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16. ABSTRACT

This study was conducted at selected dual-loop detector stations in the BHL Testbed to evaluate the data generated by a portable rapidly deployable, battery-powered traffic monitoring device called an iCone. iCones had previously been used by Caltrans to monitor vehicle speeds in work zones, and the BHL provided a unique opportunity to compare the speed values they generate against speed data from in-ground dual-loop stations. This allowed for careful comparison of the data characteristics including lane-by-lane breakdowns of speed observations and performance in a variety of traffic conditions over time. The iCones were deployed at five BHL dual-loop stations from mid-June to late August 2011. More than 8 weeks of data were collected, with several weeks of matched data between the full set of five deployed iCones and the corresponding dual-loop stations. The data was analyzed, and detailed comparisons were made between the loop data and the iCone data.

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Evaluating iCone Speed Values against Dual-Loop Speed Values

April, 2012

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For

California Department of Transportation

Division of Research and Innovation

1 INTRODUCTION

The Berkeley Highway Laboratory (BHL) Testbed is a 2.7 mile section of US Interstate 80 that runs approximately from Powell Street in Emeryville to Gilman Street in Berkeley. To collect data on this section of urban freeway, the BHL Testbed includes eight video cameras and sixteen directional dual-inductive-loop-detector stations as well as communications and database systems to handle the real-time data they generate.

This study was conducted at selected dual-loop detector stations in the BHL Testbed to evaluate the data generated by a portable rapidly deployable, battery-powered traffic monitoring device called an iCone. iCones have previously been used by Caltrans to monitor work zones and the BHL provided a unique opportunity to compare the speed values they generate against speed data from in-the-ground dual-loop stations. This allowed for careful comparison of the data characteristics including lane-by-lane breakdowns of speed observations and performance in a variety of traffic conditions over time.

The iCones were deployed at five BHL dual-loop stations from mid-June to late August 2011, with exceptions while devices were tested or redeployed after recharging the batteries. More than 8 weeks of data were collected, with several weeks of matched data between the full set of five deployed iCones and the corresponding dual-loop stations. As presented in the rest of this report, data for the week of August 9-15, 2011 was analyzed, and detailed comparisons were made between the loop data and the iCone data.

2 BHL LOOP DETECTOR STATION DESCRIPTION

There are eight dual-loop stations on all lanes in both directions of travel along I-80 in the BHL Testbed, with inductive loops deployed in pairs in each lane. The roadway has five or six lanes in each direction of travel. Each pair of loops is spaced 20 feet leading edge to leading edge, allowing direct speed observations to be derived for each vehicle that crosses both loops in the pair. The loops are wired to traffic control cabinets on the side of the freeway, where a Caltrans traffic controller collects the signal changes from loop-detector interface cards. The schematic below indicates approximately where the loop stations are located relative to the Pacific Park Plaza tower in Emeryville, which is at approximately I-80 CA postmile 4.2 or I-80 absolute postmile 9.5:

