Title

Bicycle Detection and Operational Concept at Signalized Intersections Phase 2

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Steven E. Shladover, ZuWhan Kim, Meng Cao, Ashkan Sharafsaleh, Irene Li, and Scott Johnston

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DISCLAIMER STATEMENT

Abstract

This project was created as a follow-on to PATH Task Order 6203, to extend the studies of bicyclist signal timing that were conducted in that project to a wider range of intersections and traffic signal control scenarios. This work is motivated by the legal requirement, instituted by the California Legislature, that the road network provide equal service to bicyclists as it does to motorists. Based on the preliminary findings from Task Order 6203, Caltrans issued Traffic Operations Policy Directive (TOPD) No. 09-06 effective September 10, 2009, including guidance on signal timing to serve bicyclists. Additional field measurement data on bicyclist intersection crossing behavior were needed to verify that the preliminary findings from TO 6203 would remain applicable for more diverse intersections in different parts of the state, with a full range of bicycling populations and traffic conditions. Furthermore, because questions were raised about the potentially adverse traffic impacts of providing longer minimum green times on all signal phases to meet bicyclists' needs, more extensive traffic simulations were needed to quantify the traffic impacts of a variety of signal control strategies in coordinated corridors, where the signal progressions could potentially be disrupted.

Keywords: Bicycling, traffic detection, traffic signal timing.

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Executive Summary

This project was created as a follow-on to PATH Task Order 6203, to extend the studies of bicyclist signal timing that were conducted in that project to a wider range of intersections and traffic signal control scenarios. This work is motivated by the legal requirement, instituted by the California Legislature, that the road network provide equal service to bicyclists as it does to motorists. Based on the preliminary findings from Task Order 6203, Caltrans issued Traffic Operations Policy Directive (TOPD) No. 09-06 effective September 10, 2009, including guidance on signal timing to serve bicyclists. Additional field measurement data on bicyclist intersection crossing behavior were needed to verify that the preliminary findings from TO 6203 would remain applicable for more diverse intersections in different parts of the state, with a full range of bicycling populations and traffic conditions. Furthermore, because questions were raised about the potentially adverse traffic impacts of providing longer minimum green times on all signal phases to meet bicyclists' needs, more extensive traffic simulations were needed to quantify the traffic impacts of a variety of signal control strategies in coordinated corridors, where the signal progressions could potentially be disrupted.

The PATH portable video data acquisition system was used to collect data about bicyclist crossing times and speeds at five new intersections, to complement the data previously collected at two intersections. The combined data from the seven intersections provide considerable geographical diversity (Urban, suburban and rural, including northern and southern California and Central Valley), diversity of bicycling population (commuters, recreational and serious bicyclists), and diversity of intersection size and geometry. The complete distribution of bicyclist cruising speeds was derived for all seven intersections, and the start-up timing relative to the onset of the green traffic signal phase was derived for six of the intersections. These characterizations of bicyclist behavior are expressed in terms of the complete cumulative distributions, so that a user of the data can choose which percentile of the bicyclist behavior they want to accommodate in the selection of signal timing.

The data about bicyclist crossing times show clear influences of several factors that need to be accounted for in selection of signal timing, in addition to the obvious importance of street width. Since bicyclists are strongly affected by road grades, it is necessary to allow additional clearance time for intersections with significant grades on the approaches. In addition, the demographics and trip purposes of the bicyclists influence their crossing times. Where there is a significant proportion of recreational bicyclists or families with children, the crossing times are longer.

The data are compared directly with the timing recommendations in Caltrans TOPD 09-06, showing that those recommendations appear to be generally suitable for serving the needs of 85% of the bicycling population (subject to additional adjustments needed for intersections with special circumstances such as grades or a significant proportion of children or recreational bicyclists). This provides confirmation of the validity of those timing recommendations, but does not provide a sufficiently complete set of data to

support development of a detailed handbook of timing guidelines for all combinations of conditions.

The signal timing recommendations in TOPD 09-06 would require increases in the minimum clearance intervals for wide intersections in California, with minimum green times significantly longer than the current 4 s minimum. In order to assess the implications of these changes for vehicular traffic, a detailed traffic simulation was conducted for a suburban arterial with signal progression. The bicycle-friendly signal timings were substituted for the current signal timings and traffic was simulated under moderate (mid-day) density conditions and low density conditions (20% of the mid-day volumes). In both conditions, the effects on travel speed and delays were negligible, while the number of stops increased slightly. The same corridor was simulated with the addition of pedestrian crossing phases, and the results showed that these had a much larger impact on traffic speed, delay and number of stops than the retiming for bicyclists. Since our prior research under TO 6203 already showed that the effects of signal retiming for bicyclists were negligible under peak traffic conditions, it appears to be reasonable to conclude that there should be no concerns about traffic impacts of implementing TOPD 09-06, especially when the signal timing is re-optimized after the bicycle minimum times are included.

The results reported here provide strong support for the application of the signal timing recommendations in TOPD 09-06 to accommodate the needs of bicyclists crossing intersections. This should enable new signals to be timed for bicyclists from the start, as well as enabling rational re-timing of existing signals. However, additional work will be needed to produce an authoritative handbook that can provide detailed quantitative guidance for traffic engineers regarding how to time signals for bicyclists under the full range of conditions that they will encounter in practice.

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1. Introduction

This project was created as a follow-on to PATH Task Order 6203, to extend the studies of bicyclist signal timing that were conducted in that project to a wider range of intersections and traffic signal control scenarios. This work is motivated by the legal requirement, instituted by the California Legislature, that the road network provide equal service to bicyclists as it does to motorists. Based on the preliminary findings from Task Order 6203, Caltrans issued Traffic Operations Policy Directive (TOPD) No. 09-06 effective September 10, 2009, including guidance on signal timing to serve bicyclists. Additional field measurement data on bicyclist intersection crossing behavior was needed to verify that the preliminary findings from TO 6203 would remain applicable for more diverse intersections in different parts of the state, with a full range of bicycling populations and traffic conditions. Furthermore, because questions were raised about the potentially adverse traffic impacts of providing longer minimum green times on all signal phases to meet bicyclists' needs, more extensive traffic simulations were needed to quantify the traffic impacts of a variety of signal control strategies in coordinated corridors, where the signal progressions could potentially be disrupted.

TOPD 09-06 specified that the signal timing should be based on an assumed bicyclist cruising speed of 10 mph and an additional start-up time for standing starts of 6 seconds. This was used to calculate the sum of the minimum green interval, yellow interval and red clearance interval for signal controllers as a function of the intersection width (where that was defined based on the distance from the limit line to the far side of the last conflicting lane, plus 6 feet for the length of the bicycle). The results were tabulated in a table for widths from 40 feet to 180 feet in increments of 10 feet, producing required minimum phase lengths ranging from 9.1 to 18.7 seconds. Since the default minimum green time in California has been 4 seconds, this is likely to lead to significant increases in some minimum green times, especially for wider intersections.

The promulgation of TOPD 09-06 generated controversy among local traffic engineers in California, leading to an alternate proposal by the City of Vacaville that was supported by Orange County and several other jurisdictions. These traffic engineers were concerned that the increased minimum green time requirement would produce adverse traffic impacts in several ways: depriving large, heavily traveled arterials of green time in order to serve smaller cross-streets with light traffic, not only during peak periods but also off peak; requiring excessive green times for left turning phases at large intersections where bicyclists rarely if ever make left turns; and requiring longer total cycle times to serve all phases at large 8-phase intersections, where the minimum green time would have to be increased for every phase. Vacaville proposed that the bicycle signal timing requirement be based on a 15 mph cruising speed plus a 1 second perception-reaction time and the time needed to accelerate to the cruise speed at a rate of 3 ft/s/s (about 0.1 g). They also suggested an option for intersections with a high proportion of young bicyclists, reducing the cruising speed to 10 mph and the acceleration rate to 1.5 ft/s/s (about 0.05 g).

2. Selection of Field Data Collection Sites

The original field data collection reported in the final report on PATH Task Order 6203 (PATH Research Report PRR-2009-37) was conducted at two intersections in Palo Alto and Berkeley. When these results were reported to the California Traffic Control Devices Committee (CTCDC), they indicated the need to see data from a wider range of intersections that would not just be in Bay Area suburban university towns, but would represent more of the state. This meant that it was necessary to include data from Southern California, the rural Central Valley, and at least one of the major metropolises (Los Angeles or San Francisco). Therefore, sites meeting these criteria were sought for the new data collection in this project. The project staff contacted traffic engineers and bicycle coordinators in San Francisco, Los Angeles, Long Beach, Davis, Vacaville, and Santa Monica to identify promising intersections that have a high volume of bicycle traffic and a wide range of other important characteristics that could affect bicyclist crossing times and speeds:

- bicyclist demographics (young adult, mature adult, child)
- bicycling trip purposes (commuting vs. recreational)
- local traffic conditions (density and speed, especially on the cross street)
- intersection geometry (approach widths and grades, crown on cross street).

The candidate intersections that were recommended for our consideration were as listed below, and the places where we actually collected data are indicated in boldface:

<u>San Francisco</u>:
Polk at Sutter – bike lane with strong commute bicycling and significant grade
Marina at Cervantes – high volume of recreational and family bicyclists
Market at Valencia – large intersection with heavy left-turning commute bicycling
Church at Market – wide intersection with heavy commute bicycling traffic
Market and 5th Streets – heavy bicyclist commute volumes, but no good place to park the data collection system

<u>Los Angeles</u>:
Venice at Beethoven – bicycle lane serving diverse and leisure bicyclists
Laurel Canyon at Chandler – extremely wide (180 ft), diverse population
Reseda Blvd / Oxnard St. – Near dedicated busway but not enough bicyclists
Balboa / Victory -- large intersection but not enough bicyclists
Van Nuys Blvd /Oxnard Blvd – Large intersection, but no bicycle lane or bicyclists
Chandler Blvd / Vineland – Adjacent intersection is very close; thus the collected data would not be representative
Sunset Blvd. / Silverlake Blvd. (Parkman Ave.) - Silverlake and Sunset do not meet but they are connected through a downgrade ramp, thus difficult to park/observe
Sunset Blvd./ Griffith Park Blvd. (Maltman Ave.) - three roads (Sunset, Griffith Park, and Maltman) meet in a non-typical way
Sunset Blvd. / Hyperion Ave. - the two roads meet with an angle and one side of Hyperion is a high grade uphill.

Sunset Blvd. / Santa Monica Blvd. (Sanborn Ave.) - Sunset, Santa Monica, and Sanborn meet in a non-typical way and the South side of Sanborn is uphill.
Venice Blvd / Sepulveda Blvd. – large intersection with bicycle lane, but no good place to park the data collection system
Venice Blvd / McLaughlin – bicycle lane serving diverse and leisure bicyclists
Venice Blvd / Inglewood Blvd. – bicycle lane serving diverse and leisure bicyclists
Venice Blvd / Centinela Blvd. – bicycle lane serving diverse and leisure bicyclists
Paseo del Mar / Weymouth or Patton or Gaffey - Paseo del Mar is an ocean-side scenic drive road next to many parks. All three are T-intersections with no traffic signals.
Rose / Pacific – new bike lane

Davis:
Anderson at W. 8th St. – high volume of college student bicyclists, also expecting many teen bicyclists because of nearby middle school
Cowell at Drew – high volume of college student bicyclists
Villanova at Anderson Road – high volume of college student bicyclists, also expecting many teen bicyclists because of nearby middle school
Sycamore at Covell Boulevard – large intersection with bike lanes with college and family bicyclists, but no good place to park the data collection system
F Street and E. 14th Street – T-intersection with bike lanes, high volume of teen bicyclists because of nearby middle school and high school
Arlington at Shasta Drive – T-intersection with bike lanes, near a park with very young bicyclists

Santa Monica:
Main Street at Marine – complicated urban traffic, mixed bicycling population, unusual intersection geometry producing wide range of starting positions for crossing bicyclists.
Main Street at Hill
Main Street at Ashland
San Vicente Boulevard at 7th Street
Broadway at 7th, 11th or 17th Streets
Ocean Avenue at Colorado Avenue
California Street and Ocean Avenue – left turning bicyclists
Ocean Park Boulevard and Main Street – left turning bicyclists

The seven intersections where we collected bicyclist crossing data are described below.

2.1 Polk at Sutter St., San Francisco

This intersection was chosen because it is in a high-density urban setting with a reasonably high volume of commuter bicyclists of diverse age and vigor and a significant grade on the approaches (4.5%). The intersection itself is flat, despite the grade on the approaches, and the cross-street (Sutter) is one way, which simplifies the bicyclists' responsibility to check the cross traffic status before proceeding into the intersection. They also have very good visibility of the cross traffic. These factors are the likely reasons that 60% of the standing start bicyclists at this intersection did not even wait for

the green signal, but started moving prior to the green onset. The crossing distance of 58 ft. was measured from the stop bar on the starting side of the intersection to the curb line on the opposite side (equivalent to the front edge of the pedestrian crosswalk).
The Google Earth view is shown in Figure 2.1, indicating the location of the data collection trailer and video cameras, where they provided visibility of bicyclists traveling in both directions along Polk St. The cross street, Sutter, has three lanes of heavy one-way traffic, with a posted speed limit of 25 mph, and parked cars on both sides.

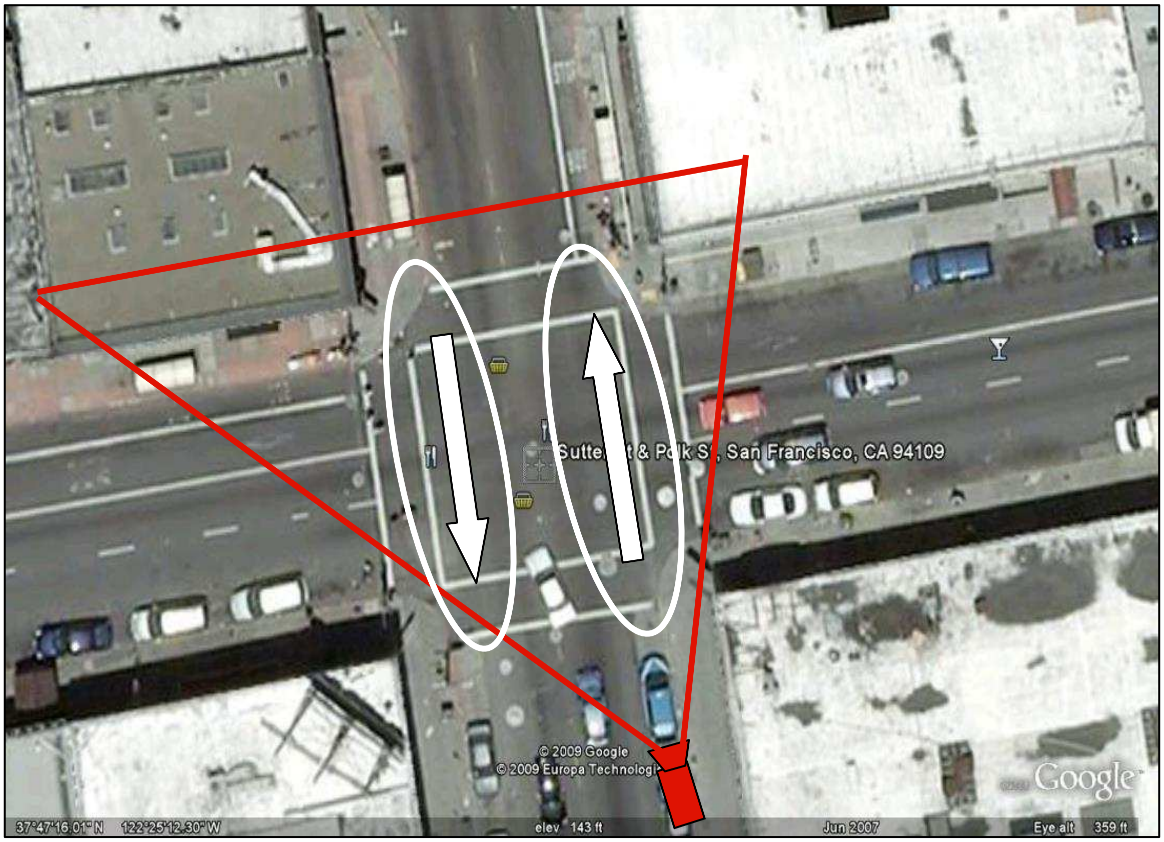

Figure 2.1 San Francisco, Polk at Sutter Data Collection Site

2.2 Marina at Cervantes, San Francisco

This site was chosen to get recreational bicyclists of diverse demographics, especially including families with children, because of its location in the tourist-heavy Marina district of San Francisco. Indeed, one Saturday of observation time yielded a large number of bicyclist samples, although many of them could not be tracked effectively because they were surrounded by high density pedestrian traffic in the crosswalk. In some of these cases, the pedestrian density was so high that it impeded the bicyclists' movements and would have corrupted the data – in these scenarios it is reasonable to assume that a pedestrian call would have been issued to the signal controller and the bicyclists would not be depending on a vehicle detector based actuation. In other cases, where the pedestrian traffic provided only limited interference with the bicyclists and/or the pedestrians were running rather than walking, the data were retained for analysis. This intersection and its approaches are flat and the cross traffic is slow and benign (entering and leaving the waterfront parking lot).

The Google Earth view of this intersection is shown in Figure 2.2, indicating the location of the data collection system and its view of the bicycle traffic. Figure 2.3 provides examples of the video data in a scenario with pedestrian congestion impeding bicycle movement (red circled bicyclists in right-hand image) and with pedestrian density low enough that the bicycle timing data were judged to be valid and useful for this study (blue circled bicyclists in left-hand image and outside the pedestrian crossing in right-hand image). The video observations of the traffic signal were troublesome at this intersection, and in some cases it was not possible to distinguish the green onset time. This limited the number of samples for which we could estimate the start-up offset time.

