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ABSTRACT

Warning systems are being developed for left-turning vehicles at intersections where protected left-turns are not warranted or cannot be provided, based on limitations of right of way or intersection capacity. These are meant to provide warnings to left-turning vehicles of vehicles approaching from the opposite direction, when the time to turn may be deemed unsafe. To implement these warning systems, it is necessary to estimate in near real time, the probability of conflict between the two approaching vehicles. A study is being conducted with the help of video and radar at various intersections, to obtain estimates of turning time and acceptable gaps for drivers under various situations. Initial pilot observations indicate that the presence of pedestrians in intersections had an immediate and substantial impact on movement of left turning vehicles. From a preliminary systematic video analysis of the intersection, in the presence of pedestrians on the destination crosswalk, the mean and standard deviation of both the gap and gap components (i.e., turning time and the “buffer” between the turning vehicle and the next oncoming vehicle) increased. On the basis of these observations, pedestrian-detection mechanisms may be useful in such intersection warning systems, with a threshold for warning that is adjusted for pedestrians when they are present or in the vicinity of the destination crosswalk.

INTRODUCTION

The IVI Infrastructure Consortium includes the Departments of Transportation of California, Minnesota and Virginia working in partnership with the Federal Highway Administration of the US Department of Transportation (DOT). The Consortium is developing infrastructure-based and cooperative Intersection Decision Support (IDS) systems. (1) (2) Within this Consortium, the University of California PATH Program and Caltrans (California Department of Transportation) are working to develop systems that help drivers avoid major types of crashes that are associated with left turns at intersections. Traditional countermeasures to crossing-path crashes create protected left turn movements through channelization and offset. In urban areas, however, such efforts to protect left-turning drivers may be prevented due to difficulties obtaining the right-of-way to install dedicated left-turn lanes or reducing the capacity of signalized intersections by providing an additional protected left-turn phase. Drivers at permissive left-turn intersections, especially at intersections with inadequate sight lines, are often exposed to conflicts or crashes with other vehicles. Importantly, human perception is limited, and many drivers have difficulty judging the speed of oncoming vehicles. Consequently, drivers who underestimate the time they need can lead to conflict with other vehicles as they turn left across the path of oncoming vehicles (i.e., “left turn across path/opposite direction” or LTAP/OD). Concerns about inaccurate judgments are especially true for older drivers. (3) (4) To overcome the problem, an IDS system is being developed to warn drivers when there is insufficient time to make the left turn. (5) LTAP-OD crashes account for 18 percent of collisions at signalized intersections, and 6.7 percent of all crossing-path crashes. (6) Overall, crossing-path crashes at intersections comprise over 25 percent of the crashes in the United States. The LTAP/OD problem is prevalent, particularly with older drivers (4) and in urban settings. (6) The current study on the impact of pedestrian presence on the movement of left-turning vehicles at intersections is based on the LTAP/OD crash scenario.

In the design of an effective IDS system, it is necessary to predict potential conflicts by detecting the motions of the turning vehicle (termed the Subject Vehicle, or SV) and of the vehicles with which it may be in conflict (termed Principal Other Vehicle/s, or POV). For the case of the LTAP/OD, the POV comes from the direction opposite as shown in the photograph in Figure 1 and in the diagram in Figure 2. When the available gap between the SV and an approaching POV is not adequate for completing a safe turn, the IDS system can alert the SV driver based on its prediction of the conflict. The alert needs to be activated early enough to give the SV driver time to stop before coming into conflict with a POV. However, it should not be so early that it will be perceived as a nuisance or that it will deter drivers from completing safe turns.

While developing the warning system for IDS, researchers observed that the presence of pedestrians in or near the destination cross walk influences turning times for the SV. This would be an important effect to be accounted in the warning system design. Normally, pedestrians cross intersections simultaneously with movement of a parallel stream of vehicles. Although this results in little conflict between pedestrians and vehicles passing straight through the intersection, pedestrians may still lead to conflict with turning vehicles. Drivers of the turning vehicles must therefore wait until crossing pedestrians depart from the path of the turning vehicle before they can safely turn. Presence of pedestrians clearly affects the turning times of left-turning vehicles. Moreover, the presence of pedestrians can create a conflict: The driver may feel pressure to turn, especially if he or she is in a lane shared with through traffic and if the driver is in a left turn pocket if a queue follows. Further, the driver may not notice the pedestrian since he or she may be focused on judging gaps between oncoming vehicles. As a result, the turning vehicle may be ‘stranded’ in the possible path of the POV, waiting for the pedestrian to clear its path.

In this study, we observe how pedestrian presence affects the movement of turning vehicles, especially left turning vehicles, and note its implications for various IDS countermeasures to be used in intersections. The present study is designed to: (i) describe a methodology for assessing the impact of pedestrian presence on SV and POV movement and interaction, (ii) provide some preliminary quantitative results, (iii) describe general implications for safety and capacity at intersections, and (iv) describe specific implications for LTAP-OD advisory systems.

