for pedestrians shows a downward movement towards a lower category (safe) unlike the expected outcome which assumes that pedestrian become restless with increasing waiting time and may take any risky maneuver to cross the road. However, this deviation can result when there are local pedestrians in the mix, since they tend to wait more and behave in a cautious way unlike tourists. Most likely the morning recording from (6 am - 8 am) captured the local pedestrian behavior to shift the expected outcome of the model.

The model exhibits that any shift in the possibility of conflicts would likely shift the pedestrian towards more safe crossing behavior as expected from the real-world observations. Presence of baggage also affects the pedestrian behavior and most likely the size of the baggage will govern the interaction. For instance, pedestrians carrying a medium or large baggage tend to walk slowly than other pedestrians without baggage and may end up in LW or RW category based on different crossing scenarios. Presence of grouping over individual shows a downward shift towards lower category. This implies that pedestrians in a group behave in a conservative way and tend to wait for the green time to cross the intersection unlike individual pedestrians. For age groups, pedestrian belonging to age-group B (40-60 years) tend to cross the road more aggressively compared to the mixed (M) age-groups with reference to age-group A (20-40 years). Although both male and female pedestrians may exhibit aggressive behavior, male pedestrian exhibit more aggressive crossing behavior than female. Directional headway between individual or group of pedestrians using the same crosswalk exhibit that increase in headway does not always result in aggressive crossing behavior.

For the MNL model, with LW as the reference level, the logit model of the i th behavior could be written as follows where , P_1, P_2, and P_3 are the probabilities of choosing to be a GW, LW, and RW, respectively; α^i is the constant, and β_k^i is the parameter of the explanatory variable x_k^i. Also, x_k^i indicates the k th explanatory variable when choosing the i th crossing behavior, such as gender, age, etc. in the model.

$$\ln\left(\frac{P_i}{P_1}\right) = \alpha^i + \sum_{k=1}^{K} \beta_k^i x_k^i \qquad (5)$$

The MNL model consist of alternative specific coefficients, which is different for each class (Table 3). The magnitude and direction of these coefficients can be interpreted using relative risk ratio, formulated from the exponential of the logit coefficients. Interpretation of the MNL model can be divided into parts due to the probability ratio for $\ln(GW/LW)$ and $\ln(RW/LW)$. Some of the predictive variables such as Average waiting time, crossing speed, female, baggage, age-group, directional headway has a positive impact on the probability of GW relative to LW. Compared to female pedestrians, male pedestrians tend to be more aggressive in crossing, which is analogous to OL model results. Conflict has the largest parameter value (-9.850) and significant at 1% level for the probability ratio of being GW and LW, showing that presence of conflict affects most significantly on the choice of crossing in green as GW and the two are negatively correlated. Similarly, pedestrian volume, presence of children, male pedestrian affects the pedestrians' choice of GW.

For the probability ratio of being RW and LW, the substantial effect of the presence of children and conflict variable is present in the negative direction. The magnitude and direction of the conflict variable in this case is almost identical to the other probability ratio. Unlike the previous case, average waiting time of pedestrians has a negative impact on the choice of crossing on red. Pedestrians in a group is likely to exhibit risky or aggressive behavior on the choice of crossing on red. The significant variables in this case include pedestrian waiting time, pedestrian volume, presence of conflict, direction headway, mixed age-group, and presence of children. Note that the significance is tested at 1%, 5%, and 10% levels (Table 3). The MNL model reflects real-world observations and detail classification effect for model estimates compared to OL.