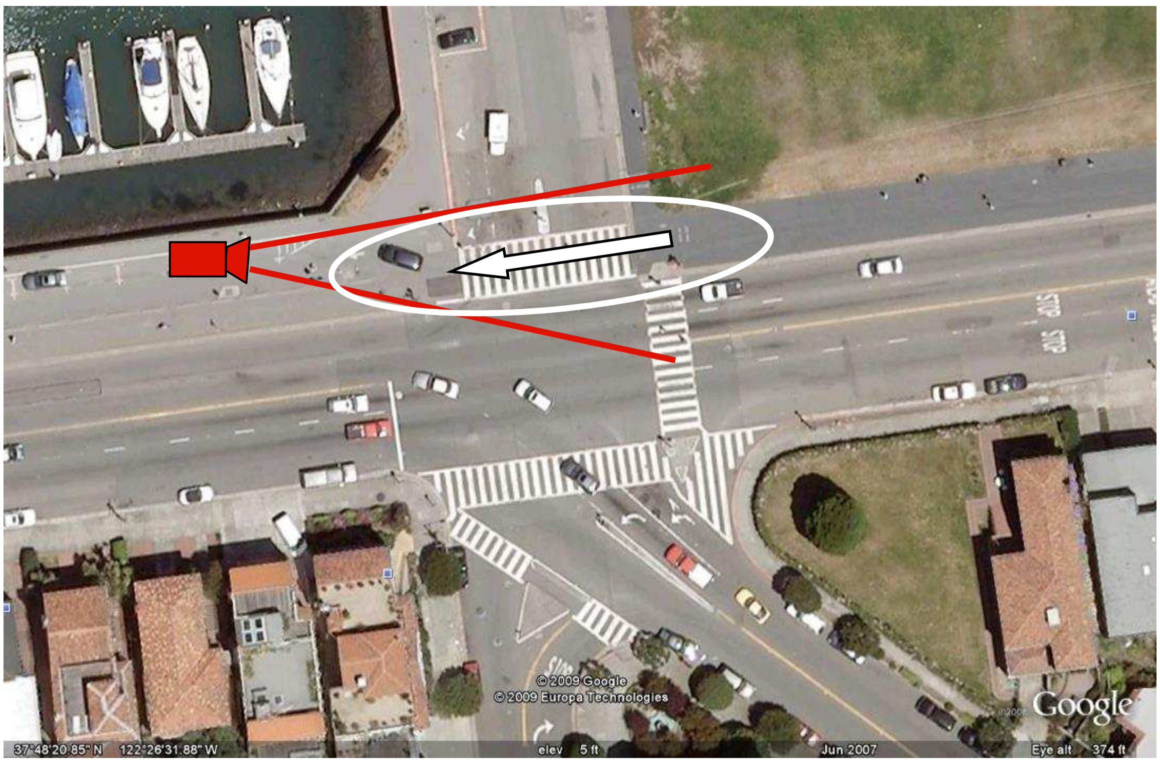

Figure 2.2 San Francisco, Marina at Cervantes Intersection

Figure 2.3 Pedestrian Interactions with Bicyclists at Marina at Cervantes: Acceptable interference for valid data (blue circles) and unacceptable interference for valid data (red circles)

2.3 Venice Boulevard at Beethoven, Los Angeles

Venice Boulevard was recommended by the City of Los Angeles because of its bicycle lanes and an expected high volume of bicyclists. We were also expecting to get a good percentage of school children because of a nearby school and of recreational bicyclists accessing Venice Beach. However, the bicyclists we observed here were actually the strong, hardy young adult commuters. We believe that this is because this is an intimidating route for bicyclists, with fast and aggressive vehicular traffic along Venice Blvd. and relatively long distances to travel to get to and from origins and destinations of interest. The intersection and its approaches are flat.

The Google Earth view of this intersection is shown in Figure 2.4, indicating the data collection van location and our view of the eastbound bicyclists along Venice Blvd.

Figure 2.4 Los Angeles, Venice at Beethoven

2.4 Laurel Canyon at Chandler, Los Angeles

Laurel Canyon was recommended by the City of Los Angeles because of its bicycle lanes, and the intersection at Chandler was particularly interesting because of its great width (180 ft), which would allow us to get a data point for one of the widest streets we are likely to encounter in California. Unfortunately, the bicycle traffic at this intersection was extremely low, and after more than a full day of observation we were only able to observe 36 standing start bicyclists and 18 rolling start bicyclists. Since it would be necessary to have many more samples than this in order to support any statistically valid analysis, we determined that we could not justify the large additional investment of time and effort that would have been needed to obtain a usable data set at this intersection.

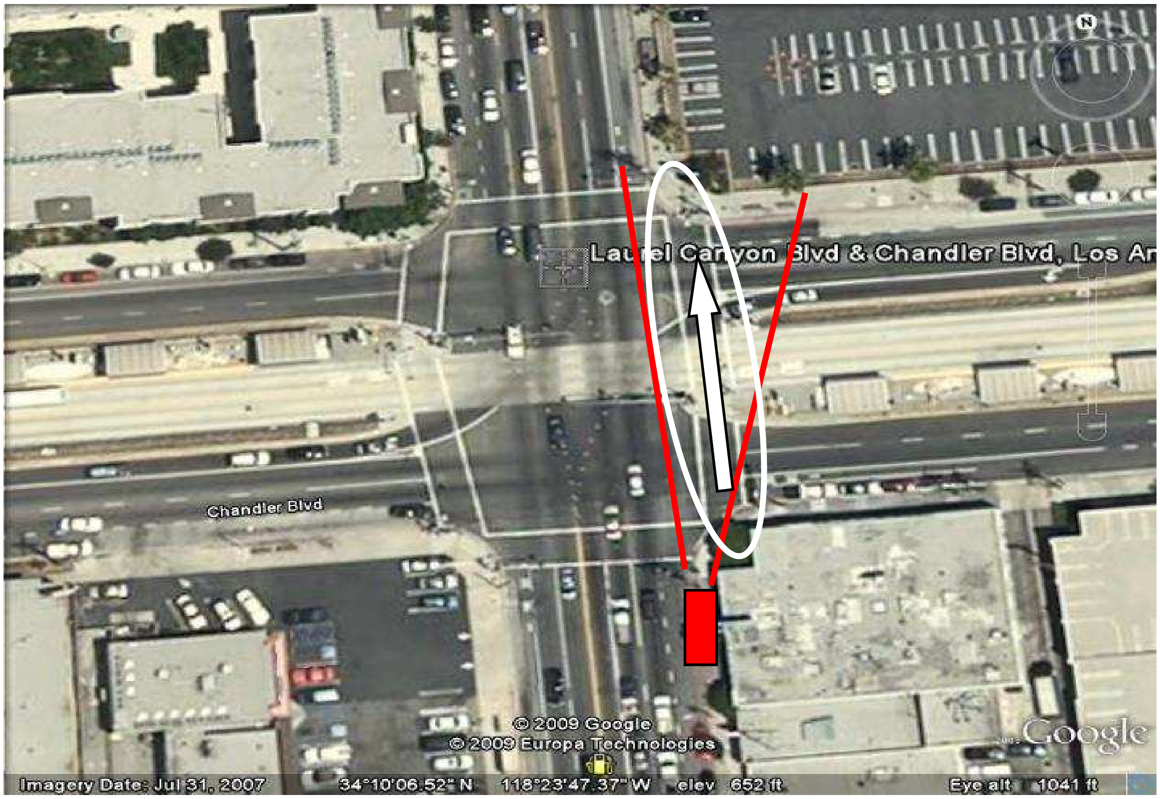

Figure 2.5 Laurel Canyon at Chandler, Los Angeles

2.5 Davis, Anderson at West 8th Street

It was very difficult to find locations with high bicyclist volumes in the rural Central Valley except in Davis, which is a well-known bicycling Mecca. So, we contacted the City of Davis for recommended locations. We were particularly interested in locations where we could collect data on school children bicycling to and from school, to understand how different their timing needs are from those of adults. We chose this intersection because of its proximity to an elementary and a middle school, but in the end the bicyclists that we observed were predominantly U.C. Davis students going to and from the campus rather than school children. There was a strong commute pattern, southbound in the morning and northbound in the afternoon, requiring slightly different alignment of the video cameras as shown in Figure 2.6. This intersection and its approaches are flat. The width of the crossing is 60 feet, representing three lanes of traffic (two though lanes, one in each direction, and a left turn lane), plus residential parking along the curbs. The speed limit is posted at 30 mph, with very light cross traffic and excellent visibility of the cross traffic by the bicyclists.

Figure 2.6 Anderson at West 8th St, Davis

2.6 Davis, Cowell at Drew

The physical characteristics and bicycling population at this intersection turned out to be very similar to those at Anderson at West 8th Street, but we had a lower volume of bicyclists here and could only observe one direction of travel. In order to conserve project resources, we decided to defer processing this set of data until we had a sufficiently diverse collection of data sets from the other sites, to make sure that we would be able to capture the widest possible variety of bicyclist crossing scenarios. This intersection is seen in Figure 2.7.

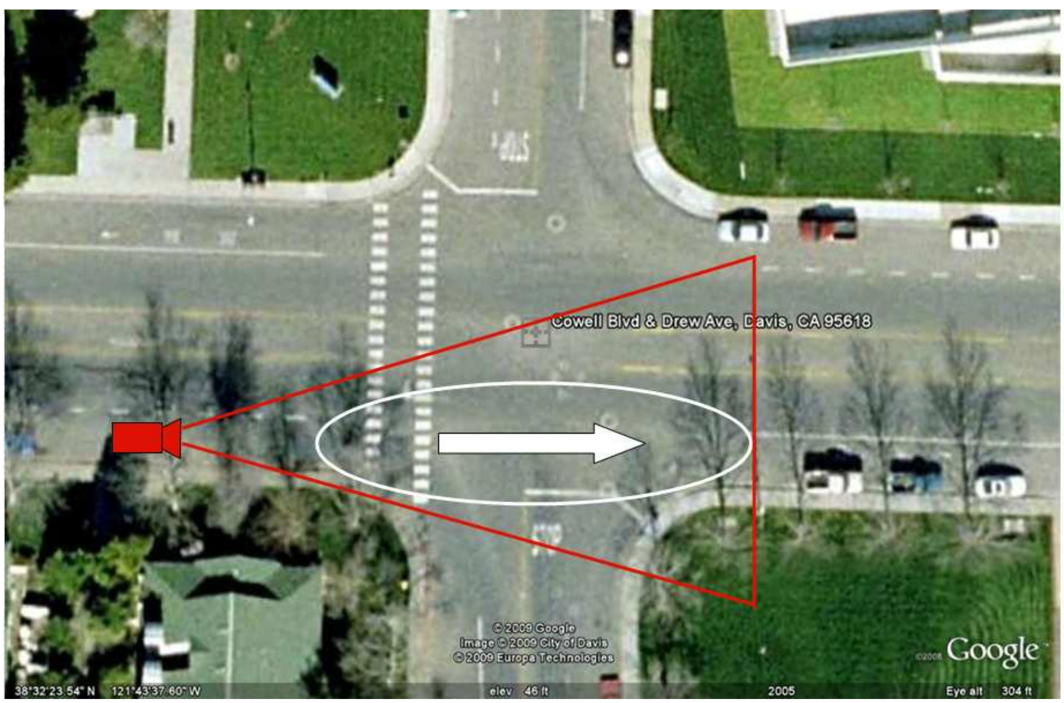

Figure 2.7 Cowell Blvd. at Drew Ave., Davis

2.7 <u>Santa Monica, Main at Marine</u>

This intersection provided us with a high-density urban setting in Southern California, with complicated traffic patterns and a diverse mix of bicyclists. Because of the unusual geometry of the intersection, with an offset side street, bicyclists tended to stop at a wide variety of locations within the intersection rather than all stopping near the stop line. The traffic density and speed were moderate and the intersection flat.

Figure 2.8 Main at Marine in Santa Monica

The characteristics of the data collection sites are summarized in Table 2.1 below.

Table 2.1 Summary of Intersection Characteristics

	Palo Alto Park at El Camino	Berkeley Russell at Telegraph	Davis Anderson at West 8th	S.F. Polk at Sutter	S.F. Marina at Cervantes	Los Angeles Venice at Beethoven	Santa Monica Main at Marine
Width Traffic lanes	125 ft, 7 lanes	84 ft, 4 lanes	60 ft, 3 lanes	58 ft, 3 lanes	63 ft, 4 lanes	63 ft. 2 lanes	48 to 84 ft. 2 lanes
Speed Limit	40 mph	25 mph	30 mph	25 mph	25 mph	25 mph	25 mph
Cross traffic	Heavy	Moderate	Very Light	One-way, heavy	Light (Driveway)	Very Light	Moderate
Intersection	Crowned	Flat	Flat	Flat	Flat	Flat	Flat
Visibility	Limited	Better	Best	Best	Best	Very good	Depends on starting point
Approach grades	Flat	-3.4%, +2.5%	Flat	+/- 4.5%	Flat	Flat	Flat
Bike traffic	Evening commute	All day	Commute	All day	(Weekend) Recreation	All day	All day
Bicyclists	Young adults	Diverse	College students	Diverse	Tourists, families	Half experts	Mix of tourists and experts

3. Bicyclist Crossing Time Data Analysis Results

The video images of the bicyclists crossing the intersections were analyzed using the method that was already described in the technical report on our previous project, UCB-ITS-PRR-2009-37. The trajectories were extracted from the video sequences using the video tracker software and these trajectories were then characterized in terms of their slopes (representing cruising speed) and the offset time from the green onset until the cruising-speed slope intersected the starting location. This provided for two parameters to fully characterize standing-start crossings and one parameter for rolling-start crossings.

The data for each intersection are first presented individually, and are then combined so that the similarities and contrasts can be seen.

3.1 Data for Polk at Sutter in San Francisco

At this intersection, we collected data on 54 and 43 standing starts in the two directions and 217 and 270 rolling starts in the two directions of travel during two days of observations. Because of the strong grade along Polk St. (about 4.5%) there was a significant difference in the speeds of the rolling start bicyclists in the two directions. The signal timing along Polk St. favored bicyclists rolling through on the green, and relatively few bicyclists had to stop for the signal. The numbers of bicyclists in each direction was too small to produce a good statistical distribution, but fortunately the intersection itself is flat so there is no significant difference between the northbound and southbound standing start bicycling, and it was possible to combine the data for both directions to produce a single distribution. The standing start trajectories for the two directions of travel are shown in Figure 3.1.

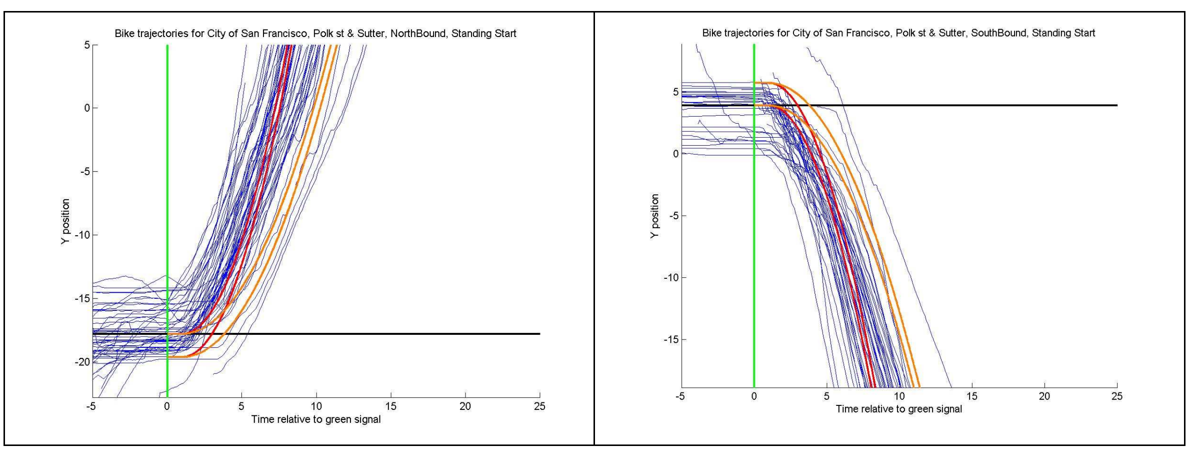

Figure 3.1 Standing-start bicyclist trajectories on Polk at Sutter, Northbound on left and Southbound on right

The red and orange profiles superimposed on these trajectories represent the formulas that were recommended by the City of Vacaville for adult bicyclists (red) and child bicyclists (orange) respectively. Although the Vacaville formula for children would serve most of the adult bicyclists at this site, the formula for adults would only serve the fastest half of this bicycling population. Note the wide range of starting locations for these bicyclists, who had to contend with vehicle traffic and parked vehicles on this crowded street and could not always stop right at the stop line.

The contrasts in the rolling start results reflect the strong grade on Polk Street. Figure 3.2 shows the histograms of the rolling speeds in the two directions and Figure 3.3 shows the cumulative distributions.