REVIEW OF PUBLISHED EVIDENCE

Of the literature relevant to this study (7) discusses various intersections where IDS measures were notionally applied. Published literature relating to conflicts and crashes at intersections that involve pedestrians and bicycles is not directly relevant since it deals mostly with evaluating effects of intersection configuration (8), geometric improvements, signage, road markings and traffic control devices. (9) (10) (11) A study dealing with human factors contributing to left-turning vehicles crashing with pedestrians concluded that a pedestrian is four times

more likely to be hit by a left-turning vehicle than by a right-turning vehicle. (12) Drivers and pedestrians, or both in cases when the vehicle is turning left, could have poorer perception of other road users, compared to the case of a through moving or a right turning vehicle, which contributes to potential conflicts.

There is very little literature on the impact of pedestrian presence on the movement of vehicles at intersections. A study by Rouphail, et al. (13), examined parts of the 1994 *Highway Capacity Manual* (HCM) that relate to interactions between pedestrians and turning vehicles. The study concluded that there are variations in vehicular saturation flow due to pedestrians. The manual further noted that the HCM might not accurately predict the effect of a moderate pedestrian or bicycle volume on turning traffic. It suggested procedures that should improve the analysis and performance of signalized intersections, subject to non-motorized interference with turning movements. It further recommends that the HCM use the saturation flow adjustment factors determined by the study and use the findings of the study in its chapters on signalized intersections and on pedestrians. The 2000 *Highway Capacity Manual* incorporates these recommendations. However, the focus of the Rouphail study is on capacity issues rather than safety.

METHODS

Video observation

To observe the movements of the vehicles at intersections, we have used video cameras and automotive Doppler radars, temporarily mounted at the roadside at typical intersections. (14) (15) The current report presents analysis of video data exclusively. The video data are used primarily to quantify the behavior of the SV. The typical placement of video camera at an intersection is shown in Fig. 3.

The extraction of the SV movement data from the video images is complicated by the wide variety of driver actions at intersections where pedestrians are crossing. In some situations, drivers proceed dangerously through a left turn at an intersection without stopping; while in others, drivers cautiously halt at the stop line, and they wait to turn until there is suitable gap in the opposing traffic and all pedestrians have cleared the vehicle's projected path. Some drivers gradually move forward into the intersection, while others drive directly into the middle of the intersection before stopping to wait for the desired gap between POV and pedestrians crossing its path.

For the purpose of analysis, the intersection is subdivided into regions in order to facilitate a systematic description of the paths that the vehicles follow, as shown in Figure 4.

Extraction of turning times using the observation tool/intersection diagram

To enable the analyst to identify specific times from the video data efficiently (for example to identify the times at which the vehicle is at any of the seven points defined in Figure 4), we developed a video "playback" tool. Figure 5 displays a screen shot of the playback tool user interface. The tool can be used to modify the speed of the video playback and record the timeline by clicking on the numbered icons. It is essentially a Quicktime video player with variable speed and adjustable frame speed capabilities that allows the analyst to mark the time of events relative to the beginning to the segment of the video.

The initial data collection for the LTAP/OD scenario was conducted at a signalized intersection (Hearst and Shattuck) in the City of Berkeley. The turning SV has a left-turn pocket, but the intersection does not have a protected left-turn signal phase, and so the SV driver must turn across two lanes of opposing traffic during the green signal cycle.

THE STUDY SITE

Located in the northeast part of Berkeley, California, Shattuck runs North-South and Hearst runs East-West. Both roads have two lanes in each direction, with Shattuck having additional left turn pockets each a single lane wide. A plan view of the intersection is shown in Figure 6. The intersection has over 2000 vehicles moving through it in the peak hour. Table 1 shows the turning movement characteristics of the intersection in 2003, during the morning and evening peak.

The signals at this intersection were controlled on a fixed cycle, with some variation with time of day. The cycle duration was 75 seconds during the hours of our observation. In the direction of Shattuck Ave, the green phase was 34.1 seconds long, amber 3.3 seconds, all-red 2 seconds and red for the remaining period.

The 1998-2002 crash data shows, that of the 29 collisions at Hearst and Shattuck, three were LTAP-OD type, and another three were left turns into pedestrians. The total number of crashes recorded for the combination of these two categories is second only to the category of signal violation that records 10 crashes.