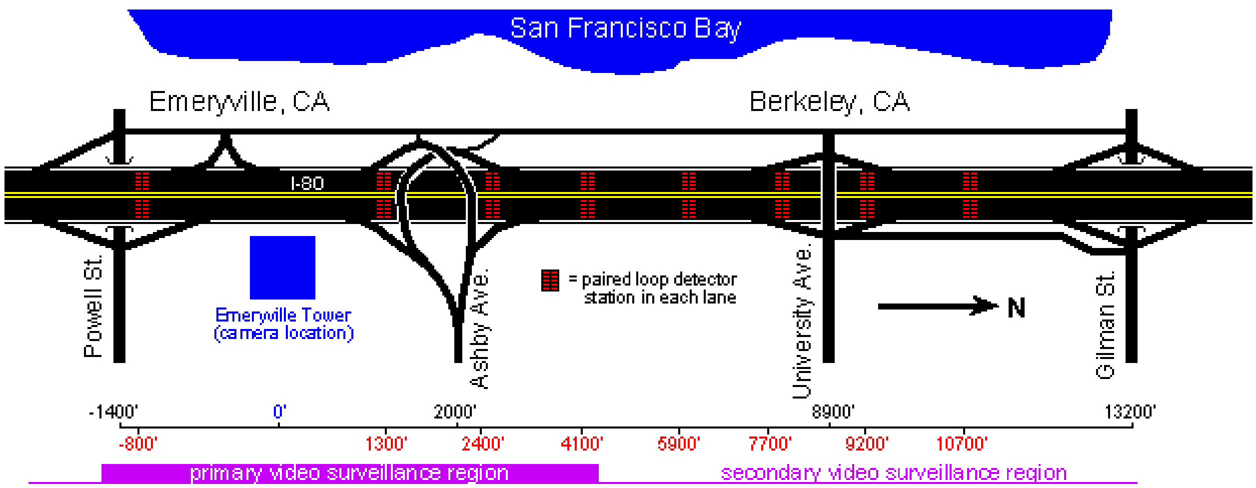

Figure 1: Diagram of BHL site and infrastructure

Loop detector actuation on/off events are collected at the cabinets and transmitted to BHL servers at PATH. Each loop event is identified by its type (on or off), station, lane, and time. Time is tracked with 1/60th of a second precision. The data for each loop event is collected into single-second groups and then each group is sent as a UPD packet over a cellular data connection. The BHL servers collect this raw data and process it to calculate data formats of interest to researchers and others. One of these data formats matches upstream and downstream loop actuations in dual-loop pairs to indicate a single vehicle crossing both loops in the pair. This matched "vehicle-stream" data is used throughout this report as the basis for speed observations at the loops.

The design of the BHL system was originally focused on reporting mainline data from sites with five lanes of travel in each direction. The BHL servers therefore produce vehicle-stream data only for lanes 1-5 in either direction, an important detail because station 8 (at Powell St) has six lanes in either direction as the freeway approaches the westbound 80/580 split (or leaves the eastbound 80/580 merge).

3 ICONE SYSTEM DESCRIPTION

Figure 2: Image from iCone User's Manual

iCone units are portable battery-powered radar devices that can be used to collect speed or vehicle count data when deployed on the roadside. They are contained in an orange-and-white striped construction barrel and are sold for various traffic-monitoring purposes, often focusing on work zone applications.

Each iCone system conducts periodic Doppler radar sweeps and analyzes the data generated by reflections from the targets in the radar field of view. When used to collect speed information, the iCone determines a single best target in each sweep and uses its speed as the current speed observation. In congested or otherwise complicated areas, the radar may not select a target in every sweep. To help ensure that a single vehicle does not dominate the speed observations, sweeps are conducted every 2.5 seconds, and values for two-minute windows are averaged (using an arithmetic mean) to produce a single speed value and count every two minutes. This data is sent over cellular data connections to servers operated by the iCone vendor. The data is then made available in real-time over the internet to authorized users like Caltrans. Additionally, iCones determine their location and the current time from GPS, and this information is sent over the cellular data links less frequently (on the order of twice an hour).

3.1 ICONE SITE SELECTION AND DEPLOYMENT

PATH was able to borrow five iCone units from Caltrans District 4 maintenance staff, who deployed them at PATH's request at sites corresponding to several of the BHL dual-loop sites. The iCones were aimed at the oncoming traffic for one direction from roadside locations meant to allow simultaneous radar and loop observation of the traffic crossing the loops. iCone deployment sites were selected to allow safe access to Caltrans personnel without requiring a lane closure. The following images show the five iCone deployment locations. In these figures, the green dots indicate the location of the iCone, the red boxes indicate the location of the dual-loops, and the yellow squares indicate the location of the traffic count cabinets. The green dots were sized to cover all reported GPS locations from the iCones as a way to indicate variance of these values. Note that iCones were always deployed on the right side shoulder of the traveled lanes. Some variance is expected as the iCones were occasionally removed for maintenance and replaced, and there is variability in individual GPS reports for fixed locations. The figures were constructed using Google Earth's satellite images and GPS placement using the standard WGS-84 model.

