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Publication Date

2006-04-01

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Gap acceptance for vehicles turning left across on-coming traffic: Implications for Intersection Decision Support design

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UCB-ITS-TSC-2006-2

April 2006

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Submission Date: November 21, 2005
Word count: 5042+ 3250

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ABSTRACT

A left-turning vehicle (Subject Vehicle, SV) attempting to cross the path of an oncoming vehicle (Principal Other Vehicle, POV) at an intersection typically does not have the right of way. The main task of the SV driver is to find an adequate opportunity in opposing traffic to initiate the left-turn maneuver. To reduce the probability of a conflict, warning systems, such as Intersection Decision Support (IDS) systems, are being developed. These systems alert drivers of SV vehicles attempting to negotiate a left turn about traffic approaching from the opposite direction. The current paper (i) describes a video system that was used to assess gap length, gap acceptance and gap rejection in a Left Turn Across Path/Opposite Direction (LTAP-OD) scenario, (ii) describes a way to characterize gap distribution (log-normal) presented to the SV driver, and (iii) illustrates how a logistic model often used to describe dose-response curves can be used to characterize gap acceptance by the SV driver. These results are used as the basis for a discussion of implications for IDS systems for alerting left-turning drivers about oncoming vehicles.

INTRODUCTION

Background

The Intersection Decision Support (IDS) Project has been developed to reduce crossing-path crashes at intersections by using emerging Intelligent Transportation Systems (ITS) technologies to provide crucial information to drivers that would help them avoid such crashes. The IDS Project is directed by an Infrastructure Consortium comprised of the U.S., California, Minnesota and Virginia Departments of Transportation (DOT). California PATH (Partners for Advanced Transit and Highways) is also a member of the IDS team.

To date, the focus of the California effort has been to reduce collisions that occur when a vehicle at an intersection turns left across the path of oncoming traffic. This situation has been termed *Left-Turn-Across-Path—Opposite Direction* (LTAP-OD). The left-turning vehicle (Subject Vehicle, SV) attempting to cross the path of an oncoming vehicle (Principal Other Vehicle, POV) at an intersection typically does not have the right of way and must choose a safe gap in the oncoming traffic. The focus of the IDS intervention is to assist the SV driver in identifying an appropriate opportunity to make the left turn. If there are oncoming vehicles, the task is to identify an adequate "gap" in oncoming traffic for the left turn. The California team has worked to develop an IDS system that provides information to the SV driver to assist in the task of choosing a safe gap.

The distribution of gaps in oncoming traffic (i.e., between successive POVs) and the acceptance or rejection of gaps by the SV driver are critical concepts in the design of an effective IDS system for LTAP-OD turns. A number of articles and reports have examined various aspects of gaps in oncoming traffic and gap acceptance. Gattis and Low *(2)* assessed factors affecting gap acceptance at nonstandard stop-controlled intersections, assessing behavior through video analysis, and using a logit-model to describe gap acceptance. Leung *et al. (3)* used a simulator to study the impact of age and alcohol on gap acceptance. Pant and Balakrishnan *(4)* used a neural network and a binary-logit model for predicting accepted or rejected gaps at rural, low-volume two-way-stop controlled intersections, finding that a neural network approach is a better predictor of gap acceptance and rejection behavior. These studies illustrate a growing interest in simulation and statistical models for representing gap-acceptance behavior.

This report uses video data from five intersections in the San Francisco Bay Area recorded from October 2, 2003 to October 14, 2004 to develop a method for analyzing (i) the distribution of gaps presented to the SV driver and (ii) gap acceptance by the SV driver.

METHODS

Definition of the Gap and Gap Acceptance

We have defined a "gap" as the opportunity to turn left before the SV must clear the intersection for an oncoming POV.[2] The length of the gap is measured as the time between the moment when the SV is presented with the

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[1] More precisely, a "gap" is the length of time between two POVs, and a "lag" is the time between an opportunity to turn such as a green light or arrival at the intersection and the arrival of a POV. In this paper we have combined these concepts and used the term "gap." Some research (e.g., Gattis JL, Low ST. Gap acceptance at nonstandard stop-controlled intersections. Mack-Blackwell National Rural Transportation Study Center, University of Arkansas, March 1998) has found differences in "gap" and "lag" acceptance. Although preliminary analyses indicate that this differentiation will not materially affect the results reported in this paper, we plan to differentiate these two concepts in further studies in this area).

[2] More precisely, a "gap" is the length of time between two successive POVs, and a "lag" is the time between an opportunity to turn such as a green light or arrival at the intersection and the arrival of a POV. In this paper we have combined these concepts and used the term "gap." Some research (e.g., Gattis JL, Low ST. Gap acceptance at nonstandard stop-controlled intersections. Mack-Blackwell National Rural Transportation Study Center, University of Arkansas, March 1998) has found differences in "gap" and "lag" acceptance. Although preliminary analyses indicate that this differentiation will not materially affect the results reported in this paper, we plan to differentiate these two concepts in further studies in this area).

opportunity (such as a green light or clear intersection) and can reasonably be assumed to be ready to initiate the left turn and the moment that a POV arrives at the path to be taken by the SV. When an SV has the intention to turn left between multiple POVs that are approaching the intersection, the gap is defined as the time that passes between departure of the rear bumper of the first POV from the left-turn path and the arrival of the front bumper of the following POV at the same point.*(1)*

The SV driver is presented with one or more gaps in which to initiate the left turn. Each of these gaps is either accepted or rejected by the SV driver. An "accepted gap" is one which is chosen by the SV driver to actually initiate and complete a left turn.