At this site, the video data was collected on two days, October 2, 2003 and again on December 11, 2003. The data collection was conducted for approximately 90 minutes on the first day and 120 minutes on the second day, in conjunction with traffic data collection by a mobile platform using computerized data acquisition and radar. (14) The pilot field observation was conducted in the late morning and early afternoon hours when traffic was not congested; in other words, traffic was sufficient to create a mixture of gap sizes. This allows the collection of diverse traffic patterns not biased towards congestion. The number of pedestrians crossing the destination crosswalk under observation during the survey period was found to be an average of 195 pedestrians in one hour.

DATA ANALYSIS & RESULTS

Turning time as a function of pedestrian presence

The first step in designing the IDS warning system is to predict when the SV will be in possible conflict with the path of the POV (i.e. when it will cross the lanes with oncoming traffic from the opposite direction). If the SV is still approaching the intersection, the time for it to reach the threshold of the intersection may be estimated based on the speed of its approach trajectory, as there is variability in approach trajectories. The time needed to traverse the opposing traffic lanes from the stop bar in the SV's original lane can be derived from the observation data. The turning times for left turning vehicles at Hearst and Shattuck are summarized in Table 2. For the purpose of this study, turning time is defined as the time from when the SV driver makes significant left-turn movement (point 55 on Figure 4) to the time the SV rear bumper leaves the travel way of POV (point 33 on Figure 4).

On Table 2, in the absence of pedestrians, turning times have a mean value of 3.0 seconds, with a standard deviation of 0.5 seconds. The presence of pedestrians raises the mean turning time to 4.4 seconds and the standard deviation to 1.5 seconds. The data with pedestrian influence increases the mean of the total sample to 3.3 seconds and the standard deviation to 1 second. In other words, the presence of a pedestrian increases the vehicle's average turning time as well as the variability of the turning time.

Accepted gap as a function of pedestrians present

In this study, gap is defined as the interval between the time the rear bumper of the first POV crosses a point in the intersection to the time the front bumper of the second POV crosses the same point. Noting the gaps between consecutive POV, in addition to noting the various LTAP/OD movements, the data set includes gaps accepted and rejected by SV drivers under different situations of left turns. Table 3 provides the mean and standard deviation of the gaps accepted by SV drivers for the entire set of observations, and for observations with and without pedestrian influence. The number of observations for accepted gaps (28) is significantly less than the number of observations for turning times (109). Several observations were dropped while linking the turning data with the gap acceptance data, primarily because for many of the left turns undertaken, the subsequent POV arrived much later compared to the time the SV made its turn. Those values were necessarily excluded from the analysis because they could not represent a real influence of the POV presence on the turning decision of the SV driver. Considering these values for gap acceptance would artificially increase the mean value of the accepted gap.

Table 3 demonstrates that in the absence of pedestrians, the accepted gaps have a mean value of 7.7 seconds and a standard deviation of about 2.5 seconds. The presence of pedestrians raises the mean value of turning time to 11.4 seconds and the standard deviation to 4.4 seconds. The data with pedestrian influence increases the overall mean to 8.7 seconds and the standard deviation to 3.5 seconds.

Turning Time, Buffer and Accepted Gap

The relation of accepted gap (G) with turning time (T) and buffer (B) may be modeled for the total dataset, for the observations with pedestrians present in the destination crosswalk and those without. The accepted gap constitutes turning time and buffer time before and after the completion of the turn, i.e. $G = T + B$. (7)

The models take a polynomial form.

$$B = \alpha_1 G^2 + \beta_1 G + \gamma_1;$$

$$T = \alpha_2 G^2 + \beta_2 G + \gamma_2;$$

$$B = \alpha_3 T^2 + \beta_3 T + \gamma_3;$$

The details of the modeled results are given in Table 4. These three combinations have a very high R^2 for the association between buffer and accepted gap, and significant t-statistics (except for the parameter G^2). The R^2 , however, is much lower for the relation between turning time and accepted gap, and turning time and buffer, and the t-statistics are insignificant. Of the models, the most robust models seem to be those of the observations without the pedestrians, and the least are those of the observations with pedestrians.

Plots showing turning times and buffers vs. actual accepted gaps give different results for observations. These include instances in which pedestrian presence affected the turning time as compared to instances in which such observations were eliminated. Turning movements have been disaggregated to show both components of the gap. The results of the analysis are reported in Figure 7. The observations show substantial variability about the trend line (i.e. for the same accepted gap, a rise in turning time above the trend line, is marked by a drop in buffer below the trend line and vice versa, as is expected, since the sum of buffer and turning time constitute accepted gap). Separating those observations with pedestrians and without pedestrians in the destination crosswalk demonstrates the large variability about the trend line in the total data is caused only by observations with pedestrians in the destination crosswalk. Figure 8 represents the 20 turns without pedestrians present, showing that the variability of buffer and turning time about the trend line is much less.