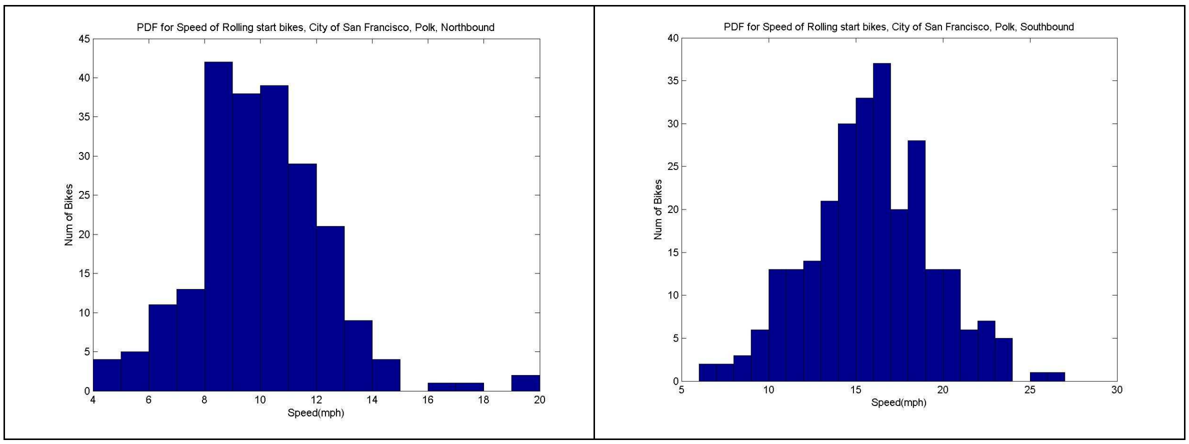

Figure 3.2 Histograms of rolling start speeds on Polk St., northbound on left and southbound on right

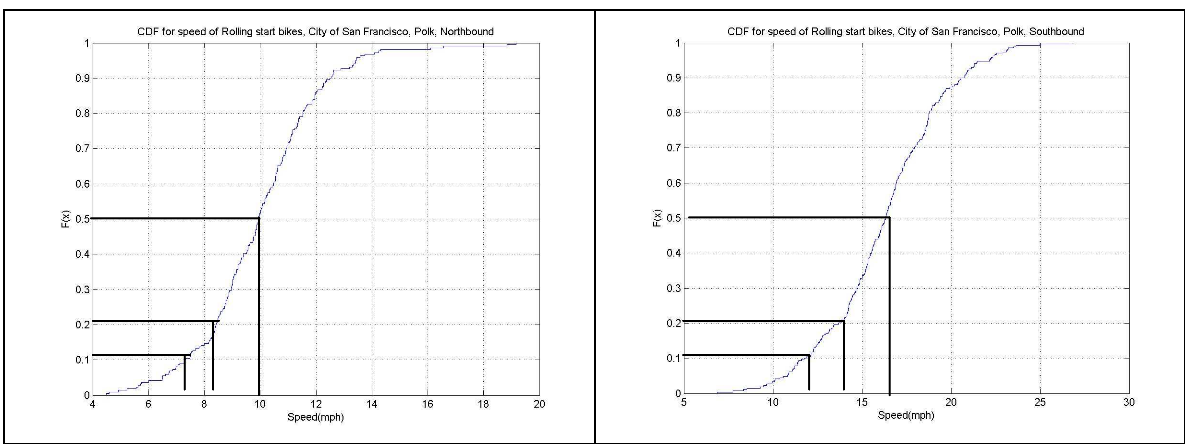

Figure 3.3 Cumulative distributions of rolling start speeds on Polk St., northbound on left and southbound on right

Because there were only a limited number of standing starts, and the direction of travel did not appear to have a significant impact on bicyclist behavior, the data for northbound and southbound standing start bicyclists were combined into a single dataset for analysis. The histogram of standing start offset times is shown in Figure 3.4 and the cumulative distribution is in Figure 3.5.

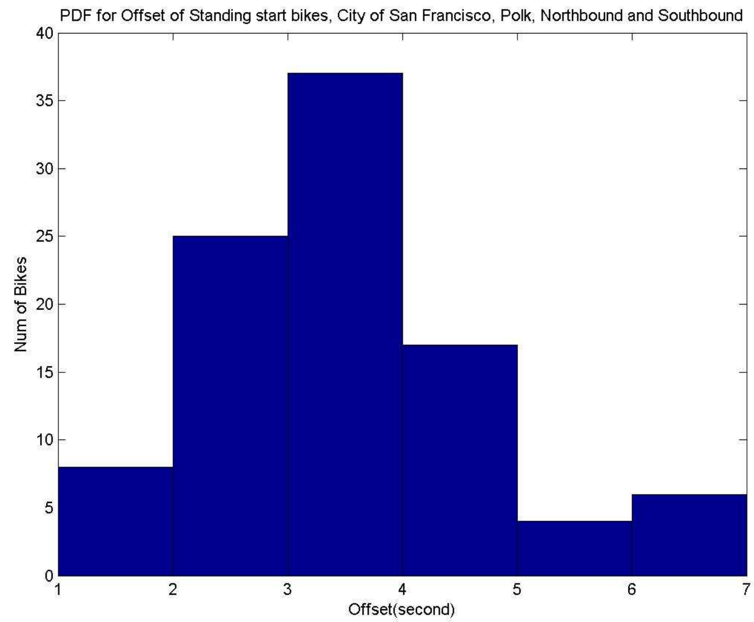

Figure 3.4 Histogram of standing start offset times at Polk at Sutter

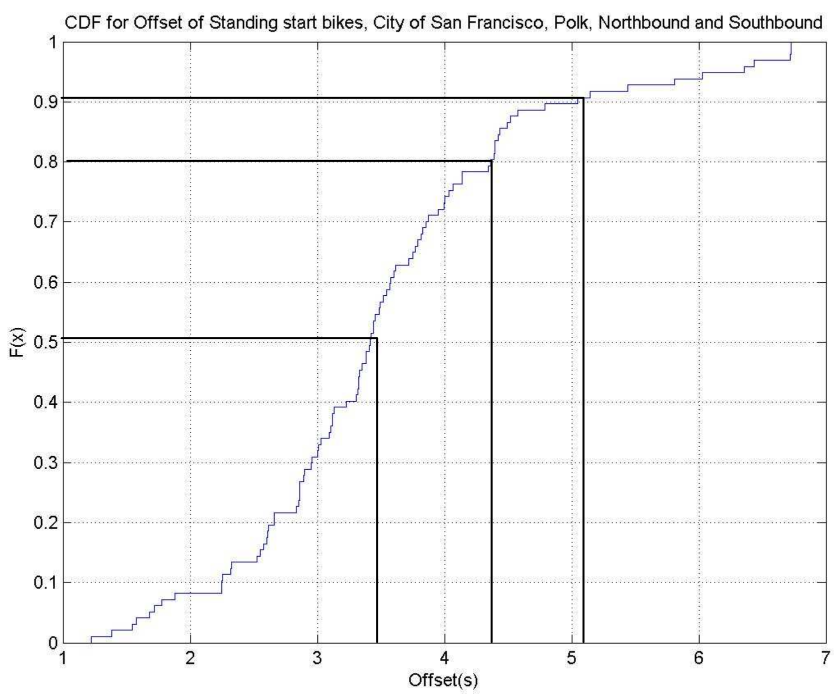

Figure 3.5 Cumulative distribution of standing start offset times at Polk and Sutter

The final crossing speeds for the standing start bicyclists at Polk and Sutter are depicted in the histogram of Figure 3.6 and the cumulative distribution of Figure 3.7. These show that we found a few very fast, sporty bicyclists here, but they are far removed from the large majority of the bicyclists. These speeds are comparable to the cruising speeds of the uphill rolling start bicyclists at this intersection.

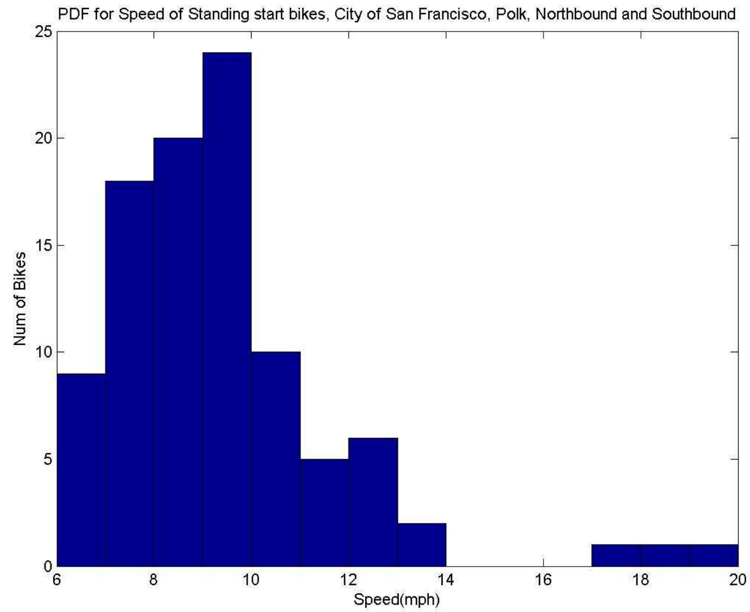

Figure 3.6 Histogram of final crossing speeds of standing start bicyclists at Polk and Sutter

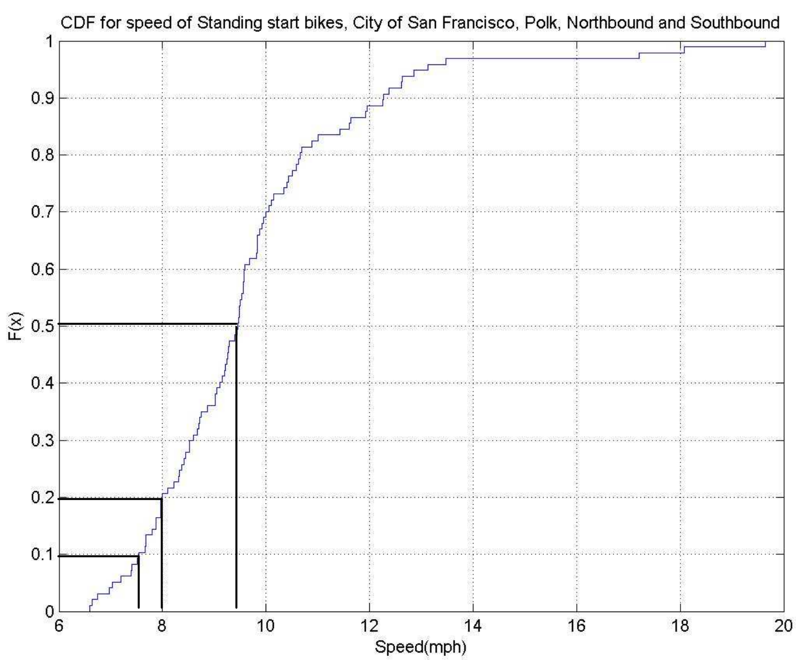

Figure 3.7 Cumulative distribution of final crossing speeds of standing start bicyclists at Polk and Sutter

3.2 Data for Marina at Cervantes, San Francisco

The data at this intersection covered both directions of travel, eastbound and westbound, in a location dominated by recreational bicyclists on a Saturday. This location had the highest density of bicyclist traffic of any of the sampled locations, and in some cases the density was so high that it was hard to distinguish individual bicyclists moving in clusters. The pedestrian traffic at this location was so dense that in some cases it impeded the motions of the bicyclists, so these data samples were not analyzed because they are not relevant for determining the crossing times of bicyclists who need to actuate green cycles through detection systems (in these cases, pedestrian calls are going to determine the selection of minimum green times).

The processed data for this intersection cover the speeds of the rolling start crossing maneuvers (107 westbound and 64 eastbound), but not the standing starts. Unfortunately the video imagery of the traffic signal status was not good enough to enable determination of the phase changes, which made it impossible to identify the offset times of the standing start bicyclists.

Figure 3.8 shows the histograms of the eastbound and westbound rolling start crossing speeds at this intersection. The cumulative distributions of these speeds are shown in Figure 3.9. Even though the shapes of the histograms look quite different from each other at this level of aggregation, when we consider the full data set in the cumulative distribution we can see that the key percentile values are really quite similar for both directions of travel. At the median and lower percentiles, the speeds are very similar for both directions. The upper tail of the westbound distribution shows higher speeds because this included the bicyclists who rode in the curb lane of Marina Blvd in that direction, not only the bicyclists who used the pedestrian crossing.

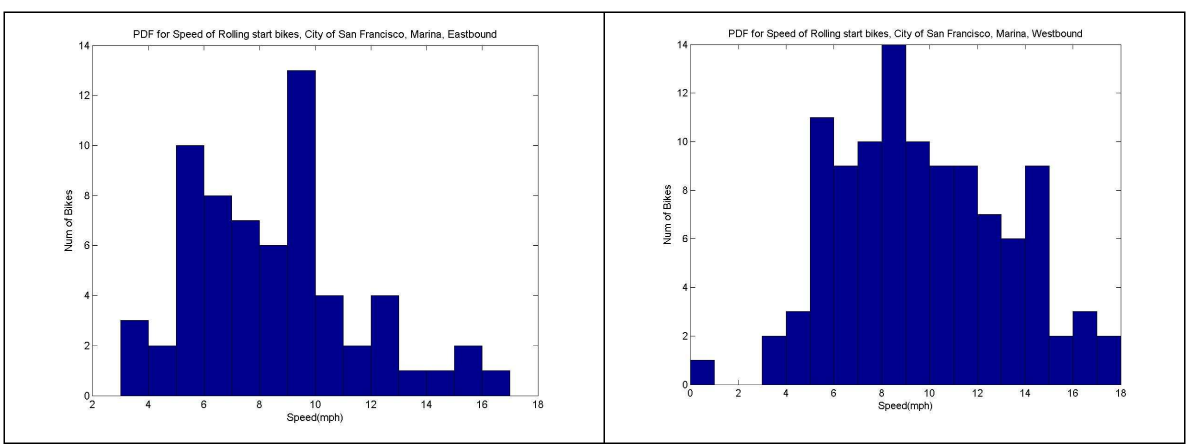

Figure 3.8 Histograms of crossing speeds for rolling start bicyclists at Marina and Cervantes, eastbound and westbound directions respectively

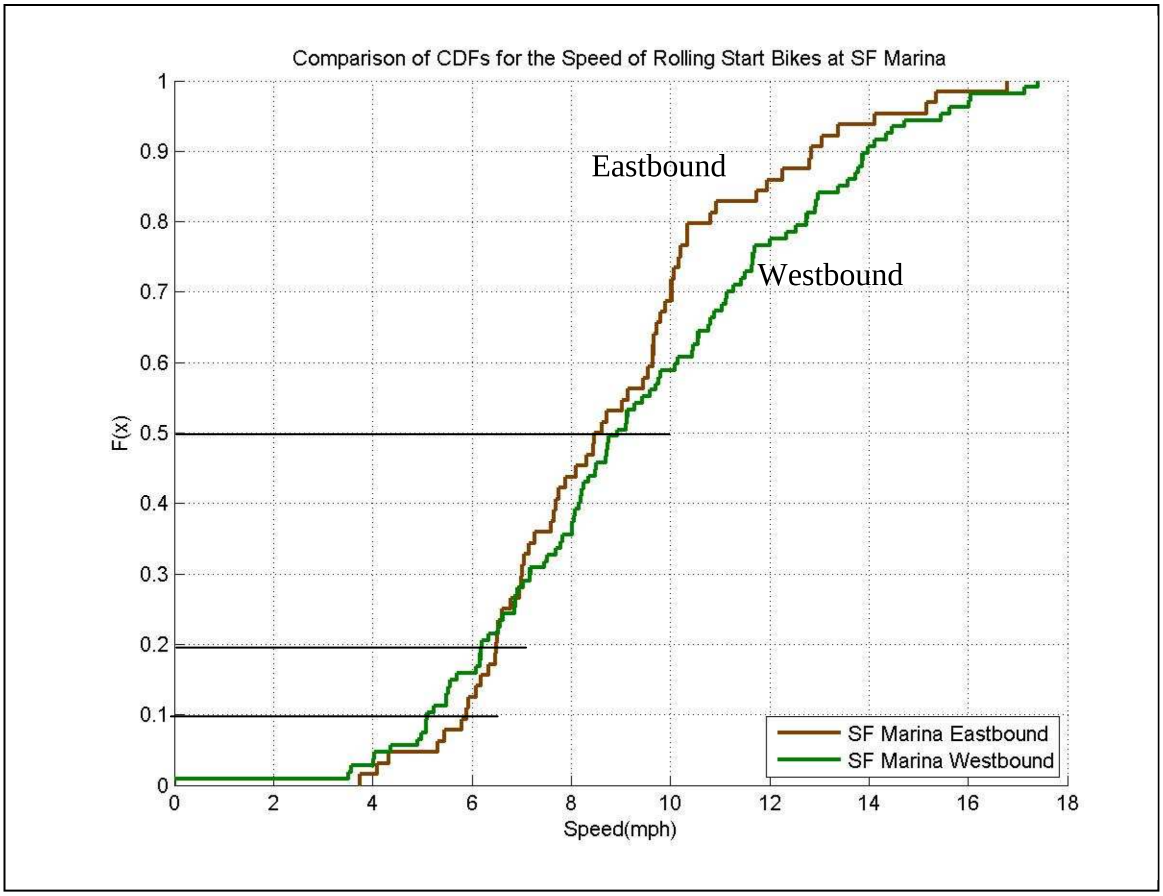

Figure 3.9 Cumulative Distribution of Crossing Speeds for Rolling Start Bicyclists at Marina and Cervantes

These bicyclist speeds are significantly slower than the rolling start speeds observed at the other intersections, including the intersections with significant positive grades. This shows the significance of the bicycling population and trip purpose for bicyclist speeds. This location was the one location with a strong recreational flavor and with a higher proportion of families and children among the bicyclist population, indicating that the bicyclist signal timing needs to be adjusted based on factors such as these.

3.3 <u>Data for Venice Blvd. at Beethoven, Los Angeles</u>

At this intersection, we collected data for westbound bicyclists, primarily in the bicycle lane on Venice Blvd., as they crossed Beethoven. Over two days of observation, we captured usable data for 79 standing start and 171 rolling start bicyclists, with a very diverse bicycling population including serious cyclists (about 50%), commuters, tourists and high school students (about 10%). The high proportion of serious cyclists is probably associated with the fact that this is a relatively intimidating bicycling environment, with very fast vehicle traffic along Venice Blvd.