Interaction Level

Interaction level identifies conflict and stratifies the actions undertaken by a vehicle or pedestrian during the interaction over crosswalk at the study location. Interaction level combines few pedestrian and vehicle attributes to define a complex scenario unfolding over the crosswalk. When ordered level A will represent the most desirable outcome and level C will reflect the worst possible outcome. Thus, using interaction level as dependent variable will aid in understanding the crossing behavior at the study intersection. The risk ratio of the OL estimates show that a handful of predictor variables such as pedestrian volume, grouping, presence of child has a risk ratio greater than 1, indicating the odds of moving toward higher category with an increase of one unit (Table 3). This implies that in a conflict situation these variables will shift towards more undesirable interaction where GW pedestrians yield, or vehicle yields to EW/LW/RW. This suggest that higher interaction level exhibits aggressive behavior from vehicles (Level B) and partially violating pedestrians (Level C). The model shows that increase in average waiting time will likely shift towards lower category. Similar result is observed for average crossing speed, vehicle waiting time, conflict type, age-group, directional headway. For instance, the risk ratio of the right-turn conflict relative to left-turn conflict is less than one and significant at 1% level. This implies that increase in right-turn conflict relative to LT conflict will likely shift towards interaction level A, where vehicles yield to GW. This behavior is expected since majority of the recorded conflicts is right-turning conflicts with high (approximately 90%) vehicle yielding rate during crossing. The model also reflects that male pedestrians are more aggressive than female.

The MNL model for the interaction level consists of alternative specific coefficients, which is different for each level of interaction (Table 3). Interpretation of the MNL model can be divided into parts due to the probability ratio for $\ln\left(A/C\right)$, and $\ln\left(B/C\right)$. Some of the predictive variables such as Average waiting time, crossing speed, female, conflict type, grouping, directional headway, age-group, baggage has positive impact on the probability of A relative to C. In a conflict scenario, male pedestrians tend to be more aggressive while interacting over the crosswalk, which is analogous to the previous model results. Presence of children has the largest parameter value (-2.532) and significant at 5% level for the probability ratio of being A and B, showing that presence of children largely affects the choice of interaction level A. Similarly, pedestrian volume, vehicle waiting time, male pedestrian affects the choice of level A relative to C. The model reflects that the increase in vehicle waiting time is most likely going to affect the interaction over the crosswalk and shift the interaction level towards B, where the GW has to yield. This is expected since longer waiting period tend to make motorists impatient and search for gap, resulting in aggressive driving. For the probability ratio of interaction level B and C, the substantial effect of the pedestrian age-group B is present in the negative direction. Unlike the previous case, increase in average crossing speed of pedestrians has a negative impact on the choice of interaction level B or GW yielding. This implies that in real-world conditions vehicles will most likely yield to a violating pedestrian for safe interaction. The model shows that in a conflict scenario, pedestrian crossing in a group is likely to yield for the incoming traffic. The presence of baggage variable indicate that vehicle will most likely yield for the baggage carrying pedestrian crossing the intersection during pedestrian green. For conflict type variable, the vehicle in a right-turning conflict will most likely yield for the GW. The significant variables in this case include pedestrian waiting time, vehicle waiting time, conflict type, direction headway, middle age-group, and presence of children

(Table 3). Compared to the OL model MNL model provides more detailed information for each of the interaction levels.

CONCLUSIONS

This study focuses on the pedestrian crossing behavior (individuals and groups), vehicle yielding action, and possible factors contributing to the conflict at the tourist location (signalized T-intersection) with high volume of pedestrian and traffic. Several attributes including pedestrian demographics (age, gender, etc.), crossing behavior (waiting time, crossing speed, etc.), and motorist characteristics (waiting time, yielding, etc.) are considered for the empirical analysis. The dataset contains 327 manually extracted events including 500 pedestrians recorded from the video cameras placed at signal poles to focus on the crosswalk interaction behavior. Out of these events, 246 are conflicts and the other 81 include regular and unique crossing behavior. Several models including binary logit, ordered logit and multinomial logit are formulated to analyze pedestrian crossing behavior, vehicle yielding action, and interaction process coupled with conflict, yielding, and pedestrian behavioral class. The primary findings include: (i) vehicles will most likely yield to an aggressive or violating pedestrian with high crossing speed for safe interaction; (ii) right-turning vehicles, when conflicts with pedestrians during pedestrian's green, will most likely yield to the crossing pedestrian; (iii) vehicles will most likely yield to the baggage carrying pedestrian crossing the intersection during pedestrian green period; (iv) longer waiting period tend to make motorists impatient and search for gap, resulting in aggressive driving, which forces the pedestrians to yield.; (vi) in a conflict scenario, male pedestrians tend to be more aggressive in crossing while interacting with a vehicle over the crosswalk as opposed to female pedestrians.; (vii) in a conflict scenario, pedestrians crossing in a group are more likely to yield to the turning vehicles.

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