Intersections Studied

Five intersections in the San Francisco Bay area were selected for study. The intersections varied by configuration, traffic volume, vehicle speeds, collision history, and other characteristics. The five intersections are listed below.

a) Hearst and Shattuck Avenues, in the downtown area of Berkeley. Both streets have two lanes of mainline traffic and left-turn pockets in both directions. We observed SVs turning left from Shattuck onto Hearst facing oncoming POVs proceeding south on Shattuck. This intersection has fairly heavy pedestrian traffic, which allowed us to observe the impact of pedestrians on SV movement.

b) Alameda and Marin Avenues, in north Berkeley. Both streets have two lanes of mainline traffic in each direction and no left-turn pockets. We observed SVs turning left from Alameda onto Marin facing oncoming POVs traveling south on Alameda. There were a high number of left turning SVs facing a relatively low volume of POVs.

c) San Pablo Avenue and a shopping plaza driveway in the city of Pinole. This intersection is defined by the entrance to a shopping plaza parking lot onto San Pablo Avenue. San Pablo Avenue is a major thoroughfare with two lanes of mainline traffic in each direction and with a single-lane left-turn pocket for vehicles entering the parking lot. A stop sign is posted for vehicles exiting from the parking lot onto San Pablo. We observed SVs turning left from San Pablo into the shopping plaza parking lot facing POVs traveling west on San Pablo.

d) El Camino Real and Chapin Avenues in the southeast area of Burlingame. Both streets have two lanes of mainline traffic in both directions, and there are no left-turn pockets on either street. Heavy traffic in this intersection was observed to travel at relatively high speeds. We observed SVs turning left from El Camino on to Chapin Avenue facing POVs traveling southeast on El Camino.

e) Brannan Ave. and Fifth Street in the downtown area of San Francisco. Both streets have two lanes of mainline traffic in each direction and no left turn pockets. This intersection is in a highly urban location. We observed SVs turning from Fifth Street on to Brannan Ave facing POVs traveling southeast on Fifth Street. A high proportion of the oncoming POVs were making right turns, which appeared to impede SV turning.

A total of 12 ¾ hours of video recordings were collected at these five intersections from October 2, 2003 to October 14, 2004. For the current analysis, we focused on patterns of gap acceptance and rejection as well as turning times for each of the intersections. Specifically, for each intersection, we assessed:

i) Distribution of gap times presented to the SV driver;

ii) Probability of gap acceptance by length of gap (using a "gap acceptance curve").

Video Data Collection and Analysis

To observe the movements of the vehicles at intersections, we used video cameras temporarily stationed at the roadside at the five intersections listed above *(5)(6)*. Each video camera was either mounted in the rear of a van parked on the street or was mounted on a tripod at a corner of the intersection. Two video cameras were used in each intersection to provide complementary views. A schematic diagram of video camera placement is shown in Figure 1.

Figure 2 illustrates the views captured by the two video cameras. The two views in Figure 2 are of vehicle maneuvers in the intersection taken at the same moment in time. Figure 2 also illustrates a video "playback" tool developed by PATH. The tool can be operated from a QuickTime video application under the MS-Windows operating system. With this tool, the user is able to modify the playback speed of the video and mark the times when specific events of interest occur. To provide a consistent way of describing SV movements, the intersection was subdivided into regions that describe the paths that the SV vehicle follows, as shown in Figure 3. The definitions used were derived from previous studies of vehicle movements at intersections *(8)(9).* In terms of estimating the time of events, we estimate the precision of this tool to be between 0.05 and 0.10 seconds *(7).*

The video data was analyzed to estimate the number and length of time of accepted and rejected gaps presented to SV drivers. Left turns initiated under conditions where there was no approaching POV vehicle were not included in the analysis. Left turn gaps in which the POV vehicle was distant--more than 12 seconds from the intersection--were universally accepted by SV drivers and were classified as "accepted" but not analyzed for length. Gaps of 12 seconds or less were included in the analysis. These gaps were categorized as "accepted" if the SV completed the turn before the POV entered the intersection and "rejected" if the SV did not complete the turn. Gaps rejected due to SVs waiting at the intersection for pedestrians to cross the destination crosswalk were also counted as "rejected gaps".

The video analysis generated the number of accepted and rejected gaps for each whole-second time period between 0 and 12. Although the video playback was capable of defining times with a much smaller degree of precision, gap length was aggregated to whole-second intervals to provide a more appropriate distribution for statistical analysis.

RESULTS

Gaps presented to the SV driver

A total of 1,573 gaps were observed at the five intersections (Table 1). Of these, 833 were measured gaps of ≤12 seconds. The distribution of ≤12 second gaps shows that the majority of these gaps were 4 seconds or shorter, with the most frequent (modal) gap length being two seconds[3] (about 30 percent), followed by gaps of three seconds (about 18 percent) and four seconds (about 12 percent) (Figure 4). The general shape of the distribution of the ≤12 second gaps was similar across all five intersections; that is, with a higher percentage of gaps between one and four seconds and a long tail to the right, although the proportion of gaps for each time period varied somewhat by location (Figure 5).