The intersection is flat, with a width of 63 feet for the crossing of Beethoven, and the bicyclists have very good visibility of the cross traffic, so they do not need to build in extra margins for dealing with uncertainty about the cross traffic. The trajectories of the standing start bicyclists at this intersection are shown in Figure 3.10.

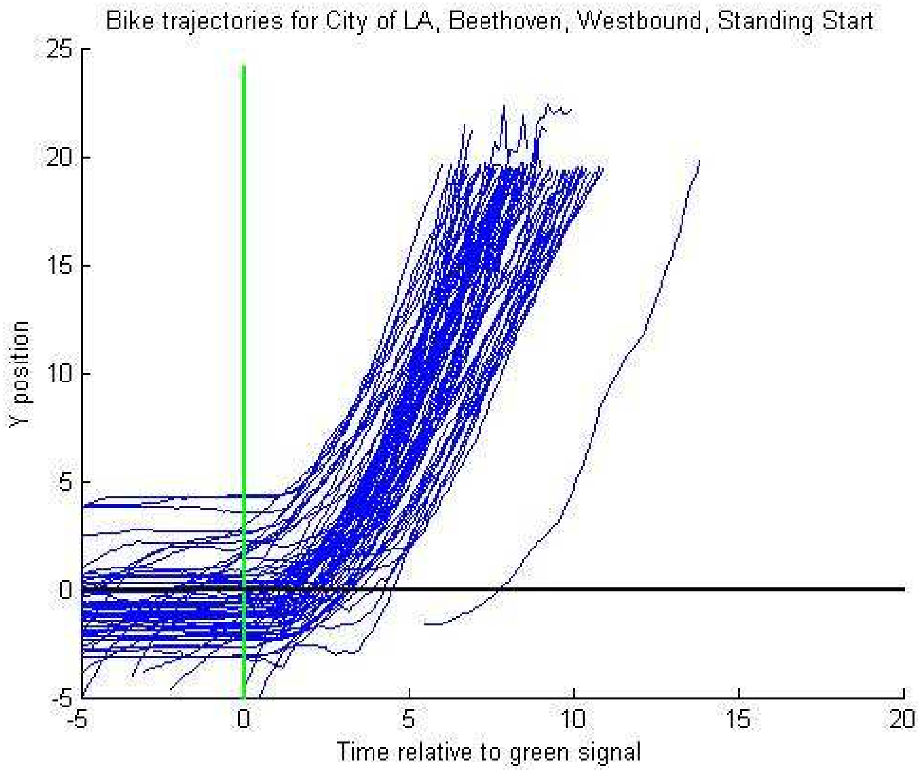

Figure 3.10 Trajectories of standing start bicyclists on Venice crossing Beethoven

The speeds of the rolling start bicyclists are shown in the histogram of Figure 3.11 and the cumulative distribution of Figure 3.12.

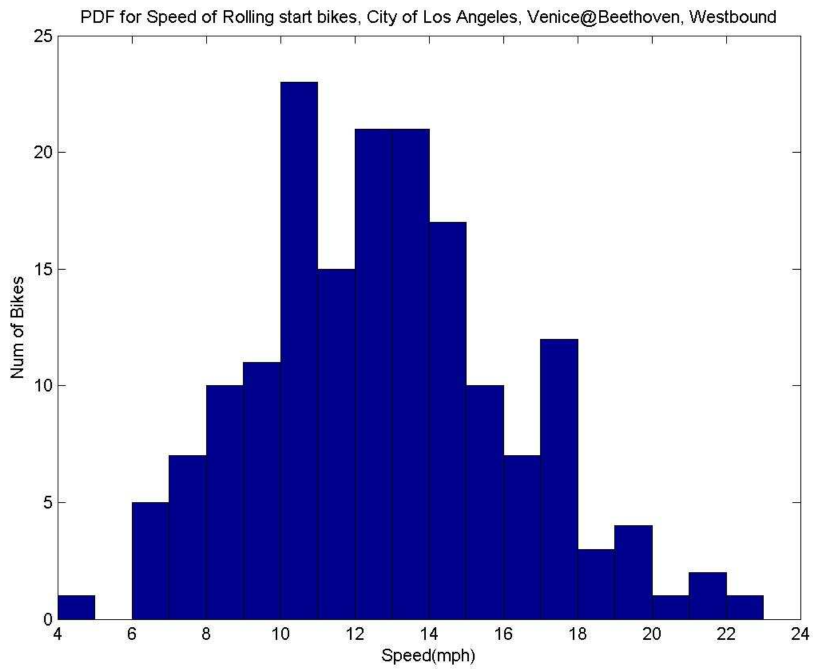

Figure 3.11 Histogram of rolling start crossing speeds on Venice at Beethoven

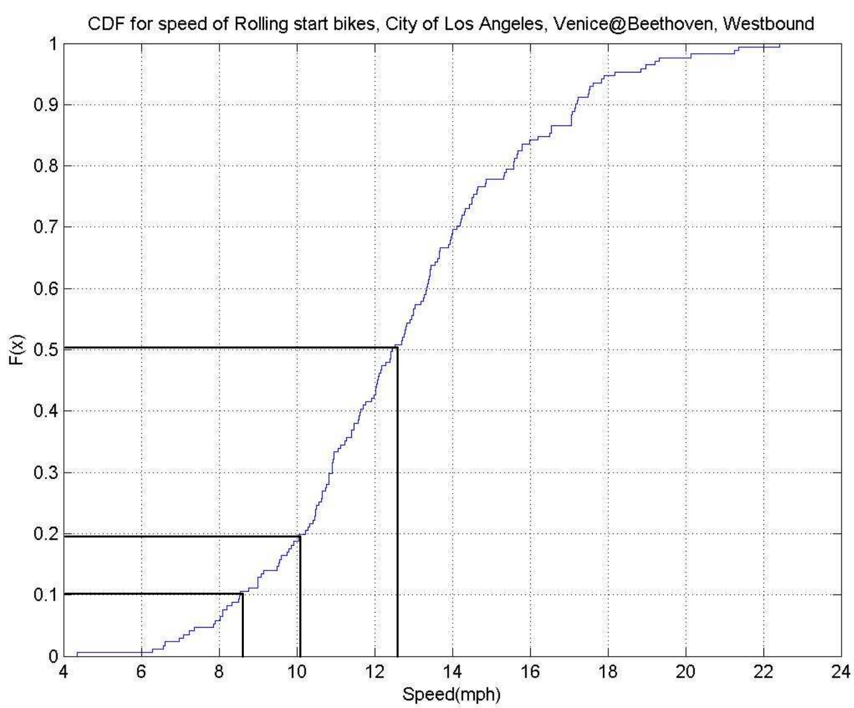

Figure 3.12 Cumulative distribution of rolling start crossing speeds on Venice at Beethoven

The standing start bicyclist crossings are characterized by their offset times and final crossing speeds. The offset time histogram is shown in Figure 3.13 and its cumulative distribution is in Figure 3.14.

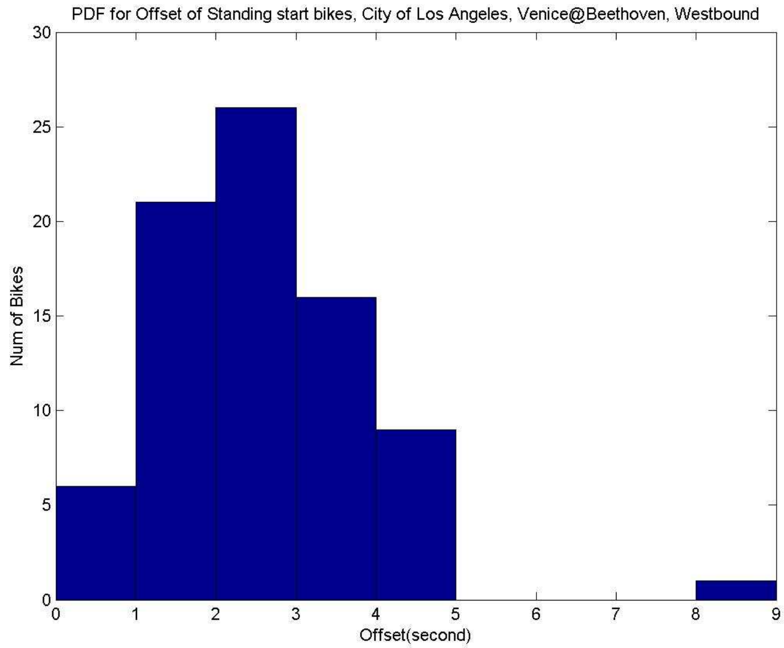

Figure 3.13 Histogram of standing start offset time for Venice at Beethoven

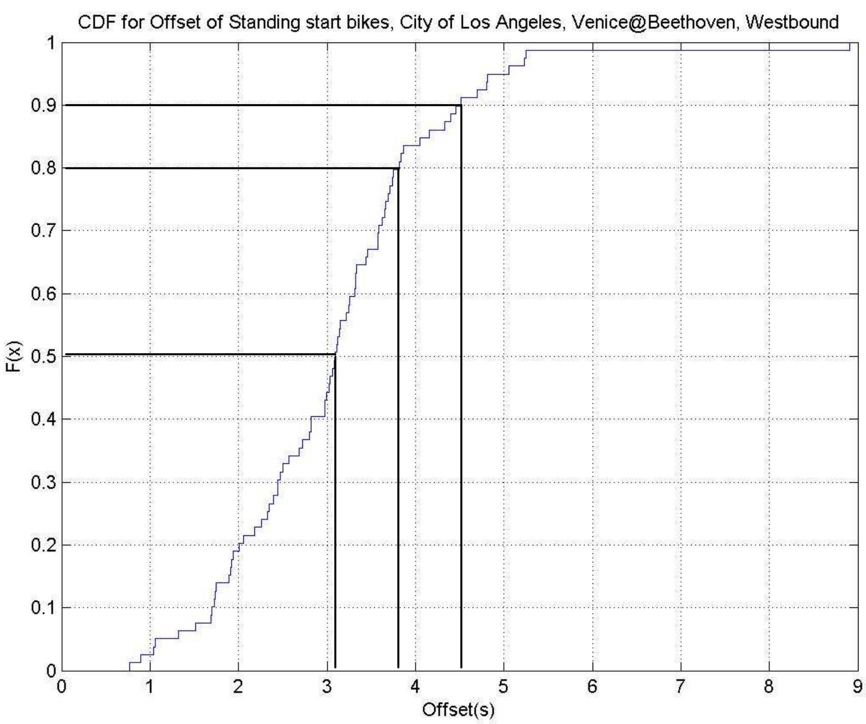

Figure 3.14 Cumulative distribution of standing start offset time for Venice at Beethoven

The final crossing speeds for the standing start bicyclists on Venice at Beethoven are shown in the histogram of Figure 3.15 and the cumulative distribution of Figure 3.16.

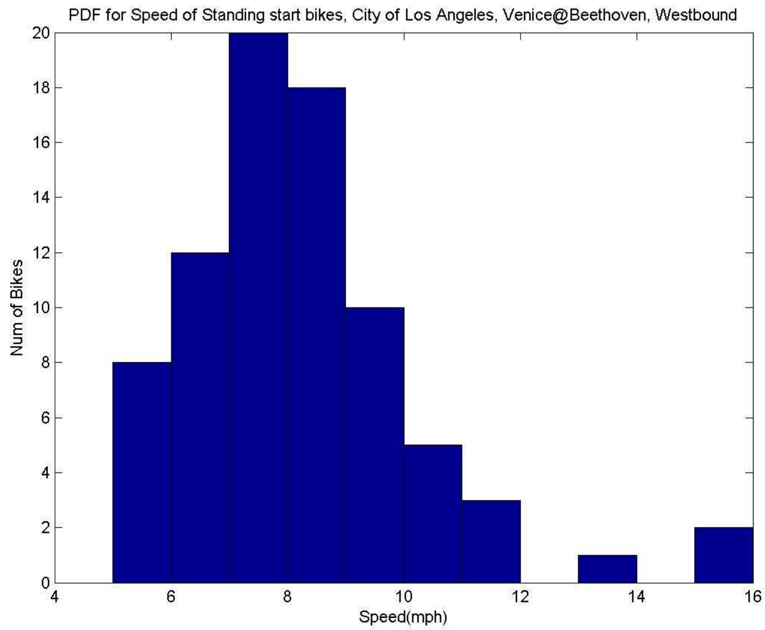

Figure 3.15 Histogram of final speeds for standing start bicyclists on Venice Blvd. crossing Beethoven

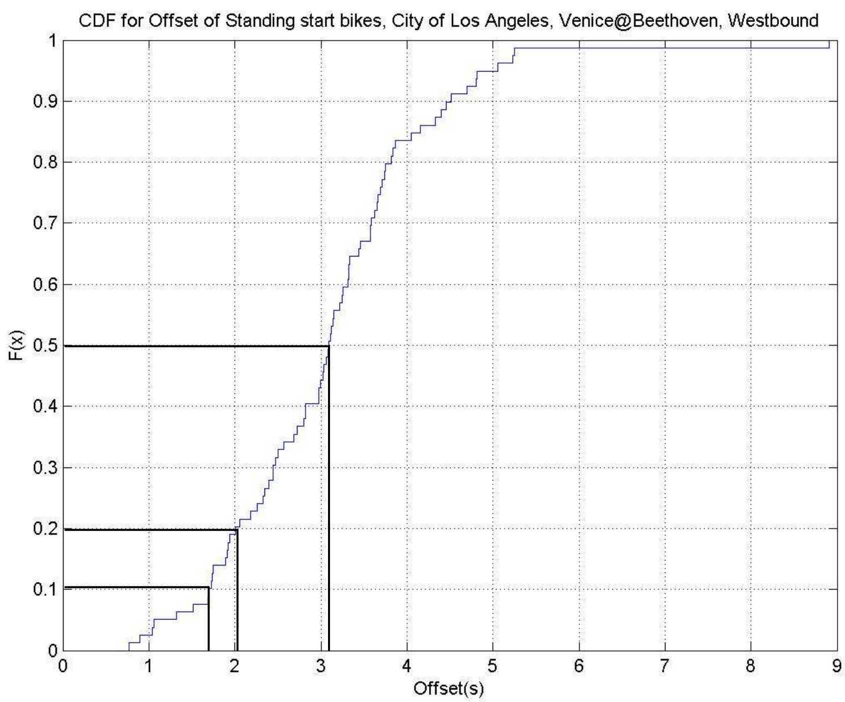

Figure 3.16 Cumulative distribution of final crossing speed for standing start bicyclists on Venice at Beethoven

3.4 Data for Anderson at West 8th Street, Davis

This intersection, in a residential area of Davis, had very heavy bicyclist traffic. Although we were hoping to observe many school children using their bicycles here, the bicycling population was dominated by U.C. Davis students commuting to and from classes. The volume of bicyclists was high enough and the flow was sufficiently directional based on the start and end of the school day that it was possible to distinguish differences between the morning and evening commute pattern bicycling trips. In two days of observations, we recorded 426 southbound rolling start crossings and 266 southbound standing start crossings (morning commute direction). In the northbound direction, we added another 161 rolling start crossings but did not have enough standing start crossings to do a separate analysis for this direction of travel.

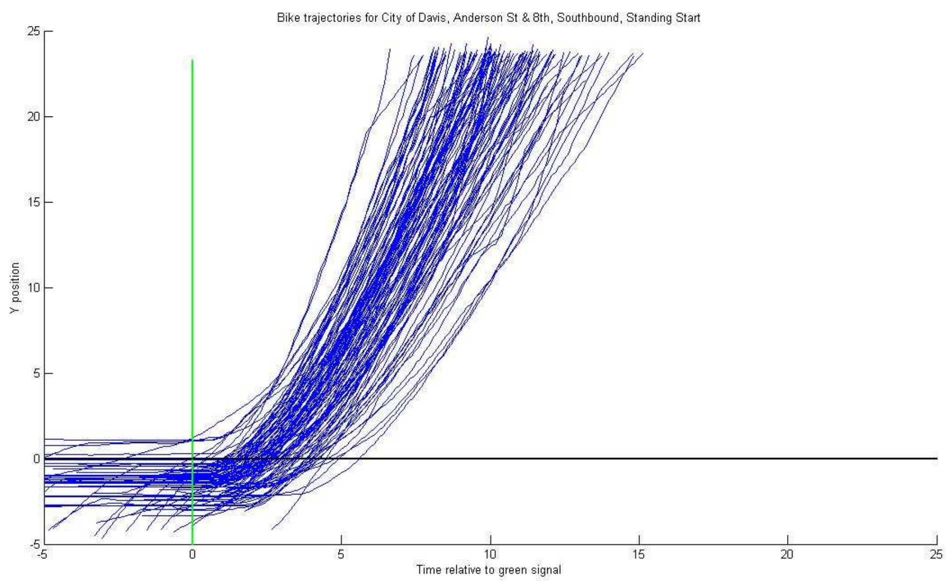

Figure 3.17 Trajectories of southbound standing start bicyclists on Anderson Rd. crossing West 8th Street

The histograms of the rolling start bicyclist speeds in both directions along Anderson at West 8th Street are shown in Figure 3.18, and the cumulative distributions of these speeds are shown in Figure 3.19. Although the population of bicyclists is largely the same (university students) and the traffic conditions similar, the northbound speeds are noticeably higher. The best explanation we can find for this is that the southbound trips were morning rides toward the U.C. Davis campus and the northbound trips were afternoon rides back home, when the riders were more eager to reach their destinations.