The consistency of the turning times can be seen from the nearly-horizontal plot of the turning times with pedestrians clustered between 3 to 6 or more seconds (Figure 7) and turning times without pedestrians clustered between less than 3 to less than 4 seconds (Figure 8). The large variability in the total accepted gap time is due to the “buffer time”. This hypothesis is also supported by the three models, in which the model of accepted gap and buffer is the only one that is statistically significant.

DISCUSSION AND CONCLUSIONS

The analysis suggests that the presence of pedestrians in the destination crosswalk increases the mean and standard deviation of the accepted gap, the buffer, or the turning time (based on definitions of these terms). These could have implications on signal timing and signal configuration and on calculations of traffic flow, as observed by Roupail. (13)

The small sample size of observations specific to a single intersection may introduce some bias in the data. For some of the coefficients in the models, statistical significance could not be achieved, as statistical significance depends on sample size. Also, the sample may not exhibit the desirable properties common to large samples namely convergence in distribution, consistency and asymptotic efficiency. However, the results obtained are intuitive given the nature of the problem, and could be validated as larger samples are obtained with the progress of the study. Furthermore, similar observations will be needed at a broader range of intersections with diverse characteristics in order to define the sensitivity of pedestrian influence to intersection characteristics.

The preliminary conclusions relate to safety and capacity of the intersection in all cases and imply that the presence of pedestrians necessitates different baselines for calculations. For this, we consider the two mechanisms at work in the cases of LTAP/OD type turn in presence of pedestrians:

- (a) the SV driver delays the start of the turn because s/he sees the pedestrian in the crosswalk, or
- (b) the SV driver has to slow down or stop in the path of POV after initiating the turn because s/he did not see pedestrians early enough.

The former may be a safe scenario, but the latter is not. The differences are evident in different effects on the turning and the buffer times. In the first case, a large buffer time may be realized before the left turn begins, where in the second case, the turning time may be greatly increased. These will have implications on the design of the warning mechanism.

To account for pedestrians, a warning mechanism may require a supplemental warning system (e.g. warning the SV of pedestrian/s in the destination crosswalk), or the warning may be activated by pedestrian/s in

the destination crosswalk just as it would be by a POV that is 'too close'. In the absence of a system warning of pedestrians crossing the street, or in cases where the SV driver does not heed the warning, if scenario (b) occurs, an additional warning system may be required that will warn the POV of the SV in its path. In all cases however, it is important that the turning vehicle be warned of pedestrians in the destination crosswalk, which means that the warning system would require an integrated capacity for pedestrian detection.

A pedestrian detection mechanism may enable a different set of warning criteria to be in effect with presence of pedestrians in the far left intersection crosswalk. Automated pedestrian detection systems may provide the means to detect the presence of pedestrians as they approach the curb before crossing the street, and then activate the pedestrian "Walk" signal without any action required on the part of the pedestrian. An emerging technology for detecting pedestrians may be adopted for this purpose. (16-24) Areas of relevance include pedestrian detection mechanisms, cross-walk warning systems, and various types of pedestrian signal configurations.

FUTURE RESEARCH

A larger number of observations will be needed to define a threshold value to prompt the alert or warning for different gap times. While research continues on the design of the warning system, future research is needed on the impact of pedestrian presence on vehicle flow.

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Figure 1: Video still, showing pedestrian presence impacting left-turning vehicle movement at Hearst and Shattuck intersection