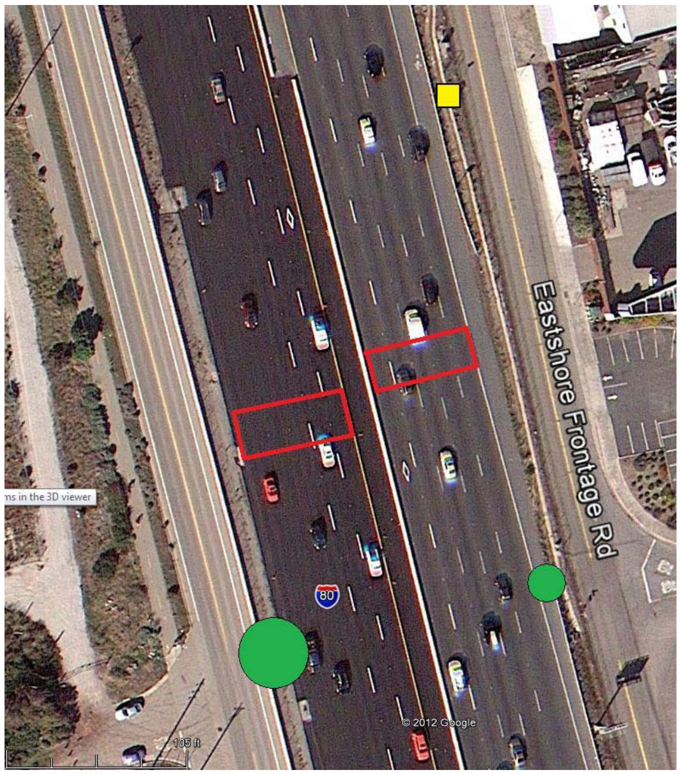

Figure 3: BHL Loop Station 1, Westbound (left) and Eastbound (right)

Two iCones were placed, one eastbound and one westbound, at BHL station 1, between the University Ave and Gilman St intersections with I-80. As the diagram illustrates, the iCone at Station 1 westbound location would detect cars just as they crossed the loop detectors. The iCone on the eastbound side would detect cars as they approached the loop detectors. The iCone on the westbound side was repositioned after recharging more frequently than the iCone on the eastbound side, giving its location a bit more variance.

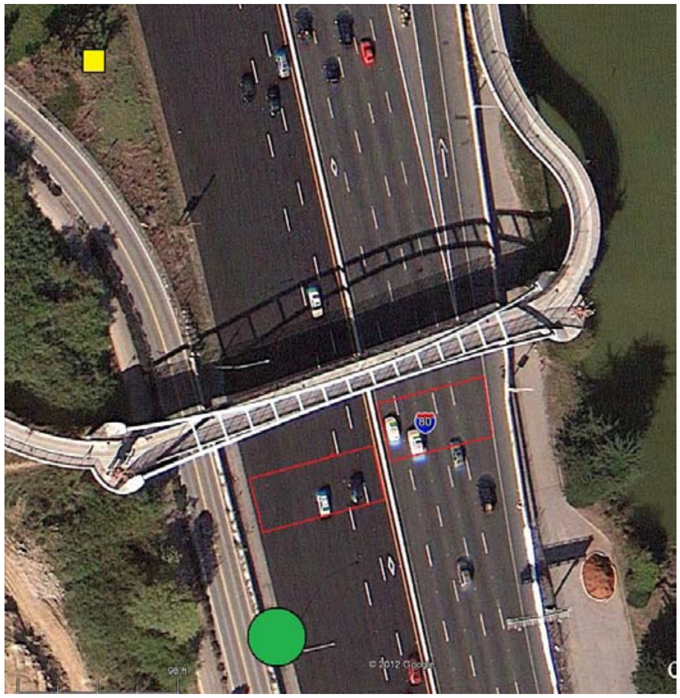

Figure 4: BHL Loop Station 3, Westbound

The iCone at BHL station 3 westbound also detected cars crossing the loop detectors, located just south of the University Ave pedestrian bridge over I-80.