For the southbound standing start bicyclists, the histogram of starting offset times is shown in Figure 3.20 and their cumulative distribution is in Figure 3.21. The final rolling speeds for these bicyclists are characterized by the histogram of Figure 3.22 and the cumulative distribution of Figure 3.23.

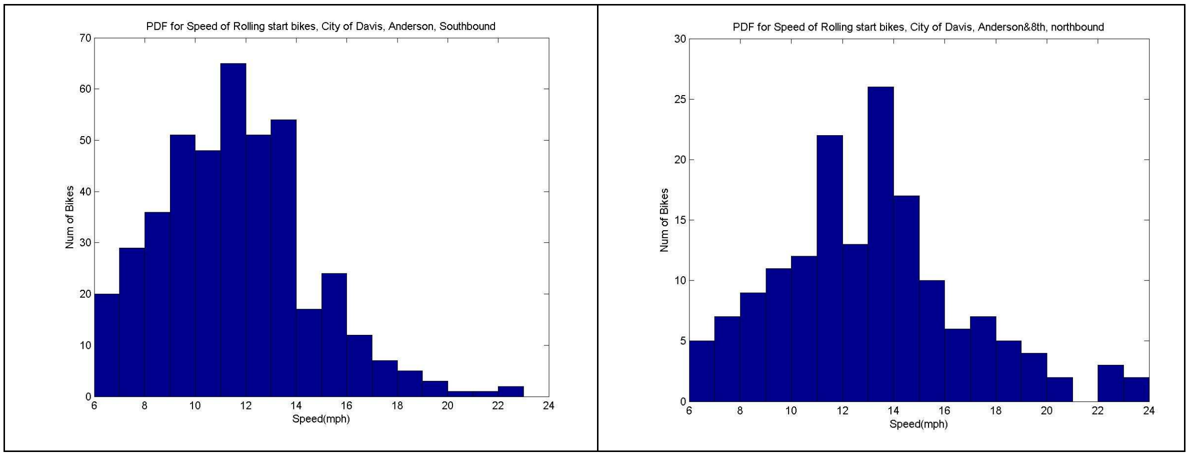

Figure 3.18 Histograms of Rolling start speeds on Anderson Rd., southbound (morning) on left and northbound (afternoon) on right.

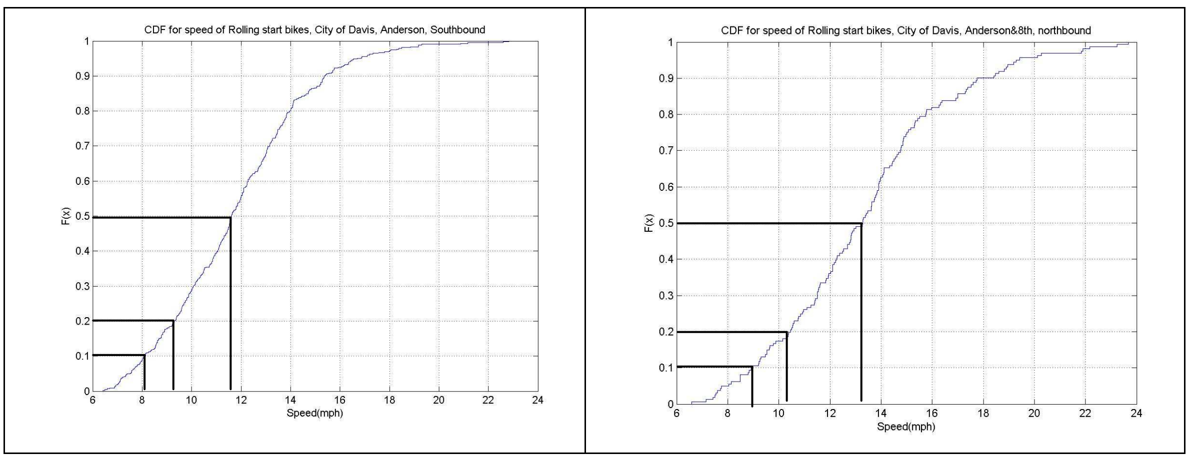

Figure 3.19 Cumulative distributions of rolling start speeds on Anderson Rd., southbound (morning) on left and northbound (afternoon) on right

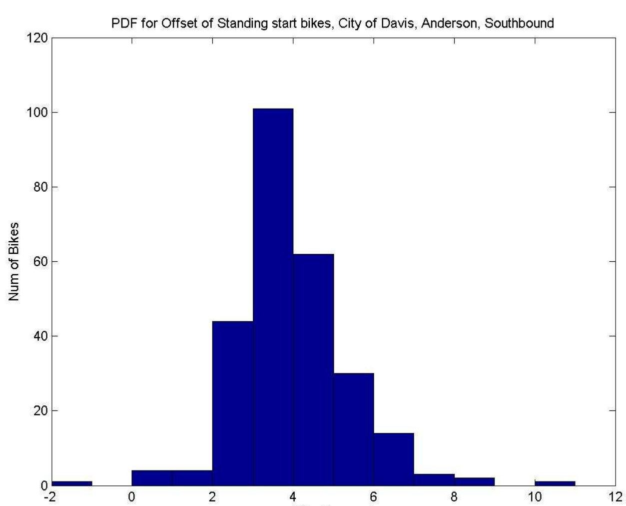

Figure 3.20 Histogram of standing start offset, southbound, on Anderson Rd.

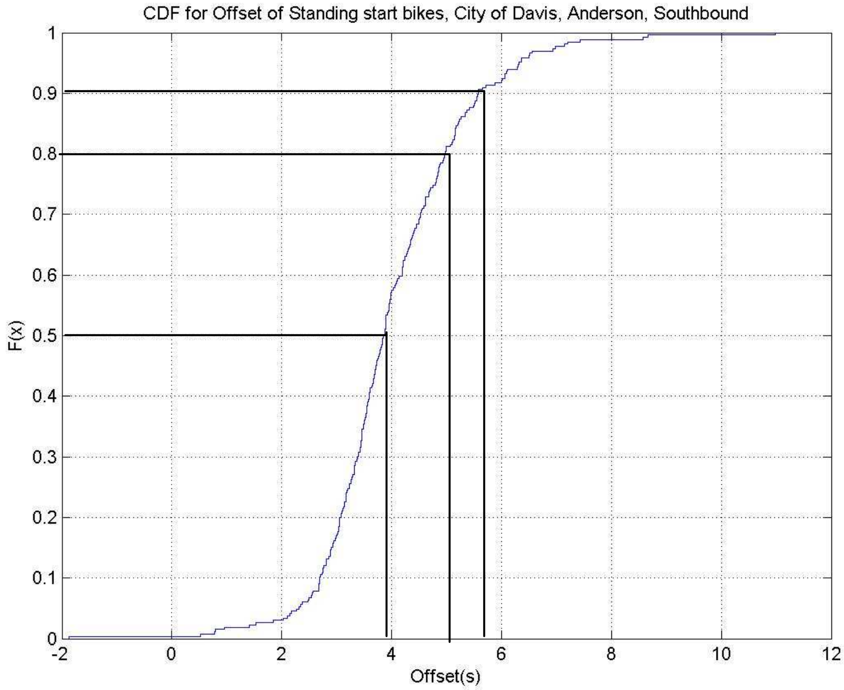

Figure 3.21 Cumulative distribution of standing start offset on Anderson Rd., southbound

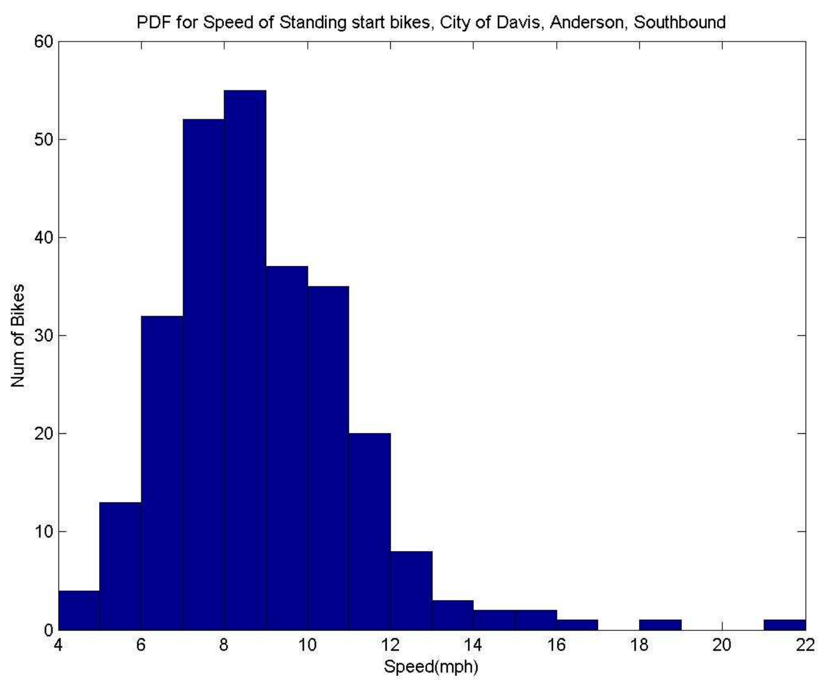

Figure 3.22 Histogram of final crossing speeds for standing start bicyclists, southbound on Anderson

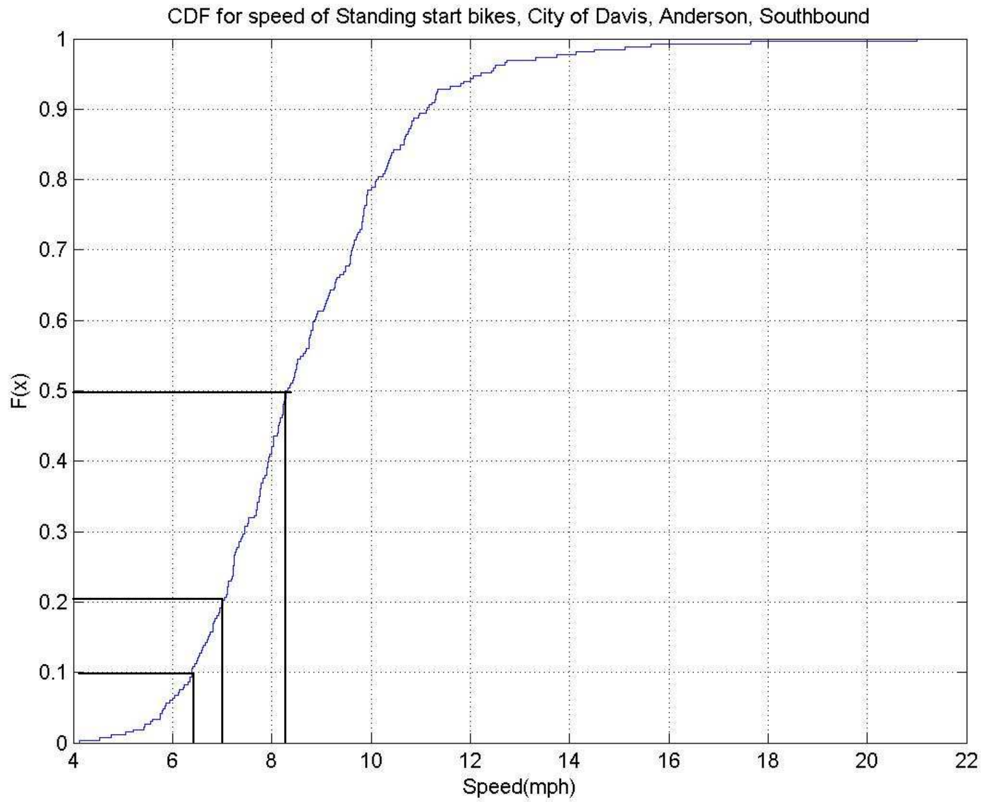

Figure 3.23 Cumulative distribution of final crossing speeds for standing start bicyclists on southbound Anderson Rd.

3.5 <u>Data for Main at Marine, Santa Monica</u>

The width of the crossing of Marine could be considered to range from 48 feet to 84 feet, depending on whether the bicyclist starts at the stop line behind the pedestrian crossing or at the curb line where the cross traffic passes. This is in a busy commercial area, two blocks from the beach, with moderate cross traffic on Marine. The bicyclists include tourists (about 40%), serious cyclists (about 40%), and commuters. The visibility of cross traffic for bicyclists depends on the starting location. The signals along Main Street seem well suited for bicyclists, generally keeping them moving smoothly. This means we observed many more rolling bikes than standing start bikes at this intersection. We also observed a lot of semi-rolling and early start bikes, anticipating the signal change. In total, we recorded usable data on 79 standing start bikes and 240 rolling bikes in three days of observations.

The trajectories of the standing start bikes are plotted in Figure 3.24, which shows the wide range of starting positions of the bicyclists here. This diversity of starting positions (and therefore of crossing width) made it impossible to characterize this intersection with a single value of width for purposes of data summarization.

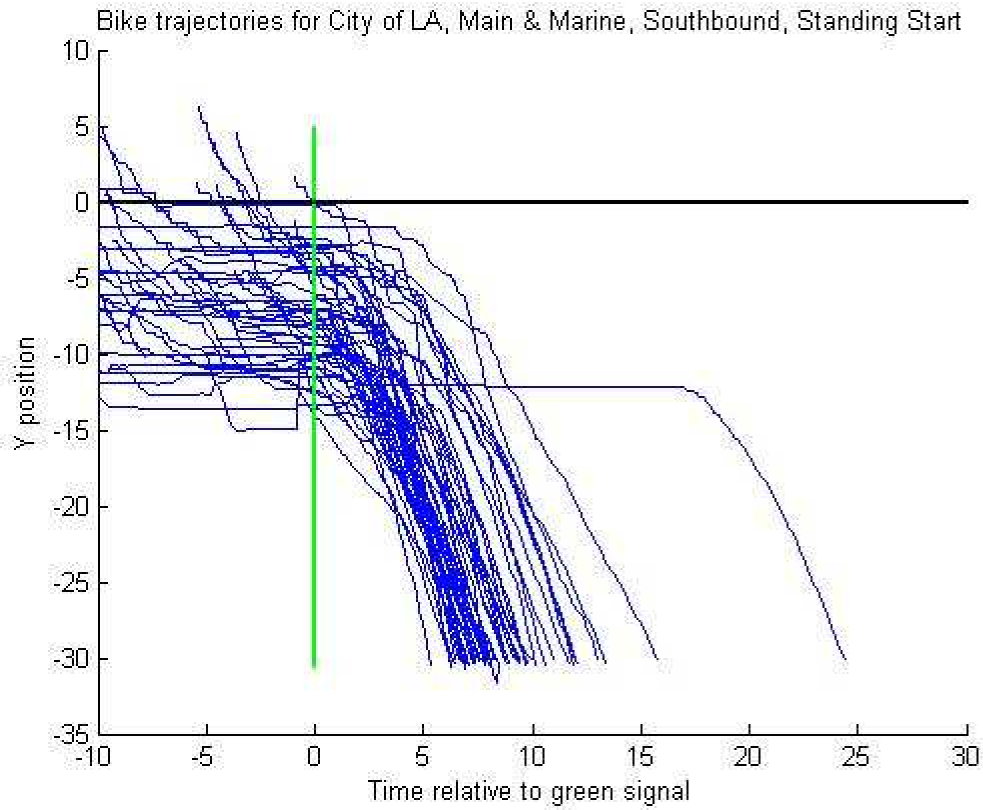

Figure 3.24 Standing start trajectories for southbound crossing of Marine on Main St. in Santa Monica

The rolling start bicyclists are characterized by the histogram and cumulative distribution plot of their cruising speeds, as shown in Figures 3.25 and 3.26.

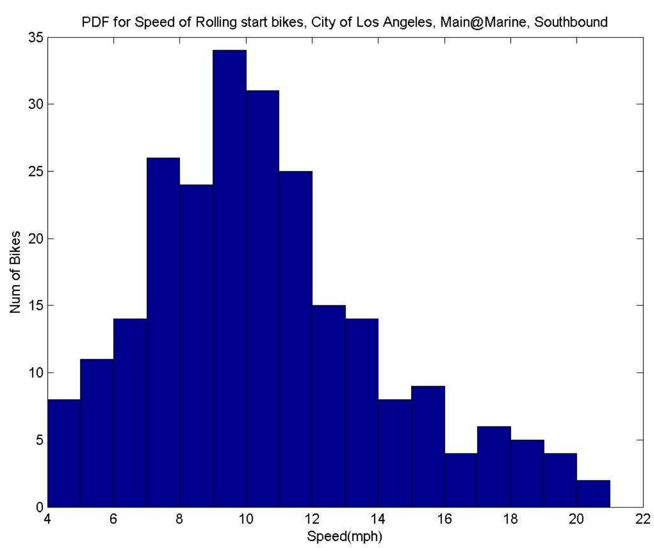

Figure 3.25 Histogram of rolling speeds of bicyclists crossing Marine on Main

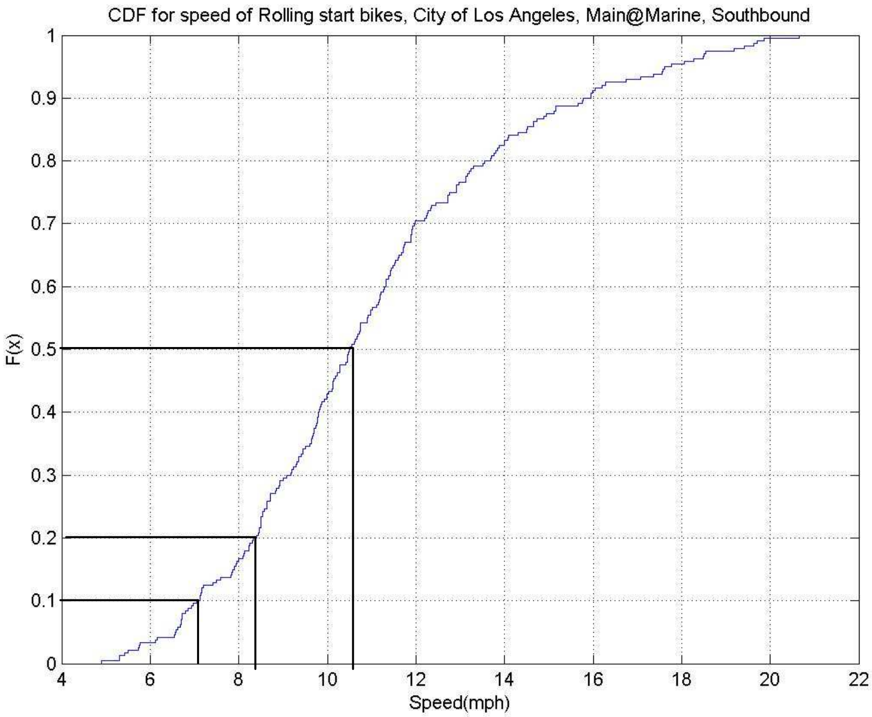

Figure 3.26 Cumulative Distribution of rolling start bicyclist speeds on Main at Marine

The standing starts are characterized by their offset times and final cruising speeds. The offset time histogram is shown in Figure 3.27 and its cumulative distribution is in Figure 3.28. One bicyclist distracted by a conversation during a signal change accounted for the single extremely long offset time sample.