Another way of illustrating the difference in traffic patterns among intersections is through comparing the number of gaps that last ≤12 seconds to the number of gaps that last for more than 12 seconds for each intersection (Table 2). A high percentage of ≤12 second gaps indicates generally smaller distances between oncoming POV vehicles and shorter gap times available to SV vehicles. One intersection, El Camino, had a particularly high percentage of gaps ≤12 seconds (about 74 percent). This is consistent with the observation that El Camino Real/Chapin had a very high traffic volume. Another intersection, Alameda/Marin, had a particularly low percentage of gaps ≤12 seconds (about 14 percent). This is consistent with the observation that there were relatively few oncoming vehicles at this intersection. For the remaining three intersections, the percentage of gaps ≤12 seconds was between 50 percent and 60 percent, indicating high variability in the distribution of gaps across intersections. It is not known whether this variation in gap distribution has an impact on driver behavior, and this is the topic for further research in this project.

Gaps presented to the SV driver as a log-normal distribution

It is easier to characterize the difference in gap distribution between intersections or across different conditions within the same intersection if it can be approximated by a known function. The distribution of gaps of ≤12 seconds can be described by a log-normal function, defined as "a continuous distribution in which the logarithm of a variable

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[3] For analyses in this report, times were aggregated into one-second intervals. A reference to a particular second refers to the integer defining the low end of the interval. For example, 2 seconds refers to the interval from 2 seconds up to, but not including, 3 seconds, etc.

has a normal distribution" *(10).* Three parameters describe the log-normal distribution: (i) amplitude, (ii) center (measure of central tendency), and (iii) width (measure of dispersion). Tests of fit indicated a good fit for each of the individual intersections and for the four intersections combined. The gaps at one intersection, Hearst/Shattuck, did not fit the log-normal distribution. This was the first intersection analyzed, and observations below the minimum gap accepted (3 seconds) were not measured. For the remaining four intersections, R-square values ranged from 0.790 to 0.953, and the total R-square value for these four intersections combined was 0.919. This value indicates that the data for these four intersections conformed very closely to the log-normal distribution, since the regression R-square value is close to 1. This value also explains how well the regression line "fits" the data; i.e., the amount of variation in the dependent variable that is accounted for by variation in the independent variable. Figure 6 shows graphically the closeness of fit for the four intersections combined with the fitted log-normal function and the actual distribution juxtaposed. Differences in gap distribution across intersections are illustrated in Figure 7, showing the difference central tendency, height, and dispersion.

The closeness of fit to the function suggests that several parameters can be used to describe differences in gap length presented to SV drivers across these four different intersections and at different times. Distribution of gap length is affected by both POV volume and platooning (the tendency for vehicles to move in clusters). Platooning, in turn, could be affected by adjacent traffic signals or other features that impact clustering. Platooning could lead to a distribution with many relatively small gaps and an extended tail of long gaps. Therefore, observations at intersections or at times of the day with more or less platooning might yield a different distribution *(1).* The gap length distributions shown in Figure 7 correspond roughly to those we would expect based on the traffic flow patterns of the individual intersections. Data from a larger number of intersections would make it possible to identify predictors of the parameters of the log-linear model, and this is also a task for future research.

Gap acceptance curves

We hypothesized that the probability of a gap being accepted would increase with gap length, and that the relationship between gap length and gap acceptance might vary across intersections. To test this hypothesis, we calculated the percentage of gap that were accepted among all 833 measured gaps of ≤12 seconds for the five intersections separately and combined.

Across all intersections, all gaps below three seconds were rejected (i.e., none were accepted), and all gaps above twelve seconds were accepted, leaving a range between 3 and 12 seconds when some but not all gaps were accepted. For the combined gaps from all intersections, the percentage of gaps accepted increased in a step-wise fashion from 3 to 12 seconds (curve labeled "Total" in Figure 8), generating a "gap acceptance curve"[4] *(1).* By interpolation, we calculated the gap lengths at which the gap acceptance rate was 15, 50, and 85 percent (Table 3). For all intersections combined, these gap lengths were 4.1 seconds, 6.0 seconds, and 8.6 seconds respectively, showing that, for the intersections combined, there was a fairly wide range of gap acceptance behavior. The general pattern was similar for individual intersections (Figure 8 and Table 3). For each intersection there was a more-or-less stepwise increase in the percentage of gaps accepted with increases in gap length, although due to small numbers for most of the gap lengths, the gap acceptance curve for individual intersections was somewhat uneven. The position and shape of the gap acceptance curves varied across intersections. For example, the gap length at which 85 percent of the gaps were accepted was relatively high for two intersections, Brannan/Fifth and San Pablo, with 11.8 and 11.1 seconds, respectively. This difference indicates that SV drivers were less likely to choose shorter gaps at these intersections.