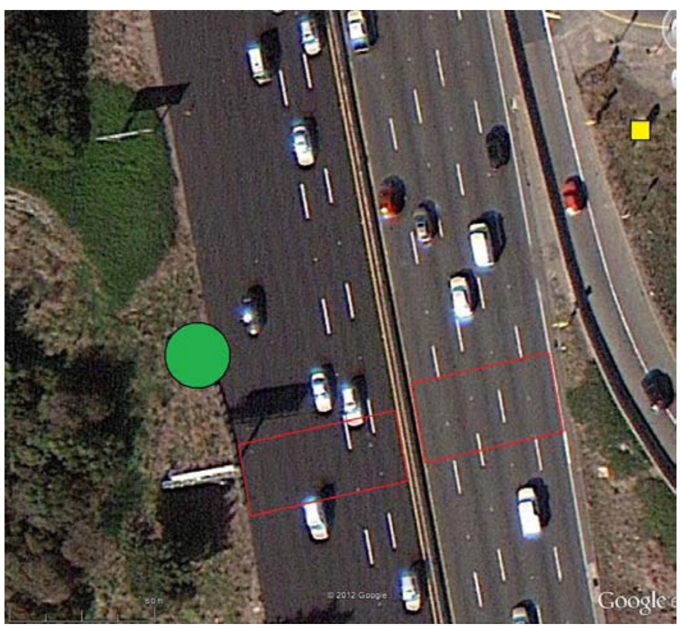

Figure 5: BHL Loop Station 6, Westbound

The iCone at BHL station 6 westbound detected cars just as they approached the loop detectors, located just north of the westbound Ashby Ave overpass.

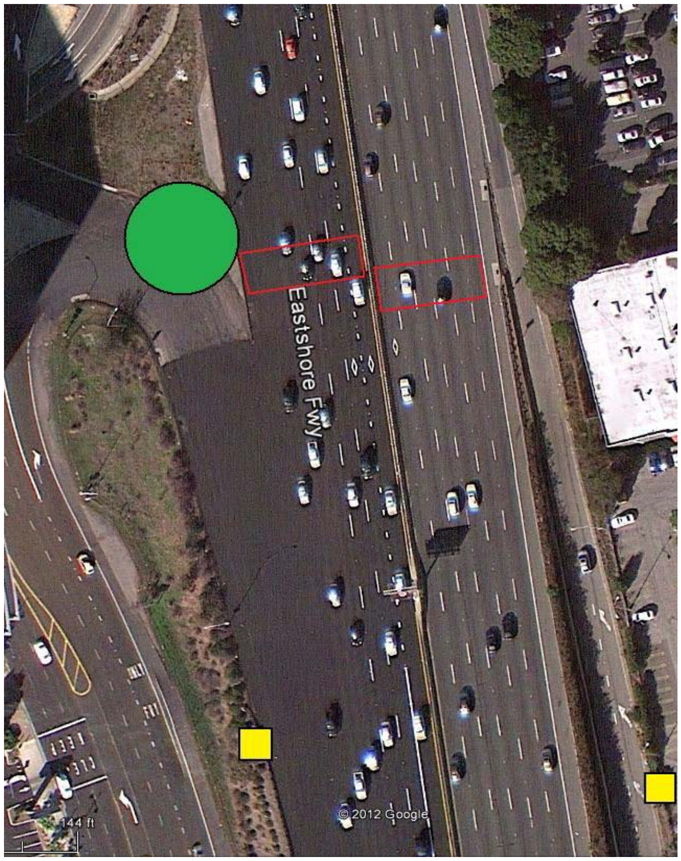

Figure 6: BHL Loop Station 8, Westbound

The fifth iCone was deployed at BHL station 8 westbound and detected cars as they just approached the loop detectors, located just north of the Powell Street underpass. This iCone was located in a merge area with traffic entering from Powell Street, and its location experienced more variance as it was repositioned and replaced between charging cycles.

4 DATA GATHERING AND SELECTION

Data was collected at the five sites outlined in section 3.1 between June 17 and August 22, 2012. Data from both loops and iCones was processed, compared, and matched. This resulted in up to eight weeks of matched data at each of the sites.

The data collection experienced a number of challenges and was ultimately discontinued as repaving was begun on the westbound lanes of I-80. Initial deployment of iCones in June placed two iCones, one at Station 1 westbound, one at Station 8 westbound. When data collection was increased to five iCones in July, iCones needed to be removed and replaced to recharge their batteries as they ran down. Short outages and minor changes in location have been taken into account in the analysis. Additionally, there was a cellular network blackout for the loop detector stations at the end of June that was corrected in the first week of July.