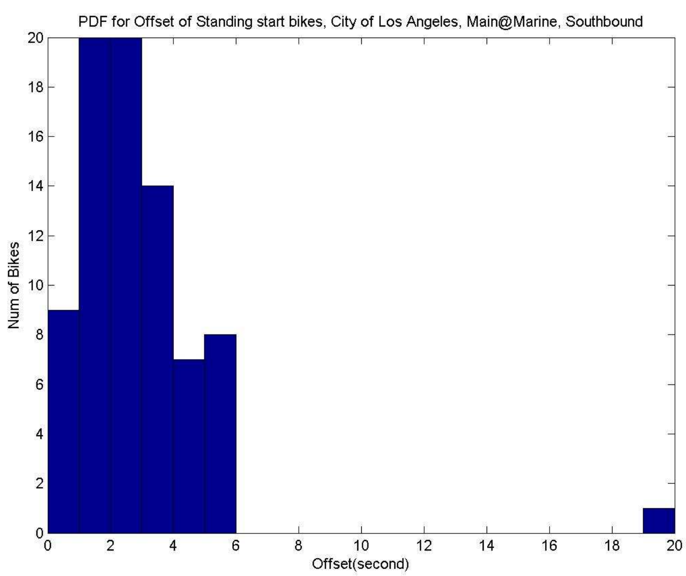

Figure 3.27 Histogram of offset times for standing start bicyclists on Main at Marine

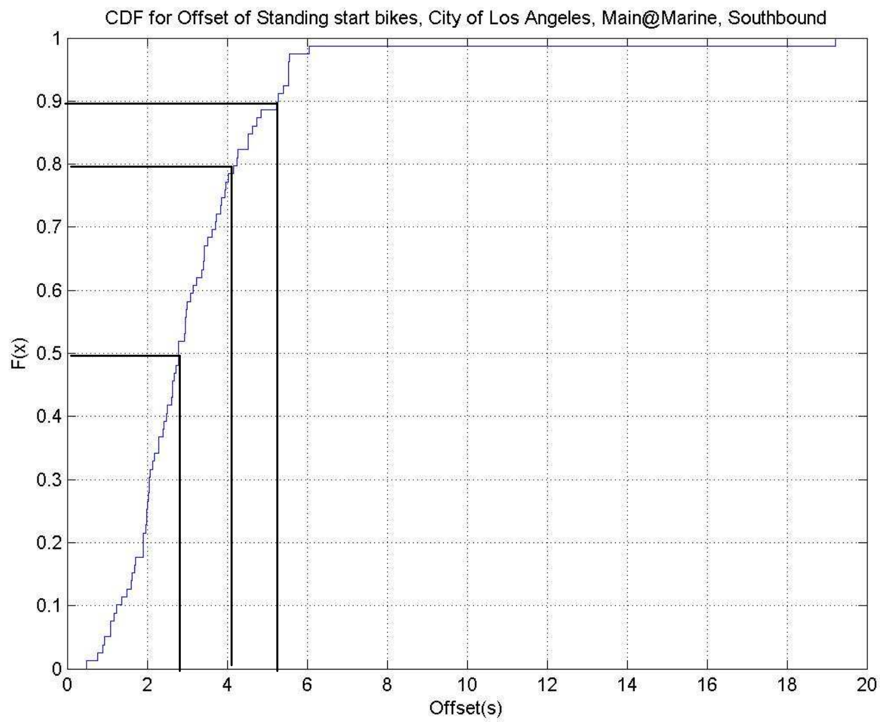

Figure 3.28 Cumulative distribution of offset times for standing start bicyclists on Main at Marine

The final cruising speeds of the standing start bicyclists are shown in the histogram and cumulative distribution of Figures 3.29 and 3.30.

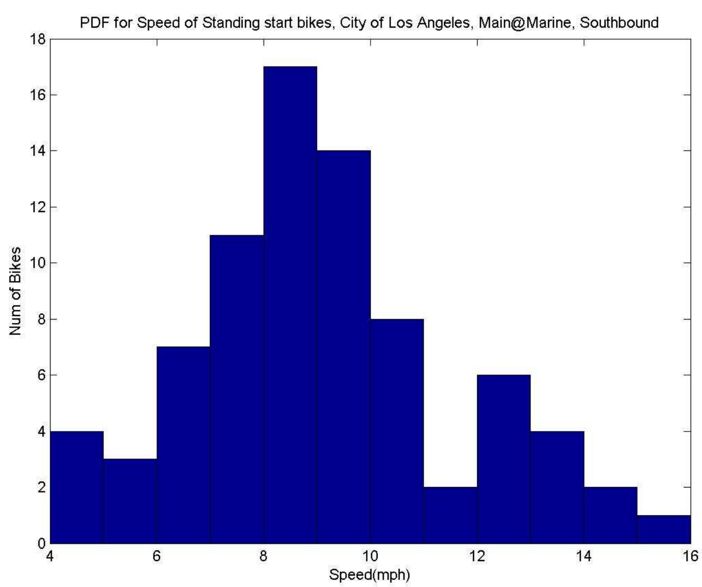

Figure 3.29 Histogram of final crossing speed for standing start bicyclists on Main at Marine

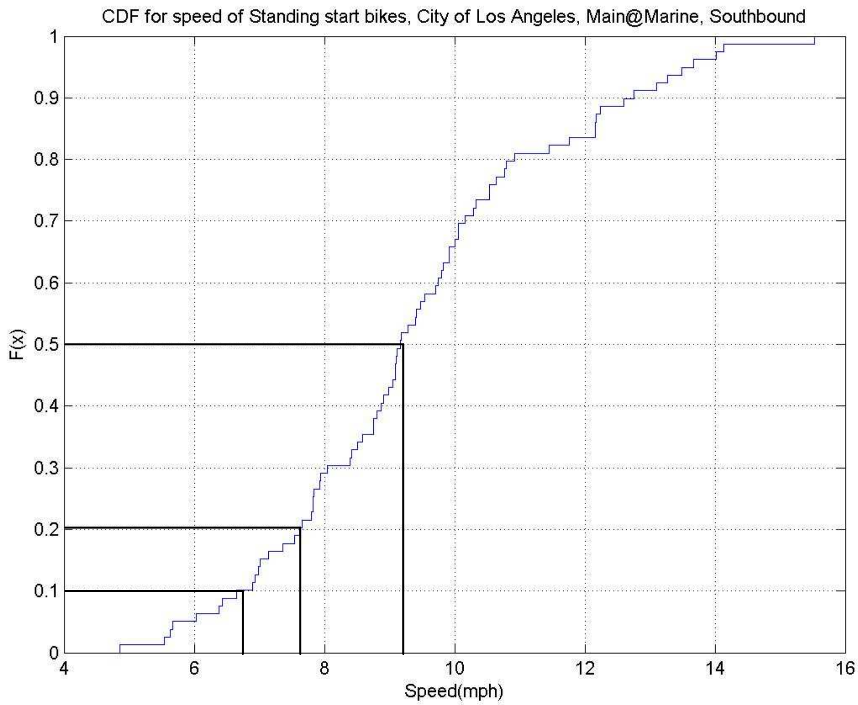

Figure 3.30 Cumulative distribution of final crossing speeds of standing start bicyclists on Main at Marine.

3.6 Comparisons of data from all observed intersections

The relationships between bicycling behavior and the characteristics of the intersections only become apparent when the data from the different intersections are plotted together, so in this section we combine the cumulative distribution plots from all the intersections that had full data sets. This begins with the cruising speed for the rolling starts, which is the simplest parameter to compare, as plotted in Figure 3.31.

It is clear from Figure 3.31 that two of the three slowest cruising speeds are for the uphill bicyclists in San Francisco and Berkeley and two of the three fastest cruising speeds are for the downhill bicyclists at the same intersections, so the strong effect of grade is obvious. The slowest cruising speeds of all, at the slow tail of the distribution, are for the family recreational bicyclists using a pedestrian crossing along Marina Blvd. in San Francisco, indicating the importance of accounting for the local bicycling population and peculiarities of the crossing. In contrast, the other fast speed distribution is for the vigorous young adults leaving the Stanford campus during the evening commute period. The bicyclists at the flat intersections in Davis and the Los Angeles area were clustered in the middle. The more recreationally oriented bicyclists in the heavier traffic of Santa Monica were somewhat slower than the U.C. Davis students in their low-density residential area, and as previously observed the Davis students going home in the evening were somewhat faster than they were heading toward the campus in the morning.

Based on these data, it looks reasonable to assume a 50%ile cruising speed of about 12 mph at flat intersections, with a 20%ile of about 10 mph and a 10%ile of about 8 mph. These values need to be reduced where there is a significant grade and where the bicycling population is weighted toward recreational bicyclists and/or families with children, or where the bicyclists must use a pedestrian crossing.

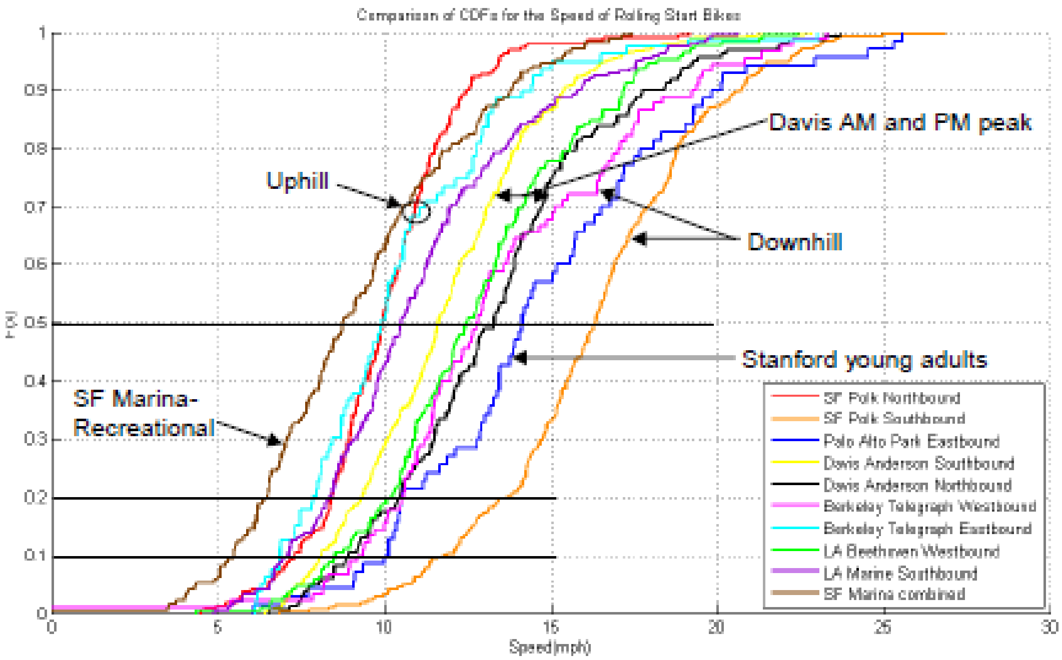

Figure 3.31 Cumulative distributions of speed observations for rolling starts at the observed intersections

The cumulative distributions of the offset times for the standing starts are plotted in Figure 3.32. For the offset times, the critical parts of the distributions are the upper percentiles, to ensure that signal timings can accommodate most of the population.

The offset time data for most of the intersections are relatively tightly clustered, with 80th percentile values around 4 seconds and 90th percentile values around 5 seconds. The outlier for offset times is Park Blvd. at El Camino Real in Palo Alto, where the offset times are exceptionally long (despite the youthful, vigorous population of bicyclists) because of three factors – limited visibility of the cross traffic, extremely fast and dangerous cross traffic requiring great caution on the part of the bicyclists, and a steep crown on El Camino making the acceleration more difficult than at most intersections. Eastbound Russell St. at Telegraph in Berkeley also had longer high percentile offset times than most intersections, again because of a visibility issue. In this case, there is a bus stop near the corner, so when a bus is stopped there it blocks the bicyclists' view of the approaching cross traffic and makes the start-up more difficult.

The third distribution of interest describes the final crossing speed for the standing-start crossings, when the bicyclists have reached a constant speed after accelerating from a stop, as shown in Figure 3.33. This plot shows a remarkably diverse set of results across the sampled intersections.

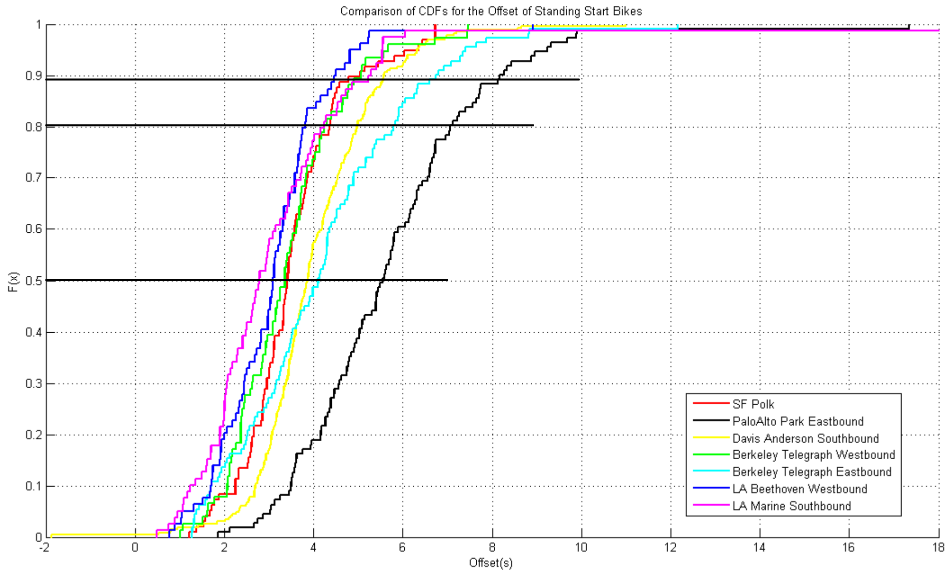

Figure 3.32 Cumulative distributions of offset times for standing start intersection crossings

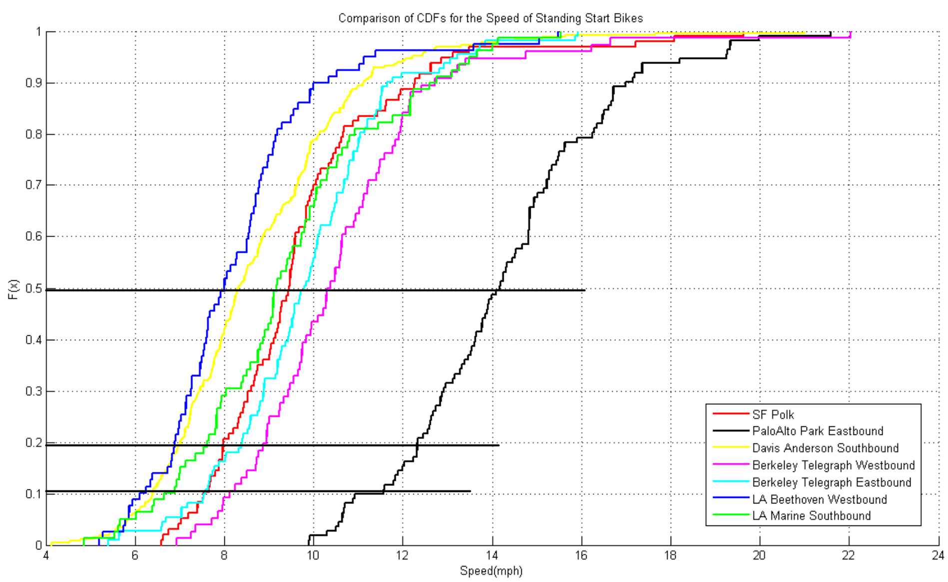

Figure 3.33 Cumulative distributions of final speeds for standing start bicyclists.

Park Ave. at El Camino Real was again the outlier, but in this case on fast side rather than the slow side. There are several reasons that the final speeds observed here were much higher than at any of the other intersections:

- these bicyclists were vigorous young adults in a hurry to get home at the end of the work day;
- they are crossing the widest street of any of the intersections for which we have data, which allows more time to accelerate up to a higher cruising speed within the observation range;
- the cross street has a strong crown profile, which means that after the bicyclists reach the mid-point of the street they are on a negative slope, which helps them accelerate to a higher speed. (When the data were re-analyzed based on the bicyclist speeds at the midpoint of their crossing of El Camino Real they were much closer to the distributions for the other intersections.)