Gap acceptance curves can be modeled by the logistic function

We next assessed whether the gap acceptance curve could be modeled or represented by a known function. The gap acceptance curves shown in Figure 8 closely resemble a logistic distribution often used to describe a dose-response *(11).* A logistic function in its simplest form describes a continuous increasing function between 0 and 1 (or between 0 percent and 100 percent. Thus, the curve rises from 0 to 100 percent and is described by the following equation:

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[4] Note that the gap acceptance curve goes from 0 to 100%. It is not a cumulative curve, but indicates the percentage of gaps accepted for a given gap length.

$$Y = \frac{100}{1 + 10^{\left(\log\left(Accept50\right) - X\right) \times Slope}}$$

This equation describes a symmetrical curve where *Accept50* is the point (in seconds) at which the gap acceptance rate is 50 percent, and *Slope* is a measure of dispersion. We calculated the *Accept50* and *Slope* for all intersections combined and for each intersection separately. The variance of these estimates for Brannan/Fifth was very high; thus Brannan/Fifth was excluded from this analysis. The lack of fit for this intersection may reflect sporadic patterns of traffic that compromised the SV's ability to predict POV behavior.

The results are given in the two right hand columns of Table 3. *Accept50* varies by over two seconds between the lowest (5.6 at Hearst/Shattuck) and highest intersections (7.6 at San Pablo Ave) and for each intersection, it is fairly close to the interpolated point at which 50 percent of the gaps were accepted (3rd column). The slope also varies substantially between the steepest (0.59 at Alameda/Marin) and the shallowest (0.23 at San Pablo Ave/Pinole). The gap acceptance curves modeled in this way are illustrated in Figure 9.

The comparison between the actual gap acceptance curve and the one calculated through the model is shown in Figure 10 for all gaps combined. For the four intersections, the R-square values ranged from 0.929 to 0.999, and the total R-square value for these four intersections combined was 0.995. Since this value is very close to 1, it is apparent that the logistic function provides a close approximation to the actual curve observed. This result means that the logistic function can be used with a good deal of accuracy to predict the gap acceptance behavior at individual intersections and to model changes in conditions within intersections (e.g. variation in traffic, weather, and types of drivers).

IMPLICATIONS FOR IDS DESIGN

These results show a wide variation in gap acceptance both among and within intersections. This variation has implications for countermeasures to prevent LTAP-OD collisions, and, in particular, for IDS systems for alerting left-turning drivers.

In the vast majority of cases, SV drivers appear to choose a gap for their left turns that is sufficiently long to avoid a collision or major conflict. Therefore, it has been suggested that one strategy for designing an IDS warning system is to mirror the usual behavior of SV drivers. *(12)* Following this suggestion, a warning would be given for gaps that a driver would usually reject, and not be given for gaps that a driver would usually accept. Presumably, this warning would be helpful if the SV driver were inattentive (e.g., cell phone use, distraction from passenger, etc.) or had impaired visibility (e.g., due to weather conditions, lighting, oncoming vehicles turning left, etc.). Therefore, the IDS system would be designed to support SV drivers in making decisions that drivers would ordinarily make if they were attentive and had adequate information.

Our observations show that SV drivers may vary considerably in their preferences about what constitutes an acceptable gap; in the present set of observations, an acceptable gap ranged from 3 to 12 seconds, even within the same intersection at roughly the same time of day. This large variation most likely reflects variation in preference of individual drivers. Yet, at a particular intersection, there is no way beforehand to distinguish drivers who are likely to accept a shorter or longer gap. This makes it difficult for the IDS system to "mirror" driver behavior, and the IDS algorithm is forced to adopt a "one-size-fits all" approach.

If a fixed gap size must be chosen as the basis for designing a warning in a particular situation, its relevance or significance will vary for different drivers. This can be illustrated by comparing alerts shown at each end of the range of the gap acceptance curve. At one extreme, we might choose a gap length (for convenience, called here a "target gap") with a *high* likelihood of being rejected normally by most SV drivers (i.e., a fairly small gap). The warning would be given for the range defined by this particular gap and all smaller gaps (gaps <= target gap). This means that many gaps *above* this range would also be rejected by many SV drivers. This discrepancy may have two consequences: (i) it may lead some SV drivers to conclude that the warning is inadequate (i.e., that a warning is not given for many gaps they would have rejected) and/or (ii) it may lead some SV drivers to think that a gap is okay that they would have otherwise rejected. The SV driver may learn (perhaps correctly) not to trust the system.

At the other extreme, we might consider a gap length with a *low* likelihood of being rejected by most SV drivers (i.e., a fairly large gap). In this case there will be many shorter gaps that would have been accepted by many SV drivers. The discrepancy would operate in the opposite direction of that above. In this case many SV drivers might think that they could have easily proceeded when an alert was given. Many drivers might learn to ignore the alerts and/or experience the warning as a "nuisance." A possible consequence is that alerts given in the event of a truly dangerous situation may be ignored.

An important concept is that of the discrepancy between the target gap length (i.e., the gap defining the warning) and the largest gap ordinarily rejected by a particular SV driver. This discrepancy will differ across drivers, and in theory can be quantified. If the target gap is fairly small and the largest gap length ordinarily accepted by a particular SV driver is just one second or so greater than the target gap, then the discrepancy will be fairly small. If the maximum preferred gap of a particular SV driver is much larger than the target gap, then the discrepancy will be large. Our present result shows that no matter what gap is chosen as the target gap, there will be a large number of discrepancies, and many of these will be of a substantial period of time.

The logistic model allows us to characterize LTAP-OD gap acceptance in terms of two parameters: (i) *Accept50*, reflecting position along the dimension of gap length and (ii) slope, representing dispersion. In general, these parameters have different implications for IDS algorithms. Differences in position along the dimension of gap length can be accommodated in IDS algorithms by adjusting the warning criterion to be shorter and longer, accordingly. Differences in slope have stronger implications. A very high slope indicates a lower dispersion, meaning that drivers will generally have less variability. This means that there will be less discrepancy for any particular driver between any particular warning point and the driver's general preference. A shallower slope, or greater dispersion, will have just the opposite implication, i.e., in general there will be a greater discrepancy between the warning point and the driver's general tendency.