Data was selected for full analysis with several goals in mind. It needed to cover all sites under consideration for the same period, including both iCone and loop data. It needed to cover at least a full week, so traffic conditions on different days could be examined. Additionally, as the data was examined, it became clear that the loop reporting at station 8 did not report the lane 6, nearest to the iCone – the BHL loop system reports only lanes 1 through 5 in any direction. As will become clear in the discussion below, missing the lane nearest to the iCone was a significant factor when comparing the iCone speed values with the loop values. Therefore station 8 westbound is not considered further in this report.

Taking all these factors into account, this report analyzes data for the week of August 9th through 15th, 2011, considering four of the five sites where iCones were deployed: station 1 westbound, station 1 eastbound, station 3 westbound, and station 6 westbound.

4.1 COMPUTATION OF LOOP SPEED AVERAGES

A direct comparison between loop speed data and iCone speed data is not possible because the devices function and report data differently. The iCone reports average speeds over two minute periods with an observation count[1]. The loop detectors report the speed of every (or nearly every) vehicle that passes over the detectors as it happens. To reconcile this difference loop detector speeds were aggregated into two-minute periods designed to match the iCone values. Aggregation was done by collecting values for each individual lane or for all five lanes at a site.

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[1] This is not a count of all vehicles passing by, but a count of how many radar sweeps produced an acceptable target and speed reading. Note that iCones can be used to count vehicles, but this study did not deploy them in that manner and is not intended to test or analyze that functionality.

Analyses were made by lane and across all lanes comparing the time-matched two-minute average values at each station for the iCone and loops.

The aggregation of loop data into two-minute periods was done with a simple arithmetic mean that added all speeds found by a given lane's loop detectors in that period and divided by the number of speed values. A speed value was counted in the two-minute window if the vehicle started crossing the downstream loop in a loop pair in the period. Thus a speed observation for a vehicle that started crossing the upstream loop in one time period but didn't start crossing the downstream loop until a later period was counted in the later period.

5 COMPARISON AND ANALYSIS

As explained in section 4, the analysis of the iCone and loop data focuses on four deployment sites for the week of August 9th-15th, 2011. For each two-minute period, iCones reported an average speed and a count. Comparable statistics were then computed for the loop detectors, finding two-minute average speed and count information by lane and across all lanes.

The goal of the analysis is to see how the iCone values and the computed loop values compare, with the assumption that the computed loop values represent data as close to ground-truth as possible. The analysis focuses on the signed average error of the iCone and loop values to give an idea of how the iCone performs for speed observation in a multi-lane freeway setting.

Computing the signed average error requires selecting a statistically significant number of individual error calculations to derive the average error. Individual error values for each two-minute window are the simple difference between the iCone speed value and the loop speed value – calculated by subtracting the iCone speed value from the loop speed value. These individual error values are analyzed in 48 30-minute periods across each day (e.g., from 3:30-3:59 AM). For each 30-minue period, the error values for the 15 two-minute periods are analyzed statistically for average, variance, etc. The report focuses mainly on the average error. While many of the plots that follow look at the average error values, additional analysis is done looking at traffic conditions, and looking at the speed and count values by themselves.

5.1 CLASSIFICATION BY TRAFFIC CONDITION

The analysis by traffic condition seeks to determine how the iCone and loop values differ based on three classifications: “Free-flow”, “Normal”, and “Congested”. These are indicated in the plots by different colored circles. Each of these circles corresponds to the classification of a single 30-minute period. When examining these plots, keep in mind that the 30 minute periods were classified based on count and speed criteria as follows:

For a given day’s data for a given scope (single lane, or all lanes at a single site), a count of all vehicles that crossed the loop detectors was pre-computed for each two-minute period. Average counts were generated for each 30-minute period in a day by averaging the pre-computed counts for the 15 two-minute periods in that 30 minutes. The maximum value of these 30-minute averages was considered the “daily maximum”. Then each 30-minute average value was compared to one third of that daily maximum to determine if the 30-minute period was low-volume or not.