The intersection of Russell at Telegraph had the second-highest speeds across most the cumulative distribution. It is no coincidence that this was the second-widest street where we collected data, so the street width appears to be particularly significant to this distribution. The intersections at Beethoven, Polk and Anderson were all in the range of 60 feet wide, while the intersection at Marine varied from 48 to 84 feet wide, depending on where the bicyclists actually started their crossing.

The key percentiles of the observed bicyclist crossing behaviors observed at the selected intersections were as tabulated in Table 3.1 below:

Table 3.1 Key Percentiles of Observed Bicyclist Crossing Behaviors

%ile accommodated	**Start-Up Offset Time**	**Final Speed from Standing Starts**	**Constant Rolling Speed (Roll thru)**
90% Park Blvd., Palo Alto	8.1 s	11.5 mph (10%ile)	10.0 mph (10%ile)
90% Russell St., Berkeley	6.0 s	8.2 down, 7.6 up	9.3 down, 6.8 up
90% Anderson Rd., Davis	5.6 s	6.4 mph	8.1 (AM) 8.9 (PM)
90% Polk St., S.F.	4.8 s	7.8 mph	11.5 down, 7.3 up
90% Venice Blvd., L.A.	4.5 s	6.1 mph	8.6 mph
90% Main St., Santa Monica	5.2 s	6.7 mph	7.1 mph
90% Marina Blvd., S.F.	--	--	5.4 mph
80% Park Blvd., Palo Alto	7.0 s	12.3 mph (20%ile)	10.6 mph (20%ile)
80% Russell St., Berkeley	5.0 s	8.8 down, 8.4 up	10.5 down, 7.8 up
80% Anderson Rd., Davis	4.9 s	7.0 mph	9.3 (AM) 10.4 (PM)
80% Polk St., S.F.	4.35 s	8.3 mph	13.4 down, 8.4 up
80% Venice Blvd., L.A.	3.7 s	6.8 mph	10.0 mph
80% Main St., Santa Monica	4.2 s	8.9 mph	8.3 mph
80% Marina Blvd., S.F.	--	--	6.3 mph
50% Park Blvd., Palo Alto	5.5 s	14.2 mph	14.1 mph
50% Russell St., Berkeley	3.7 s	10.4 down, 9.8 up	12.8 down, 10.0 up
50% Anderson Rd., Davis	3.8 s	8.2 mph	11.6 (AM) 13.2 (PM)
50% Polk St., S.F.	3.5 s	9.3 mph	16.3 down, 10.0 up
50% Venice Blvd., L.A.	3.1 s	8.0 mph	12.5 mph
50% Main St., Santa Monica	2.8 s	9.1 mph	10.5 mph
50% Marina Blvd., S.F.	--	--	8.8 mph

4. Simulations to Show Traffic Impacts of Increased Minimum Green

In this chapter, we use an example corridor to study and discuss the impact of reflecting bicycle green time requirements in signal timing. Since such impact has previously been shown to be negligible under congested traffic conditions, the focus of this section is on the impact under low to medium flow conditions.

4.1 Corridor and Scenario Description

The study corridor is Bouquet Canyon Road in Santa Clarita, California. The SYNCHRO model files for this corridor are completely coded with road geometry and turning volumes, as well as signal timing information. The 3-mile study section is between Lowes and Plum Canyon Road along Bouquet Canyon Road with twelve signalized intersections (See Figure 4.1). The cycle length along the corridor is 120 seconds and most intersections have a pedestrian phase available if called for.

The corridor uses different timing plans for morning peak, afternoon peak, and mid-day traffic. For purposes of this study, we start with the mid-day traffic as the moderate flow condition, which is significantly lower than the AM/PM peak volumes; and for the low flow condition we further reduce the mid-day volume significantly.

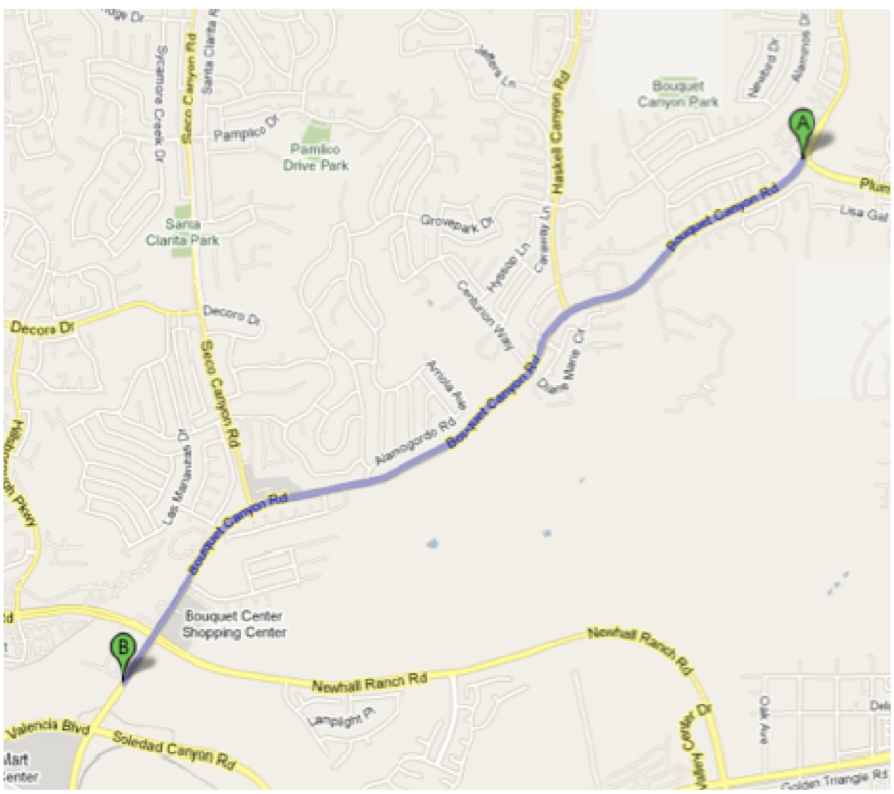

Figure 4.1: Study Corridor

SYNCHRO is used in this study to test the impact of minimum bicycle clearance time requirement. Table 4.1 shows the minimum split requirements for the different scenarios that were tested. Note that since it is typically bicycles traveling on a side street that would require a longer than usual minimum green to cross the major arterial, Table 4.1 lists minimum green requirements only for the phases that serve the side streets.

Scenarios

In Scenario 1, the signal timing is chosen based entirely on serving the vehicle traffic along this corridor, without regard to bicyclists or pedestrians. Thus, in Scenario 1,

Minimum split = Minimum initial + Yellow + All red

The signal timing splits and offsets are optimized and network wide MOEs are recorded (Table 4.2).

Then, in Scenario 2, the minimum green is set to reflect the bicycle green time requirement (from Caltrans document TOPD 09-06) based on the distance that a bicycle needs to clear to cross the intersection safely. In this scenario,

Minimum split = Minimum initial for bicycle + Yellow + All red

Network MOEs for Scenario 2 are also recorded, where Scenario 2a reports MOEs under un-optimized timing plans and Scenario 2b represents the network running re-optimized signal timing plans.

Scenario 3 represents the corridor when there are significant pedestrian volumes and the pedestrians are requesting pedestrian crossing phases, so that these become the minimum split:

Minimum split = Pedestrian walk + Flash don’t walk + Yellow + All red

Scenario 4a adds bicycle minimum green requirement on top of Scenario 3 and Scenario 4b demonstrates the impact with a re-optimized timing plan.

Table 4.1. Minimum split requirement

Intersection	No. of Lanes	Auto (seconds)	Auto+bicycle (seconds)	Auto+ped (seconds)	Auto+ped+bicycle (seconds)
Lowes *	10	12	14.6	12 *	14.6
Newhall Ranch	13	11	17.3	39	39
Best Buy *	10	12	14.6	12 *	14.6
Espuelle	10	8.5	14.6	39.5	39.5

Seco Canyon	7	15	11.9	35	35
Alamogordo	6	8.5	11.2	33.5	33.5
Central Park	6	8.5	11.2	34.5	34.5
Centurion	6	12	11.2	22	22
Haskell	9	9	13.9	33	33
Urbandale	8	8.5	13.2	33.5	33.5
Wellston	8	10.5	13.2	33.5	33.5
Plum Canyon	8	13	13.2	33	33

Note: The intersections noted with a * do not have a pedestrian phase accompanying the side street phases.

4.2 Impact under moderate traffic flow conditions

As stated in Section 4.1, the moderate flow condition represents the mid-day network demand, as shown in Figure 4.2 below.

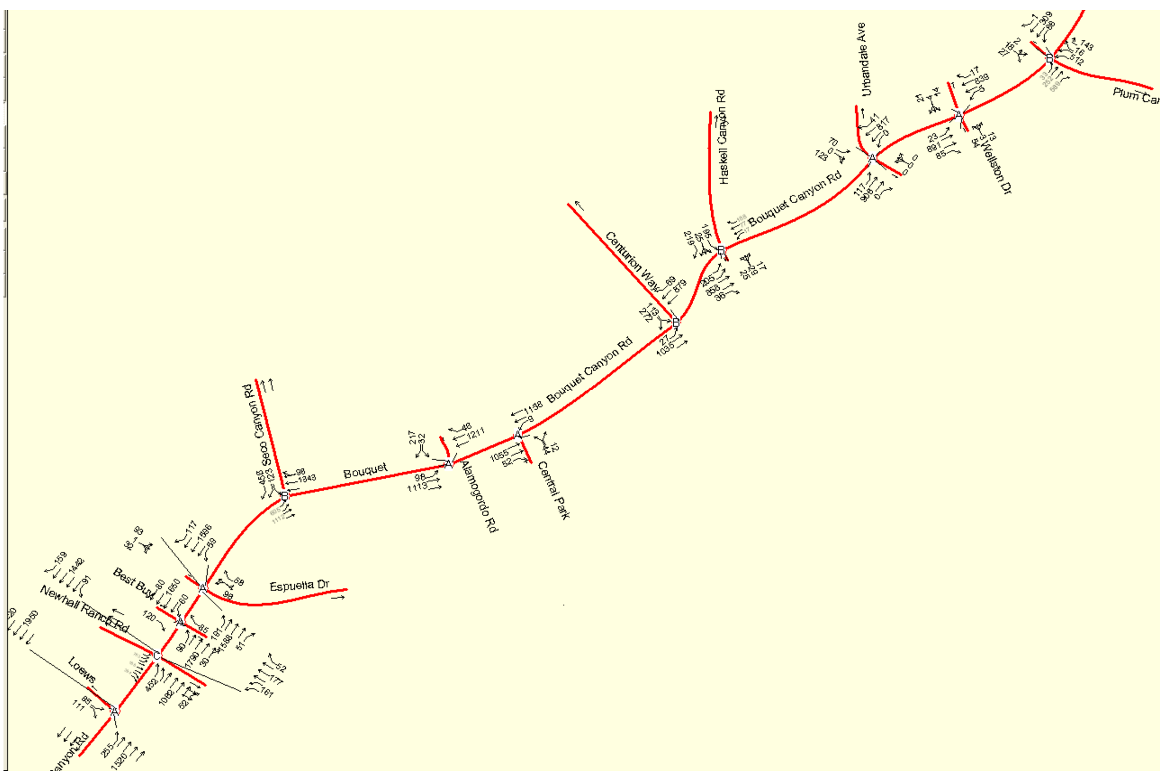

Figure 4.2: Intersection Turning Volumes

With moderate demand, the network performance MOEs for each scenario are shown in Table 4.2.

Table 4.2. Network MOE Comparison (moderate flow condition) for different signal timing scenarios

	Scenario 1	Scenario 2a	Scenario 2b	Scenario 3	Scenario 4a	Scenario 4b
Total Delay (hr)	124	124	124	168	169	169
Number of Stops	13153	13601	13807	14218	14322	14711
Average Speed (mph)	28	28	28	25	25	25
Total Travel Time (hr)	320	320	320	364	365	365
Distance Traveled (mile)	9100	9100	9100	9100	9100	9100

Note:
Scenario 1 – Auto only;
Scenario 2a – Auto+Bicycle;
Scenario 2b – Auto+Bicycle, signal timing re-optimized;
Scenario 3 – Auto+Pedestrian;
Scenario 4a – Auto+Pedestrian+Bicycle
Scenario 4b – Auto+Pedestrian+Bicycle, signal timing re-optimized.

As shown in Table 4.2, the network wide MOEs are very similar among Scenarios 1, 2a, and 2b, and among Scenarios 3, 4a, and 4b. Adding the bicycle green requirement (going from Scenario 1 to 2a or 2b) has an imperceptible effect on total delay, average speed and total travel time and causes only a 3.4%~4.9% increase in number of stops network-wide, while adding the pedestrian green time requirement (Scenarios 3 and 4) causes a much bigger impact (26% increase in total delay, 11% decrease in average speed, 12% increase in travel time, and 8.1% increase in stops). Table 4.3 shows green splits for through traffic on the mainline, which provides an intersection-level comparison of the scenarios.

Table 4.3. Comparison of green splits under moderate flow condition (seconds)

	Cross Street Name	Traffic direction	Scenario 1	Scenario 2b (%change [1])	Scenario 3 (% change [2])	Scenario 4b (% change [3])
#1	Lowes	NE	97.0	96.3 (-0.7)	97.0 (0.0)	96.3 (-0.7)
		SW	57.5	56.8 (-1.2)	57.5 (0.0)	56.8 (-1.2)
#2	Newhall Ranch	NE	52.0	54.0 (3.8)	46.0 (-11.5)	46.0 (0.0)
		SW	41.0	42.0 (2.4)	46.0 (12.2)	46.0 (0.0)
#3	Best Buy	NB	76.0	76.2 (0.3)	76.0 (0.0)	76.2 (0.3)
		SB	72.0	72.4 (0.6)	72.0 (0.0)	72.4 (0.6)
#4	Espuelle	NB	70.1	70.1 (0.0)	59.0 (-15.8)	59.0 (0.0)
		SB	57.8	57.8 (0.0)	59.0 (2.1)	59.0 (0.0)
#5	Seco Canyon	EB	95.0	95.0 (0.0)	85.0 (-10.5)	85.0 (0.0)
		WB	55.0	55.0 (0.0)	50.0 (-9.1)	50.0 (0.0)

#6	Alamogordo	EB	89.7	89.7 (0.0)	83.5 (-6.9)	83.5 (0.0)
		WB	65.7	65.4 (-0.5)	62.5 (-4.9)	64.5 (3.2)
#7	Central Park	EB	69.7	69.7 (0.0)	62.0 (-11.0)	62.0 (0.0)
		WB	92.2	92.2 (0.0)	77.5 (-15.9)	77.5 (0.0)
#8	Centurion	NE	80.5	80.5 (0.0)	64.5 (-19.9)	64.5 (0.0)
		SW	53.5	53.5 (0.0)	48.5 (-9.3)	48.5 (0.0)
#9	Haskell	EB	60.0	59.6 (-0.7)	55.0 (-8.3)	55.0 (0.0)
		WB	53.0	52.6 (-0.8)	50.0 (-5.7)	50.0 (0.0)
#10	Urbandale	NE	68.1	68.1 (0.0)	63.0 (-7.5)	63.0 (0.0)
		SW	55.5	55.5 (0.0)	50.5 (-9.0)	50.5 (0.0)
#11	Wellston (60scycle)	EB	37.0	36.8 (-0.5)	26.5 (-28.4)	26.5 (0.0)
		WB	37.0	36.8 (-0.5)	26.5 (-28.4)	26.5 (0.0)
#12	Plum Canyon	NE	25.8	25.8 (0.0)	39.3 (52.3)	41.7 (6.1)
		SW	50.9	50.9 (0.0)	62.4 (22.6)	63.8 (2.2)

Note:
Scenario 1 – Auto only;
Scenario 2b – Auto+Bicycle, signal timing re-optimized;
Scenario 3 – Auto+Pedestrian;
Scenario 4b – Auto+Pedestrian+Bicycle, signal timing re-optimized.
[1] Percentage change comparing with Auto only scenario
[2] Percentage change comparing with Auto only scenario
[3] Percentage change comparing with Auto+Pedestrian scenario

As shown in Table 4.3, adding bicycle minimum green requirements (Scenario 2b) has a negligible impact on the green time provided to through movements along the corridor (maximum 3.8% decrease, with most intersections unaffected). In comparison, pedestrian green time requirements pose a much bigger impact (Scenario 3). Figure 4.3 provides a more visual comparison of the green splits of the different scenarios.

4.3. Impact under low traffic flow condition

To study the bicycle green time requirement impact under low traffic flow conditions (to represent late night or early morning), the mid-day volumes used for analysis in Section 4.2 are further reduced by 80% to a low traffic flow level and the Scenarios defined in Section 4.1 are compared under this flow condition in this section. Network performance MOEs for each scenario under low traffic flow condition are shown in Table 4.4.

Similar to the results under moderate flow conditions, the network-wide MOEs are very similar among Scenarios 1, 2a, and 2b, and among Scenarios 3, 4a, and 4b. The bicycle green requirement has minimal impact on all reported network wide MOEs, especially after the signal timing is re-optimized. Under low flow conditions, the pedestrian green time requirements again show a bigger impact (12.5% increase in total delay, 3.0% decrease in average speed, 3.5% increase in travel time, and 20.8% increase in stops). Adding the bicycle green requirements on top of those for pedestrians, again no additional impact is observed (as shown in Table 4.4, Scenarios 3, 4a, and 4b). Using the green splits for through movements along the corridor, Table 4.5 provides an intersection-level comparison of the scenarios.