Given the differences in gap times in different intersections, warnings would need to be tailored to each intersection and might vary by weather or lighting conditions. In addition, gap acceptance times are expected to vary by gender, age, and other characteristics of drivers. Parameters of the logics function could be used to characterize differences across intersections, across conditions within the same intersection, and across different categories of drivers.

Alternative to a fixed gap size would be to provide more information to drivers about approaching POV(s) with which they could make judgments about a turn based on their own experience and preferences. One strategy might be adapted from pedestrian signals with "countdowns" of time left before the light changes to yellow. The information allows a pedestrian to hurry up and cross the street, stop at the median, or wait for the next light, depending on their own abilities and preferences. Similarly, a signal for left-turning vehicles could light only when one or more POVs were approaching within a certain generous gap. Drivers would be alerted to the presence of an approaching POV and would see an indication of how much time was available to complete the left turn before arrival of the first approaching POV. Like pedestrians, SV drivers would learn to judge appropriate gaps in terms of how much time they or their vehicles would need to cross two or three lanes of oncoming traffic.

FUTURE RESEARCH

There results of this paper, and consideration of the implications for IDS alert systems, suggest two general areas of research.

The first area recommended for future research is to identify factors that influence gap acceptance for SV drivers in LTAP-OD scenarios. For example, the distribution of gap lengths varies substantially by intersections and within the same intersection as a function of traffic volume, speed, and degree to which vehicles are platooning, and it is important to know if this impacts gap acceptance behavior. At a given intersection, *longer* average gap lengths will mean that an SV driver will find it easier to find an adequate gap. However, longer gap times could also lead an SV driver to have a lower expectation that a POV will appear. A *shorter* average gap will mean that the SV driver will find it more difficult to find an adequate gap. In this circumstance, the SV driver may be more likely to choose an inadequate gap (especially if the delay leads to impatience) or to accelerate more quickly than normal through the turn. Further work is needed to assess how the distribution of gap lengths affects driver behavior. Other factors also may influence gap acceptance behavior by SV drivers, including time in the signal cycle, weather conditions, lighting, etc. The impact of these conditions on gap acceptance behavior needs to be studied in order to be able to calibrate IDS systems.

The second area recommended for future research is the evaluation of actual driver reactions to warnings based on different target gaps. A reasonable and testable hypothesis is that the probability of reactions is directly related to the size and direction of the discrepancy between the target and the preferred minimum gap. A related question is to determine which consequences are most important to avoid. A starting assumption is that the most serious error is to fail to warn in the case of a gap that is either dangerous or is perceived to be by the most conservative SV drivers. If this is true, then the warning must be generally conservative, i.e., given for all gaps that have even the minimal chance of rejection by SV drivers along with all other gaps with a greater change of rejection (i.e., the first option above). However, this must be balanced against the resulting increase warnings possibly experienced as “nuisance” warnings by some SV drivers. The balance between these two types “errors” depends on actual SV driver reactions. It is crucial to understand actual SV driver reaction to variation in the target gap length chosen for triggering the warning. This SV driver reaction is being studied by the Berkeley IDS team.

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ACKNOWLEDGEMENTS

The authors wish to express gratitude for the generous assistance from the City of Berkeley, California, especially Charles Deleuw and John Harris of the Public Work Department. We are also indebted to the support provided by our colleagues, Askhan Sharafsaleh, David Nelson, Thang Lian, Bart Duncil, Aleksandr Zabyshny, Susan Dickey, and Paul Kretz, who generously provided their assistance in the execution of the field observation task.

This work was performed as part of the Intersection Decision Support project under the sponsorship of the Federal Highway Administration in cooperation with the State of California Business, Transportation, and Housing Agency Department of Transportation. Preparation of this paper was supported by the U.C. Berkeley Traffic Safety Center, whose funding is provided by the California Office of Traffic Safety through the Business, Transportation, and Housing Agency. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the sponsoring organizations. This paper does not constitute a standard, specification, or regulation.

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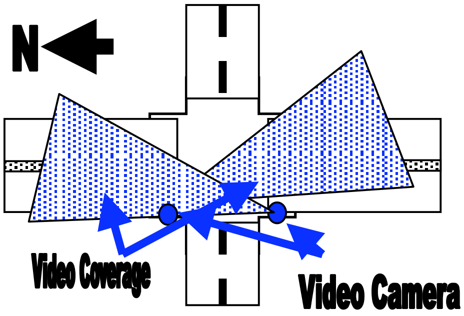


Figure 1. Video data collection fields for observing SV and POV movements.