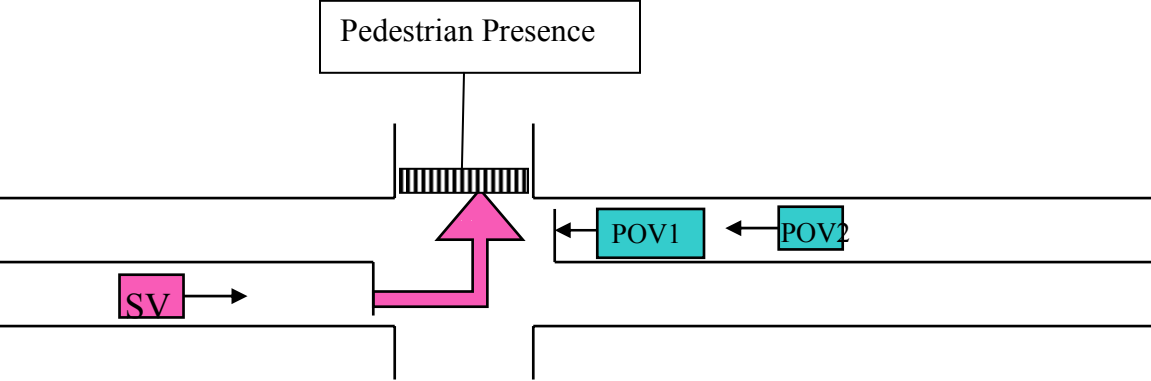


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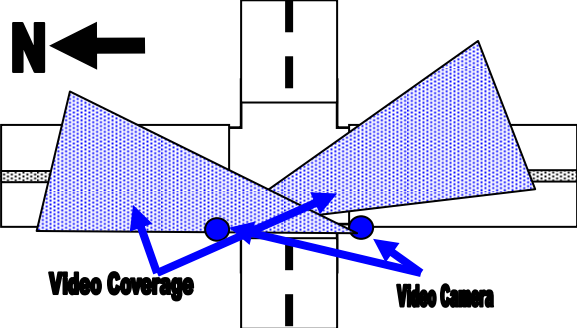
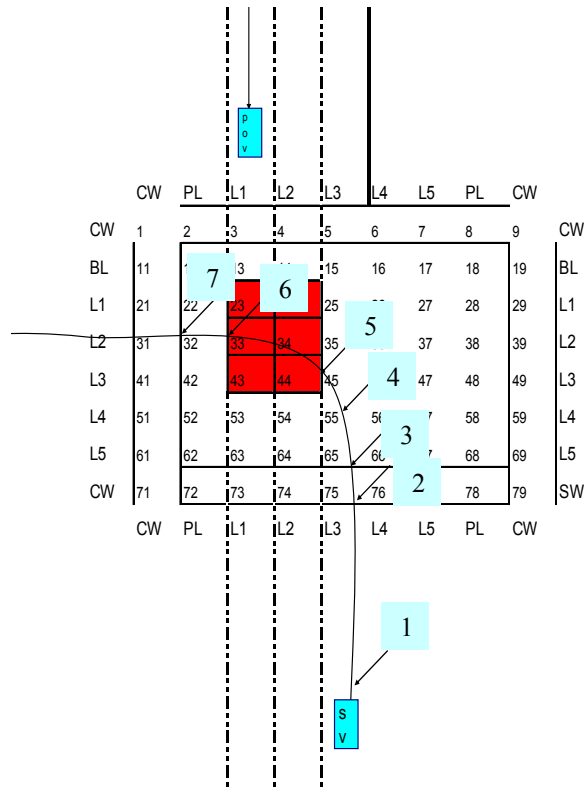


Figure 3: Video Data Collection Fields of View

Figure 4: Different points in an intersection label turning path of SV



CW=crosswalk, PL=parking lane, BL=bicycle lane and Lx = traffic lane x.

Seven points marked in the turning path of the SV

1. SV entering left-turn pocket
2. SV entering crosswalk (front bumper)
3. SV crossing the inner (into the intersection) line of crosswalk (front bumper)
4. SV shows significant left-turn movement
5. SV encroaches into POV traveled way (front bumper)
6. SV leaves the travel way of POV (rear bumper)
7. SV crosses the inner (into the intersection) line of crosswalk (rear bumper)