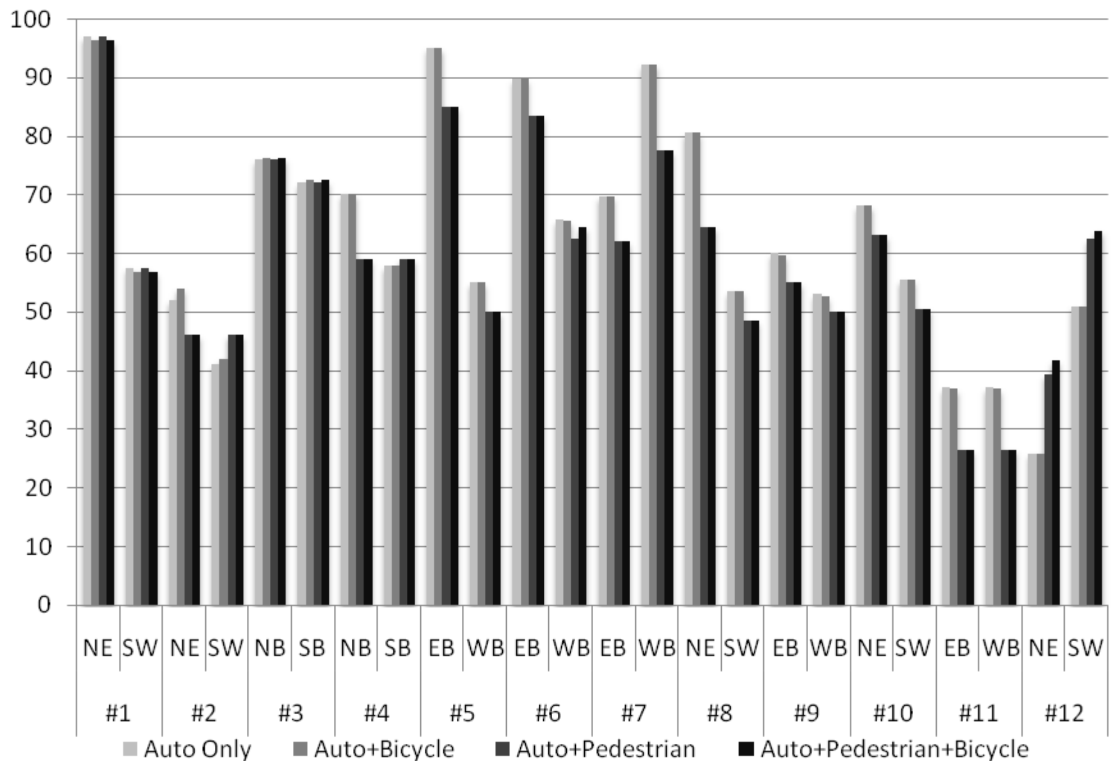

Figure 4.3. Mainline through movement green split comparison (moderate flow condition)

Table 4.4 Network MOE Comparison (low flow condition)

	Scenario 1	Scenario 2a	Scenario 2b	Scenario 3	Scenario 4a	Scenario 4b
Total Delay (hr)	16	16	16	18	18	18
Number of Stops	1480	1507	1479	1789	1789	1788
Average Speed (mph)	33	33	33	32	32	32
Total Travel Time (hr)	55	55	55	57	57	57
Distance Traveled (mile)	1820	1820	1820	1820	1820	1820

Note:
Scenario 1 – Auto only;
Scenario 2a – Auto+Bicycle;
Scenario 2b – Auto+Bicycle, signal timing re-optimized;
Scenario 3 – Auto+Pedestrian;
Scenario 4a – Auto+Pedestrian+Bicycle

Scenario 4b – Auto+Pedestrian+Bicycle, signal timing re-optimized.

Table 4.5. Comparison of green splits under low flow condition (seconds)

		Traffic direction	Scenario 1	Scenario 2b (%change[1])	Scenario 3 (%change[2])	Scenario 4b (% change[3])
#1	Lowes	NE	82.0	82.0 (0.0)	84.0 (2.4)	82.4 (-1.9)
		SW	41.5	41.5 (0.0)	45.5 (9.6)	44.9 (-1.3)
#2	Newhall Ranch	NE	34.0	30.7 (-9.7)	46.0 (36.3)	46.0 (0.0)
		SW	34.0	30.7 (-9.7)	46.0 (36.3)	46.0 (0.0)
#3	Best Buy	NB	61.0	60.4 (-1.0)	67.0 (9.8)	65.4 (-2.4)
		SB	61.0	60.4 (-1.0)	67.0 (9.8)	65.4 (-2.4)
#4	Espuelle	NB	45.6	45.9 (0.7)	59.0 (29.4)	59.0 (0.0)
		SB	43.2	43.5 (0.7)	59.0 (36.6)	59.0 (0.0)
#5	Seco Canyon	EB	79.0	79.0 (0.0)	71.0 (-10.1)	71.0 (0.0)
		WB	40.0	40.0 (0.0)	44.0 (10.0)	44.0 (0.0)
#6	Alamogordo	EB	82.1	82.1 (0.0)	68.5 (-16.6)	68.5 (0.0)
		WB	44.1	44.1 (0.0)	38.5 (-12.7)	38.5 (0.0)
#7	Central Park	EB	46.0	46.0 (0.0)	42.0 (-8.7)	42.0 (0.0)
		WB	82.5	82.5 (0.0)	67.5 (-18.2)	67.5 (0.0)
#8	Centurion	NE	61.5	61.5 (0.0)	51.5 (-16.3)	51.5 (0.0)
		SW	33.5	33.5 (0.0)	32.5 (-3.0)	32.5 (0.0)
#9	Haskell	EB	43.0	42.1 (-2.1)	43.0 (0.0)	43.0 (0.0)
		WB	43.0	42.1 (-2.1)	43.0 (0.0)	43.0 (0.0)
#10	Urbandale	NE	48.1	48.1 (0.0)	43.0 (-10.6)	43.0 (0.0)
		SW	43.6	43.6 (0.0)	38.5 (-11.7)	38.5 (0.0)
#11	Wellston (60scycle)	EB	32.5	30.8 (-5.2)	23.5 (-27.7)	23.5 (0.0)
		WB	32.5	30.8 (-5.2)	23.5 (-27.7)	23.5 (0.0)
#12	Plum Canyon	NE	34.9	32.0 (-8.3)	42.9 (22.9)	43.2 (0.7)
		SW	62.5	58.6 (-6.2)	61.5 (-1.6)	59.8 (-2.8)

Note:
Scenario 1 – Auto only;
Scenario 2b – Auto+Bicycle, signal timing re-optimized;
Scenario 3 – Auto+Pedestrian;
Scenario 4b – Auto+Pedestrian+Bicycle, signal timing re-optimized.
[1] Percentage change comparing with Auto only scenario
[2] Percentage change comparing with Auto only scenario
[3] Percentage change comparing with Auto+Pedestrian scenario

As shown in Table 4.5, adding bicycle minimum green requirements (Scenario 2b) has a very small impact on the green time provided to through movements along the corridor (maximum 9.7% decrease, with many intersections unaffected). In comparison, pedestrian green time requirements pose a substantially bigger impact (Scenario 3). Figure 4.4 provides a more visual comparison of the green splits of the different scenarios.

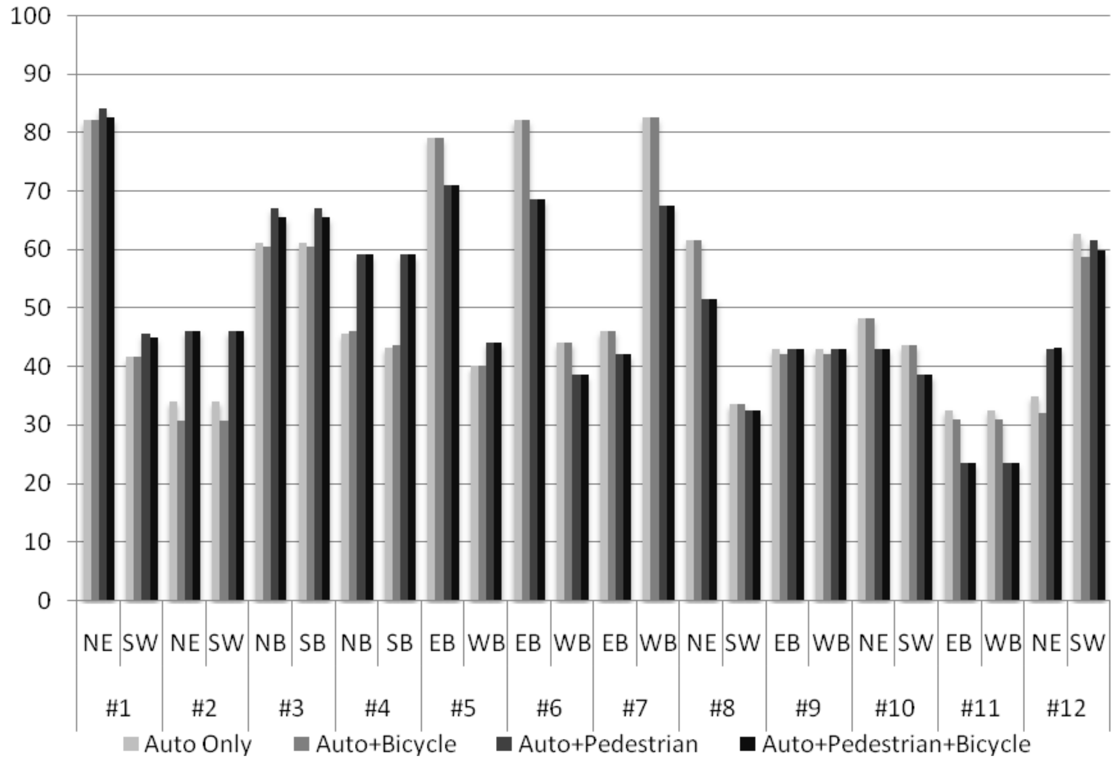

Figure 4.4. Mainline through movement green split comparison (low flow condition)

4.4 Conclusions

Using SYNCHRO as the signal timing simulation and optimization package, this chapter shows the impact of bicycle minimum green requirements under moderate and low traffic flow conditions. The results show that applying a reasonable bicycle minimum green requirement has a small to negligible effect on the performance of the corridor, both network-wide and at the intersection level, under both moderate and low volume traffic conditions. Previous simulation work already showed that under high traffic volumes we should expect enough vehicular traffic on the cross streets to actuate a green phase at least as long as minimum needed for bicyclist crossings, so the increased minimum bicyclist crossing time requirement has no practical effect on traffic.

5. Signal Timing Recommendations

The field data show significant diversity in the timing that bicyclists needed to cross intersections throughout California. With a limited number of intersections and many variables that could explain the variations, it was not possible to separate out all of the effects directly to develop a comprehensive bicyclist signal timing handbook at this stage. We have focused on intersection width as an obvious and measurable influence on the time that bicyclists need to cross, and suggest formulas based on width to represent the timing needed to accommodate the 80%ile and 90%ile bicyclists at each intersection. However, width does not tell the whole story because the crossing times also depend on:

- bicyclist demographics (age, bicycling experience, trip purpose and time of day)
- visibility that bicyclists have of cross traffic and the speed and density of that cross traffic
- local intersection geometry (grades, road surface crown).

The total crossing time distributions for standing start bicyclists should be used to select the total time provided for clearing the intersection (green plus yellow plus all-red interval). Agencies often have their own specific rules for limiting the duration of yellow and all-red intervals, but the selection of the yellow interval should at least be informed by the distribution of bicyclist rolling start speeds so that bicyclists do not get caught in the dilemma zone with undue frequency.

The total crossing time distributions as a function of crossing width W (ft.) can be summarized based on summation of the distributions for offset times and intersection width divided by final crossing speed. In our previous report, we were able to show that the offset times and final crossing speeds of individual bicyclists were not correlated, so the distributions can be added without introducing bias. The combinations of offset times and cruise speed crossing times produce equations for the 80th and 90th percentile total crossing times of:

- **T80 = 7.0 + 0.055 W (Park Blvd., Palo Alto)**
- **T80 = 5.0 + 0.079 W (Russell St., Berkeley)**
- **T80 = 4.9 + 0.097 W (Anderson Rd., Davis)**
- **T80 = 4.35 + 0.082 W (Polk St., S.F.)**
- **T80 = 3.7 + 0.10 W (Venice Blvd., L.A.)**
- **T80 = 4.2 + 0.077 W (Main St., Santa Monica)**

- **T90 = 8.1 + 0.059 W (Park Blvd., Palo Alto)**
- **T90 = 6.0 + 0.086 W (Russell St., Berkeley)**
- **T90 = 5.6 + 0.106 W (Anderson Rd., Davis)**
- **T90 = 4.8 + 0.087 W (Polk St., S.F.)**
- **T90 = 4.5 + 0.112 W (Venice Blvd., L.A.)**
- **T90 = 5.2 + 0.102 W (Main St., Santa Monica)**

When these are plotted it is possible to see the diversity of these crossing behaviors graphically, as shown in Figure 5.1. In this figure, the 80%ile crossing times are indicated by dashed lines and the 90%ile crossing times are solid lines, representing the six intersections for which we have substantial data, each of which is plotted in a different color. Because the crossing distance at Main St. in Santa Monica varied significantly among bicyclists, its data (orange lines) show an exceptionally wide variation between the 80%ile and 90%ile samples and are not assigned any specific value of intersection width here.

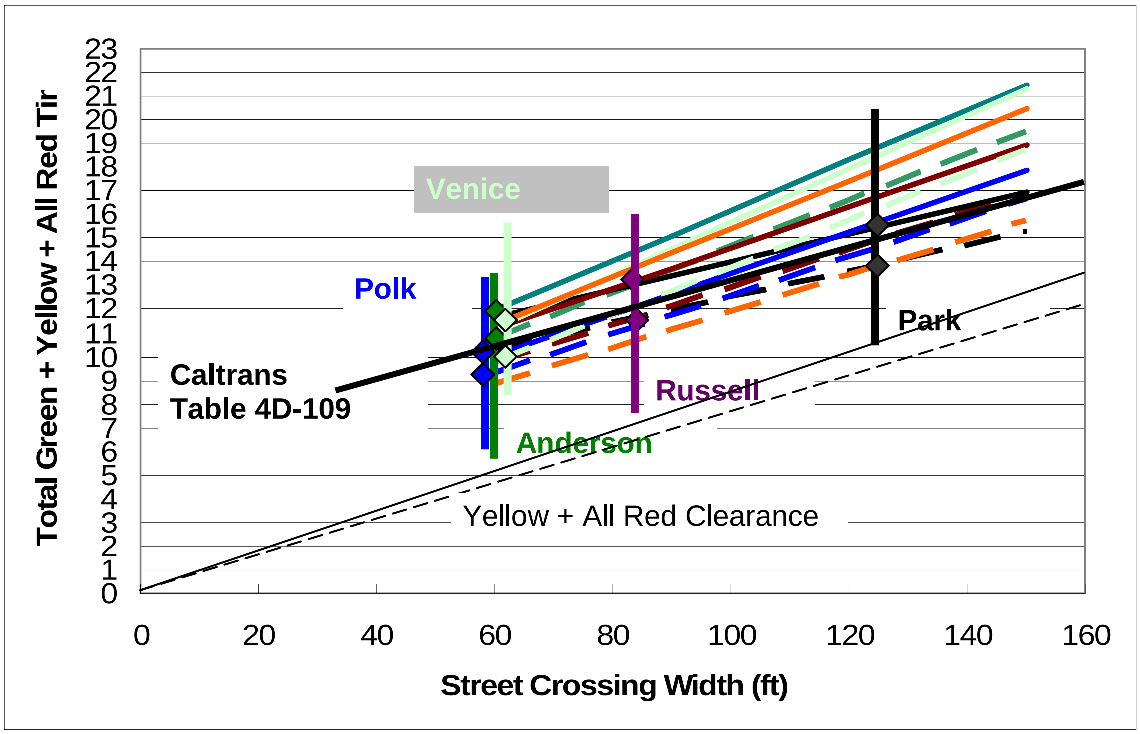

Figure 5.1 Crossing Times as a Function of Street Width

Superimposed on top of the data is a black line representing the minimum bicycle timing defined in Table 4D-109 of Caltrans' Traffic Operations Policy Directive 09-06, issued September 10, 2009. This line, which was defined based on a subset of the data reported here, appears to represent a reasonable approximation to the 85%ile bicyclist needs.

Before these timing criteria are applied to a specific intersection, it would be advisable to consider whether there are special conditions that could affect the bicyclist needs at that intersection. The conditions that could require longer signal timing for bicyclists include:

- significant proportion of children or casual recreational bicyclists
- restricted visibility of cross traffic by bicyclists seeking to cross
- high-speed cross traffic (posted speed above 30 mph) posing an increased threat to bicyclists
- significant grades or road surface crowns making it more difficult for bicyclists to accelerate to full speed.

On the other hand, if the bicycling population is exceptionally vigorous and physically fit at an intersection, it may be possible to shorten the timing slightly from the values shown here.

The observed rolling start bicyclist speeds can also be used to estimate yellow plus all-red clearance intervals for bicyclists who are just entering the intersection at steady cruising speed at the yellow onset. The observed 10%ile and 20%ile bicyclist speeds of 8 and 9 mph respectively would indicate yellow clearance intervals of:

$Y80 = 0.076\ W$ to accommodate 80% of bicyclists
$Y90 = 0.085\ W$ to accommodate 90% of bicyclists

These are indicated by the black lines shown in the lower part of Figure 5.1. Unfortunately these values are so much larger than the values that would typically be applied at the wider intersections that it is likely to be difficult to gain acceptance of these values (such as 10 seconds for the 125 foot width of El Camino Real at Park Blvd.).

References

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