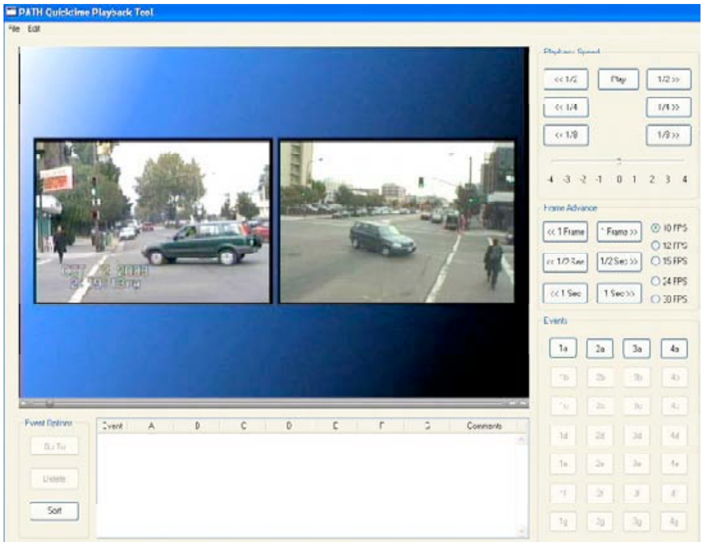
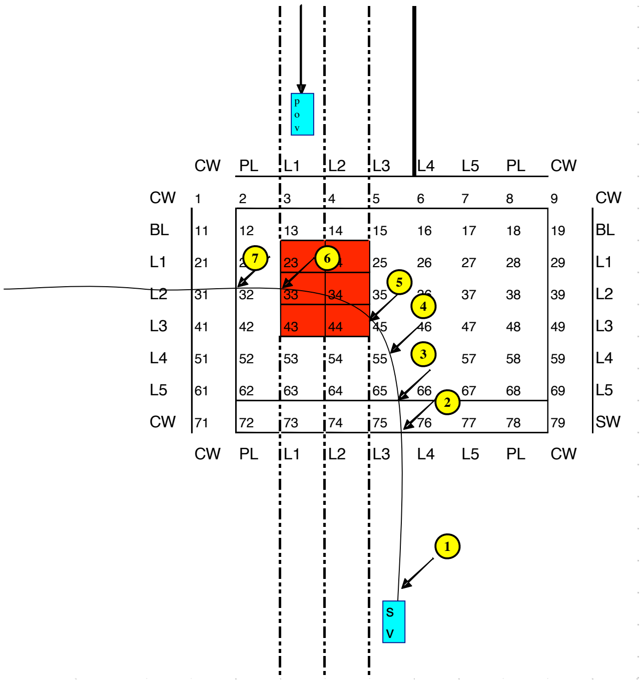


Figure 2. Example of simultaneous views from the two video cameras and illustration of the user interface for the video analysis tool.



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)

Figure 3. Arrows indicating points in the turning path of the SV at an intersection

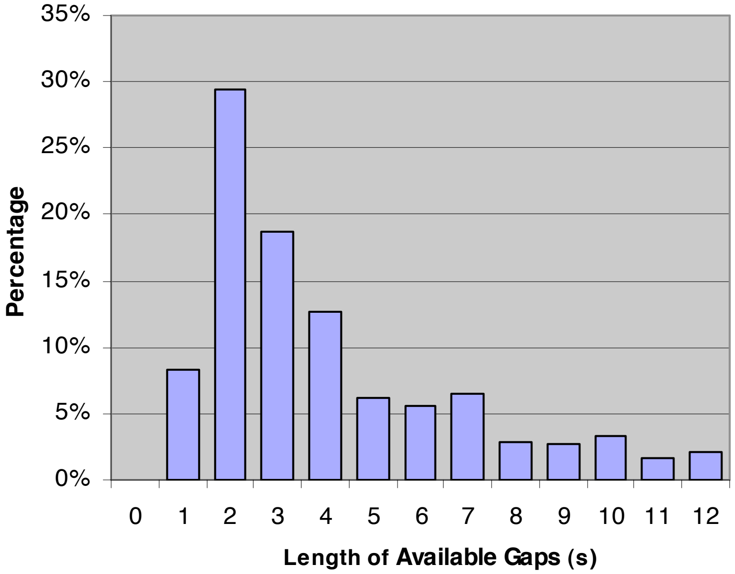
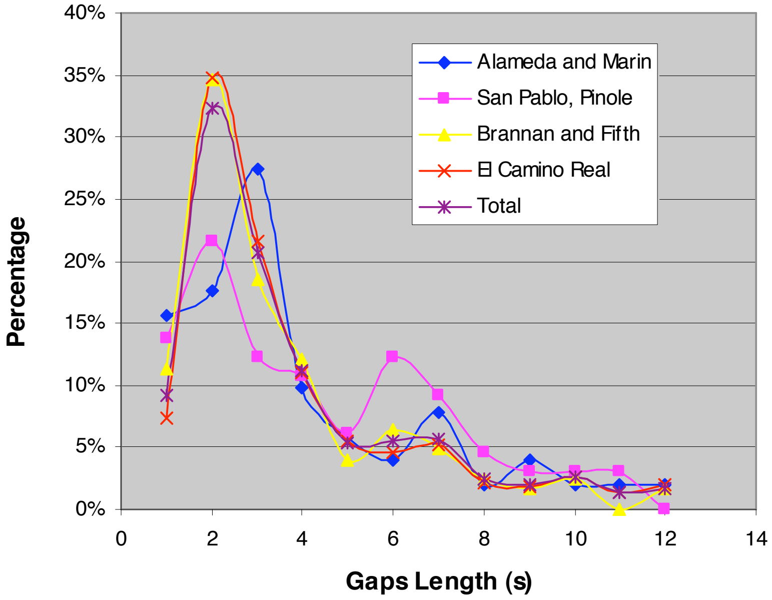


Figure 4 Distribution of gap lengths of 12 seconds or less for all intersections combined (n=833).