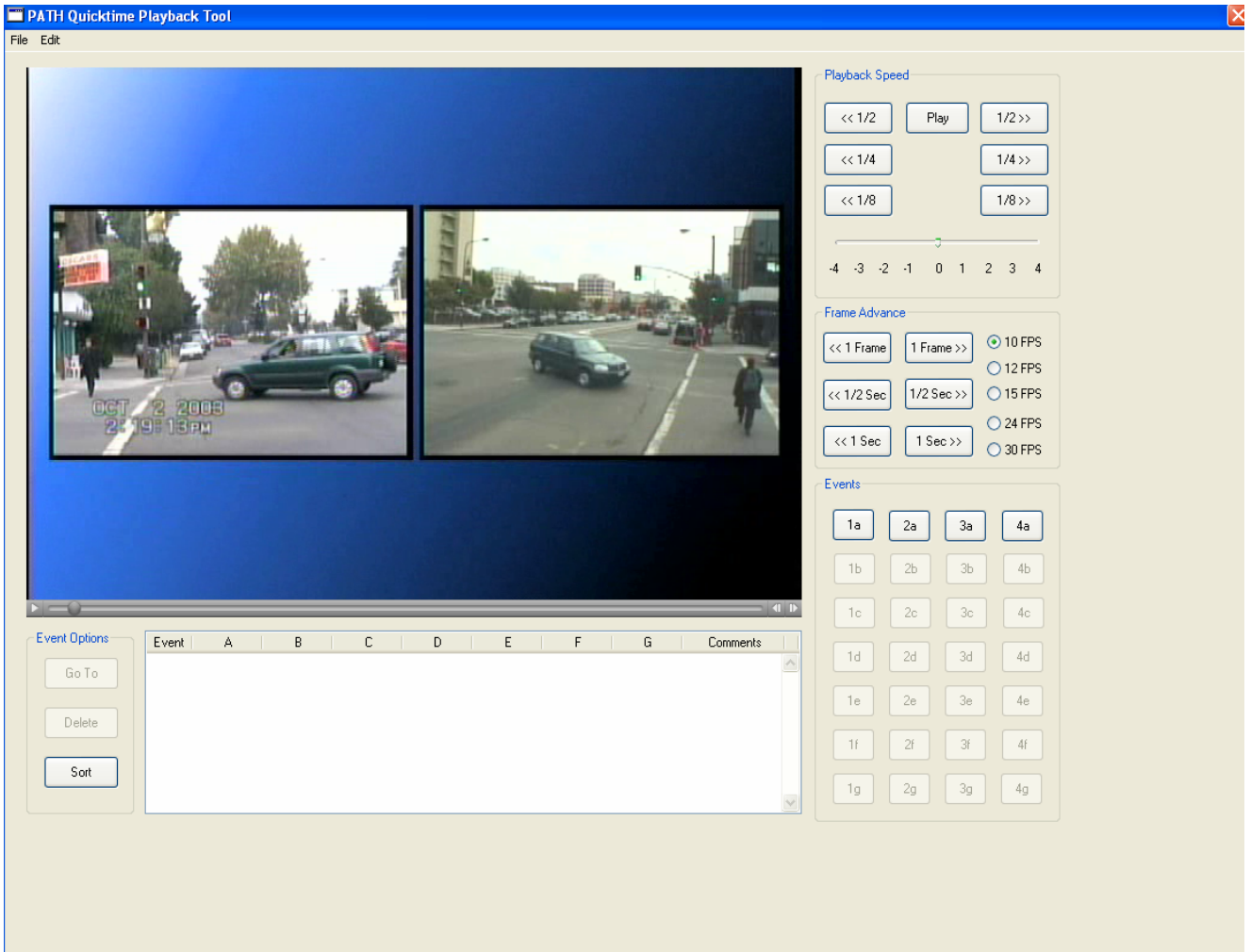


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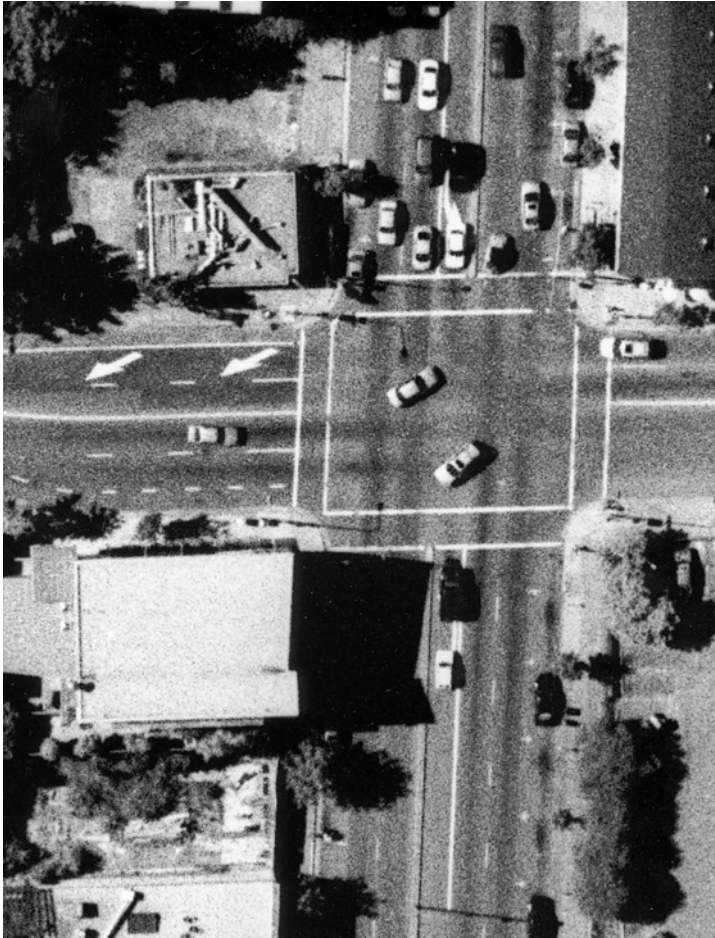


Figure 6: Aerial view of Hearst and Shattuck (North at top of figure.)