Note: Shattuck and Hears is not included since no gaps less than 3 seconds were measured at the time of the observations

Figure 5 Distribution of gap lengths of 12 seconds or less for individual intersections (n=833).

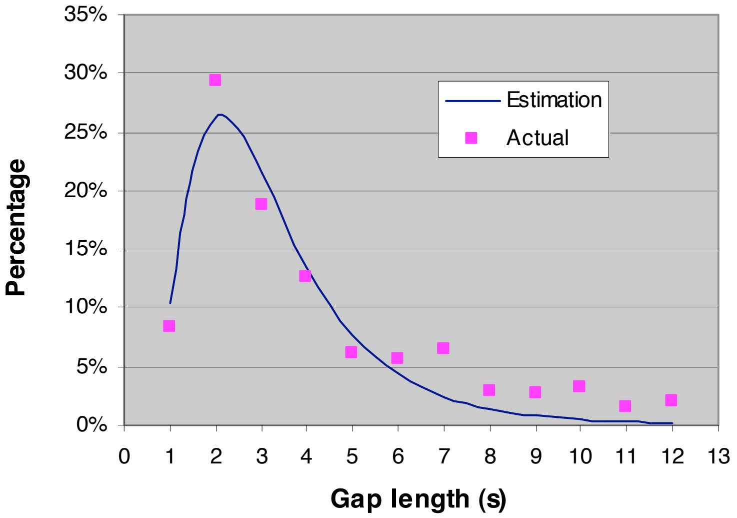
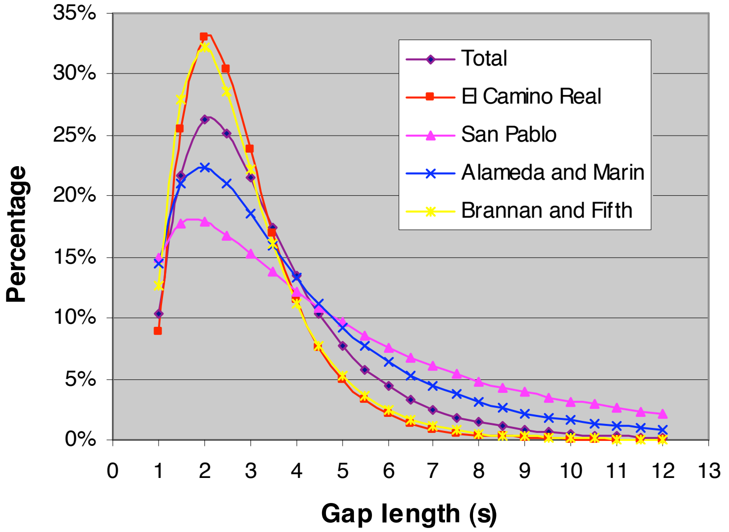
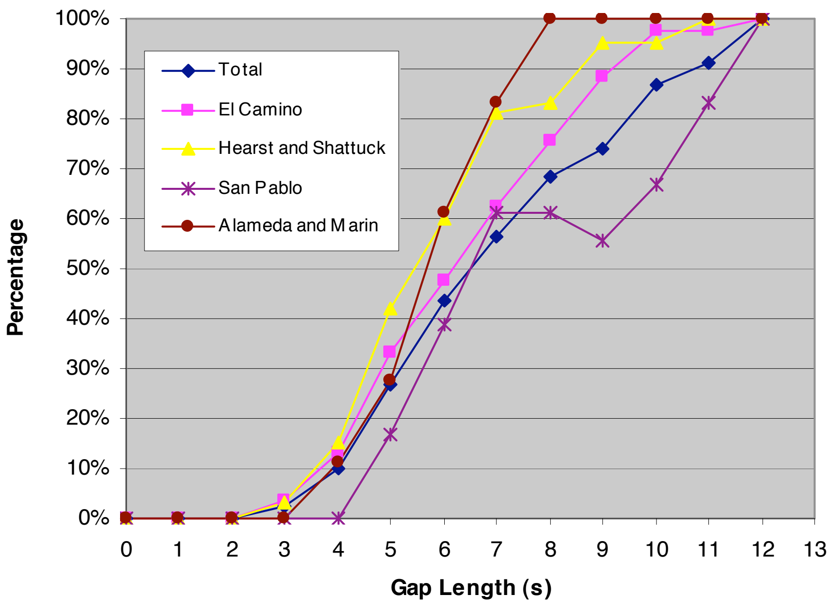


Figure 6 Actual vs. lognormal function for gap length distribution for all intersections combined.



Note: Shattuck and Hears is not included since no gaps less than 3 seconds
were measured at the time of the observations

Figure 7 Log-normal function fitted to distribution of gaps presented to the SV driver for individual intersections.



Note: Brannan and Fifth was excluded from the analysis since the variance of the parameters estimated in the logistic model was very high.

Figure 8. Percent of gaps of 12 seconds or less accepted by gap length by intersection and overall.