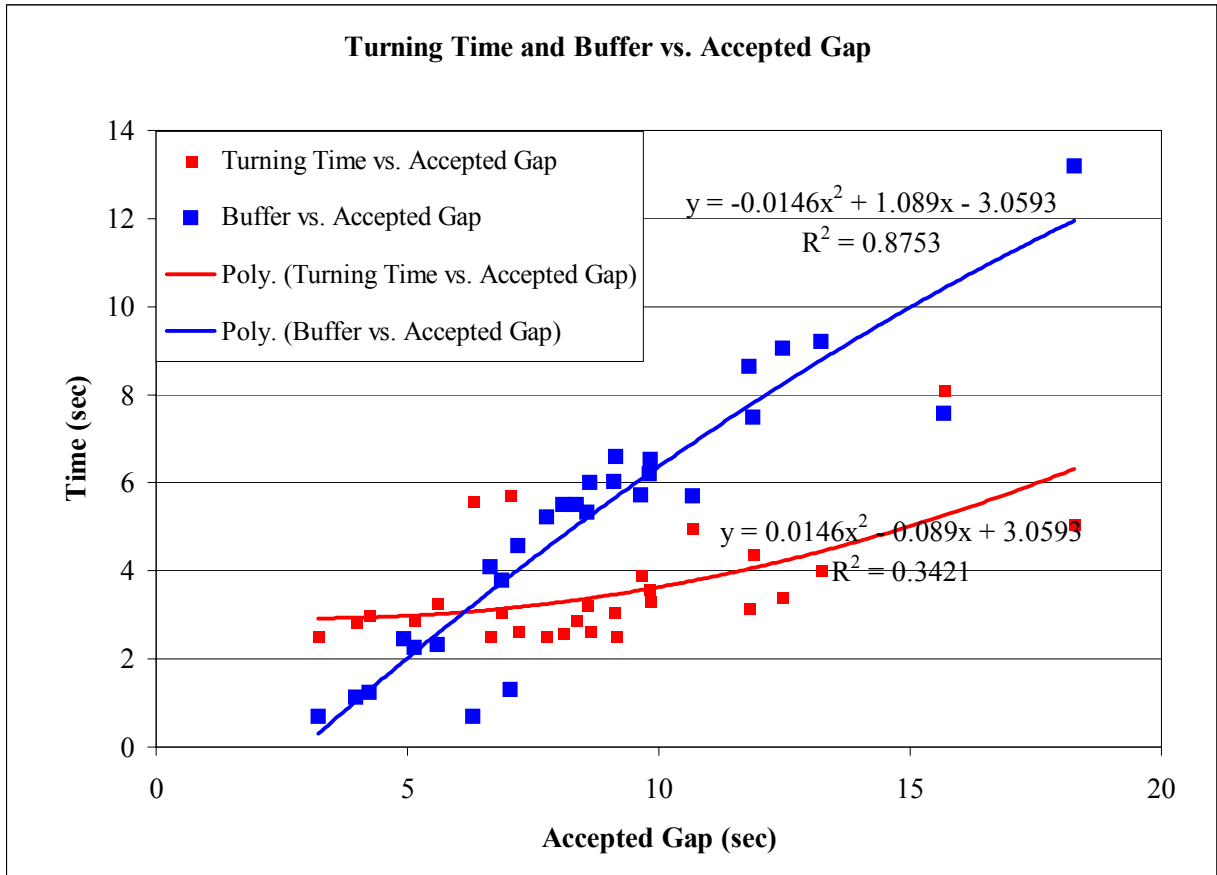


Figure 7: Turning Time vs. Accepted Gap for all vehicles on Hearst-Shattuck

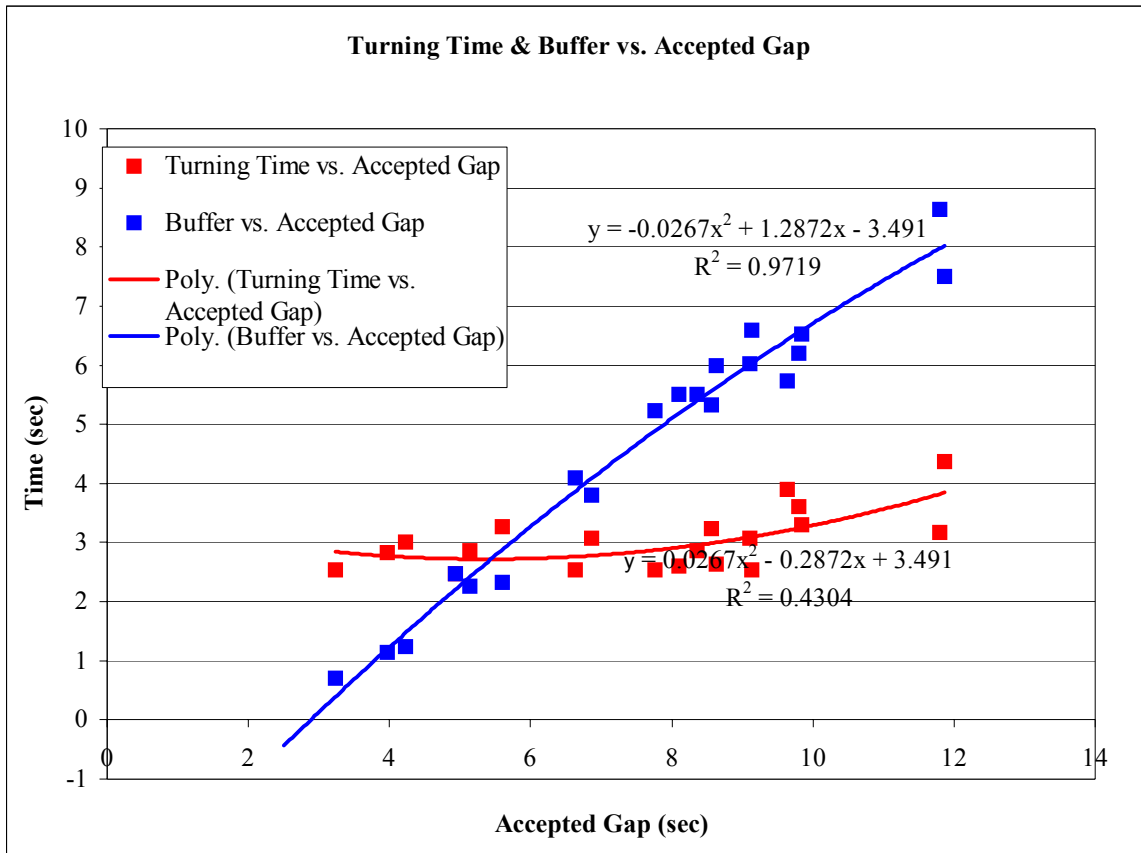


Figure 8: Turning Time vs. Actual Accepted Gap for vehicles without pedestrian influence on Hearst-Shattuck

Table 1: Turning Movement at Hearst & Shattuck intersection, 2003 (19)

	Northbound			Southbound			Eastbound			Westbound			Total
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	
AM Peak	19	291	43	199	810	57	31	278	24	11	225	51	2039
PM Peak	34	715	63	117	537	54	67	232	20	122	321	136	2418

Table 2: Observed Turning Time Statistics

Type of Turn	Number of Observations	Mean Turning Time* (s)	Standard Deviation (s)
Complete data set	109	3.3	1.0
Data for which pedestrian present in destination crosswalk	22	4.4	1.5
Data for which pedestrian absent in destination crosswalk	87	3.0	0.5

* Time from first significant turning to clearing POV lane

Table 3: Observed Accepted Gap Statistics

Type of Turn	Number of Observations	Mean Accepted Gap[†] (s)	Standard Deviation (s)
Complete data set	28	8.7	3.5
Data for which pedestrian present in destination crosswalk	8	11.4	4.4
Data for which pedestrian absent in destination crosswalk	20	7.7	2.5