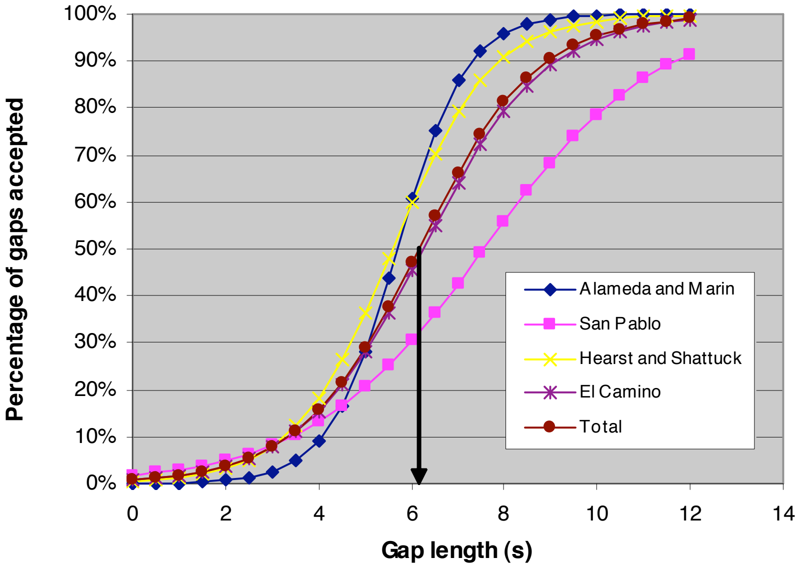


Figure 9 Logistic function describing acceptance of gaps of 12 seconds or less for four intersections (excluding Brannan and Fifth). Arrow is Accept50 for curve representing four intersections combined.

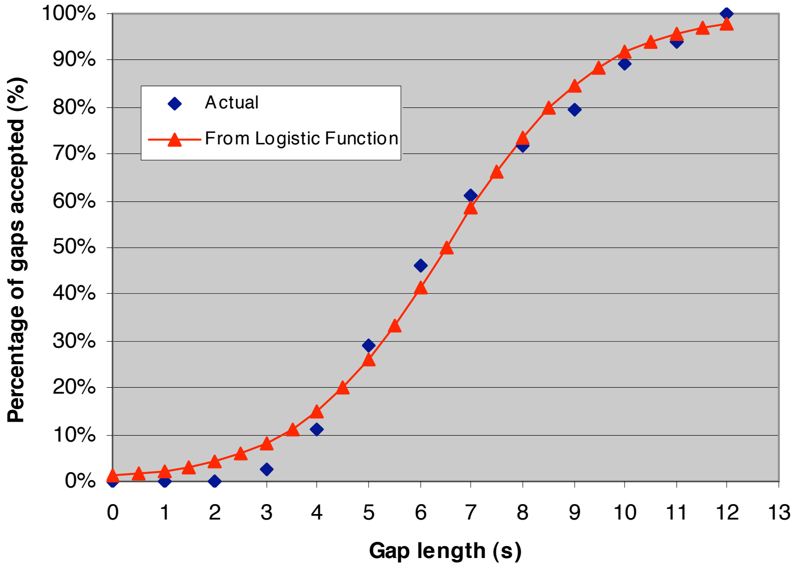


Figure 10 Actual vs. logistic function gap acceptance curve for all intersections combined

Table 1 Gap lengths observed (accepted and rejected) at five intersections (N=1573).

Intersection	Accepted Gaps			Rejected Gaps			Overall Total
	<=12 seconds *	>12 seconds **	Total	<=12 seconds	>12 seconds ***	Total	
Alameda/Marin Berkeley	12	324	336	39	0	39	375
Brannan/Fifth San Francisco	7	118	125	117	0	117	242
El Camino/Chapin Burlingame	88	175	263	416	0	416	679
Hearst/Shattuck Berkeley	44	65	109	45	0	45	154
San Pablo Ave/ Pinole	14	58	72	51	0	51	123
Total	165	740	905	668	0	668	1573

*Turning time and gap size recorded

**Turning time was recorded, not gap size—in many cases gap size over 12 seconds was indeterminate because no POV was in sight.

***There were no rejected gaps over 12 seconds

Table 2 Percentage of gaps that were 12 seconds or less

Intersection	**Total number of gaps observed**	**Percentage of gaps that were 12 seconds or less (%)**
Alameda/Marin	242	13.6
Brannan/Fifth	679	51.2
El Camino Real/and Chapin	154	74.2
Hearst/Shattuck	375	57.8
San Pablo Ave/Pinole	123	52.8
All Intersections	1,573	53.0

Table 3 Statistics for gap acceptance curves by intersection and for all intersections combined.

	Gap lengths in seconds (interpolated) at which 15, 50, and 85 percent of gaps are accepted			**Parameters of logistic model describing the gap acceptance curve**	
Intersection	**15%**	**50%**	**85%**	**Accept50**	**Slope**
Alameda/Marin	4.2 sec	5.7 sec	7.1 sec	5.7	0.59
Brannan/Fifth	5.6 sec	11.3 sec	11.8 sec	*	*
San Pablo/Pinole	4.9 sec	6.5 sec	11.1 sec	7.6	0.23
Hearst and Shattuck	4.0 sec	5.4 sec	8.2 sec	5.6	0.41
El Camino Real/Chapin	4.1 sec	6.2 sec	8.7 sec	6.2	0.33
All intersections**	4.1 sec	6.0 sec	8.6 sec	6.1	0.34

*Estimate unstable
** Not including Brannan and Fifth