[†]Time interval between clearing of the projected line of turn of SV by the rear bumper of the POV preceding the turn and that by the front bumper of the POV following the turn

Table 4: Model of relationship between Turning Time, Buffer and Gap

		R ²	Coefficients	Coefficient value	t-stat	Lower 95%	Upper 95%
Total Sample	Turning Time & Gap	0.34	Intercept	3.06	2.46	0.5	5.62
			G ²	0.01	1.16	-0.01	0.04
			G	-0.09	-0.34	-0.63	0.45
	Buffer & Gap	0.88	Intercept	-3.06	-2.46	-5.62	-0.5
			G ²	-0.01	-1.16	-0.04	0.01
			G	1.09	4.17	0.55	1.63
	Turning Time & Buffer	0.07	Intercept	-0.55	-0.11	-11.07	9.96
			TT ²	-0.20	-0.82	-0.71	0.31
			TT	2.41	1.01	-2.50	7.31
With Pedestrians	Turning Time & Gap	0.12	Intercept	6.66	1.09	-9.02	22.34
			G ²	0.02	0.50	-0.10	0.14
			G	-0.45	-0.40	-3.33	2.43
	Buffer & Gap	0.86	Intercept	-6.66	-1.09	-22.34	9.02
			G ²	-0.02	-0.50	-0.14	0.10
			G	1.45	1.30	-1.43	4.33
	Turning Time & Buffer	0.02	Intercept	11.07	0.70	-29.86	51.99
			TT ²	0.12	0.22	-1.35	1.60
			TT	-1.62	-0.26	-17.59	14.36
Without Pedestrians	Turning Time & Gap	0.43	Intercept	3.49	4.48	1.85	5.14
			G ²	0.03	1.85	0	0.06
			G	-0.29	-1.31	-0.75	0.18
	Buffer & Gap	0.97	Intercept	-3.49	-4.48	-5.14	-1.85
			G ²	-0.03	-1.85	-0.06	0
			G	1.29	5.87	0.82	1.75
	Turning Time & Buffer	0.17	Intercept	5.28	0.31	-31.15	41.70
			TT ²	0.58	0.36	-2.83	3.99
			TT	-2.00	-0.19	-24.54	20.53