For speed, each two-minute period for a scope (single-lane or all-lanes) had pre-computed average speed values from the iCone and the loop detectors. For each 30-minute period, the 15 two-minute speed values were averaged for the iCone as well as the loop detectors. These two averages were then averaged to get the average speed for the 30-minute period. If that average speed was greater than 50 mph, the period was considered to be high-speed.

Taken together, if a period was not high-speed, it was labeled "Congested". Otherwise, if it was high-speed and not low-volume, it was labeled "Normal". Finally, if the period was high-speed and low-volume, it was labeled "Free-flow".

5.2 ICONE VS LOOP SPEED PLOTS

These plots show how the iCone speed value compared to the loop speed values at the same time of day for a sample day at a sample station. The first plot shows the loop speed across all lanes compared to the iCone. The next five show the loop speed in individual lanes compared to the iCone speeds.

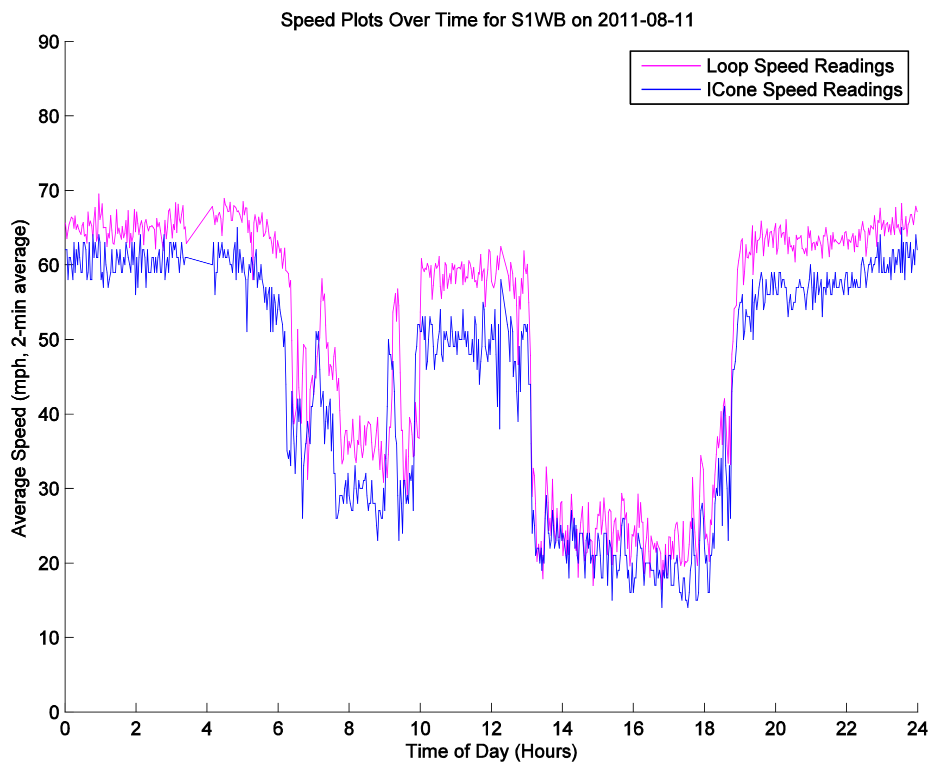

Figure 7: All lanes Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

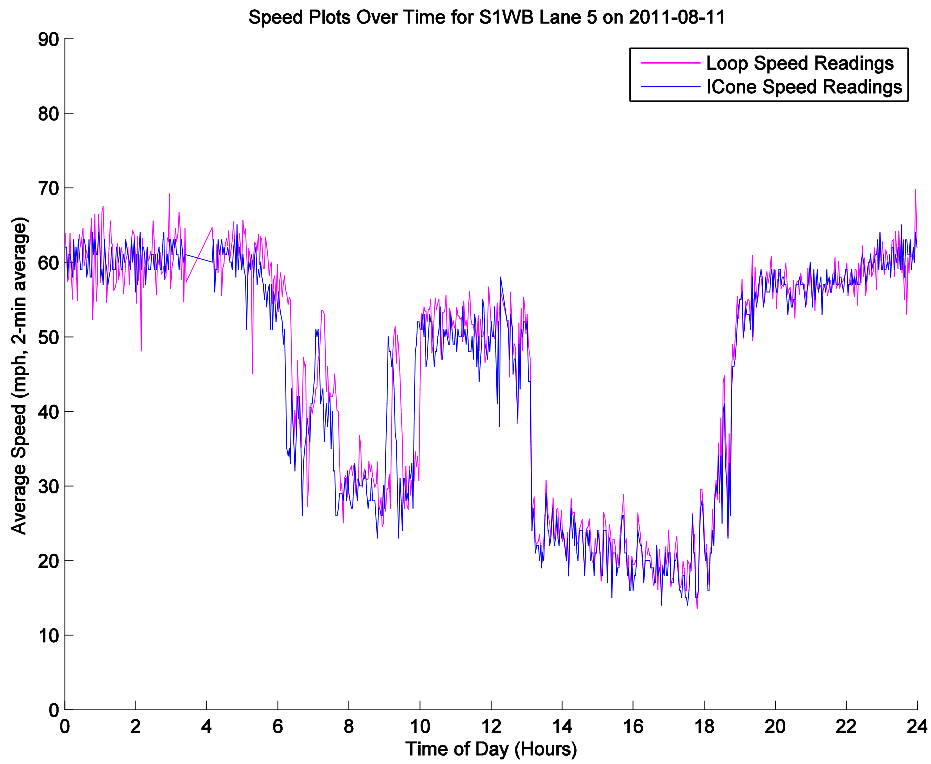

Figure 8: Lane 5 Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

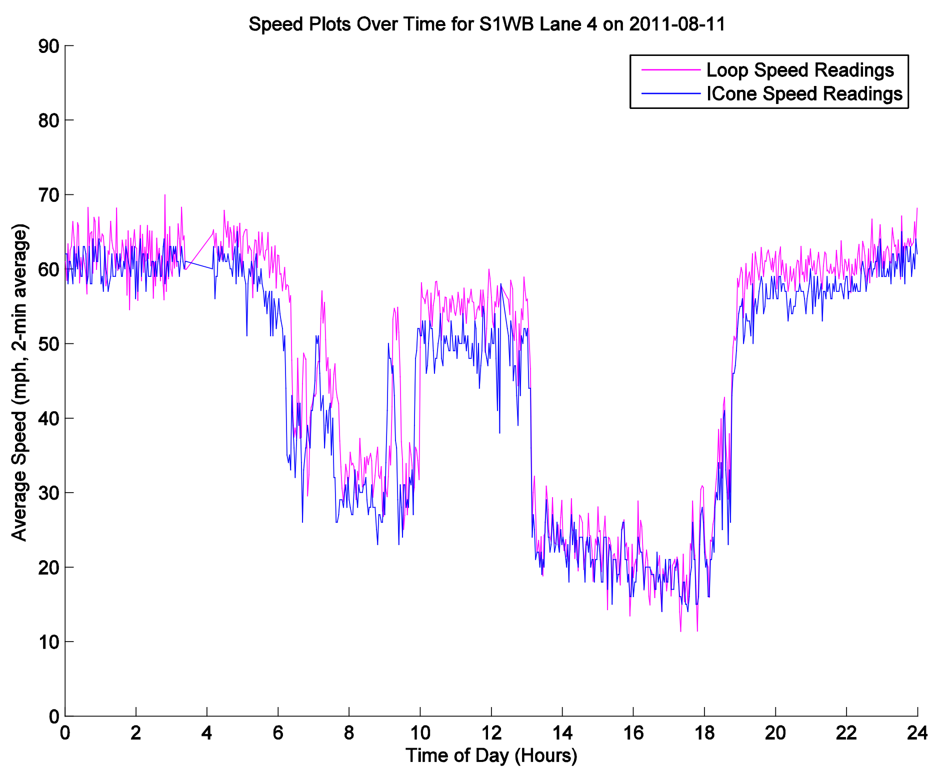

Figure 9: Lane 4 Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

Figure 10: Lane 3 Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

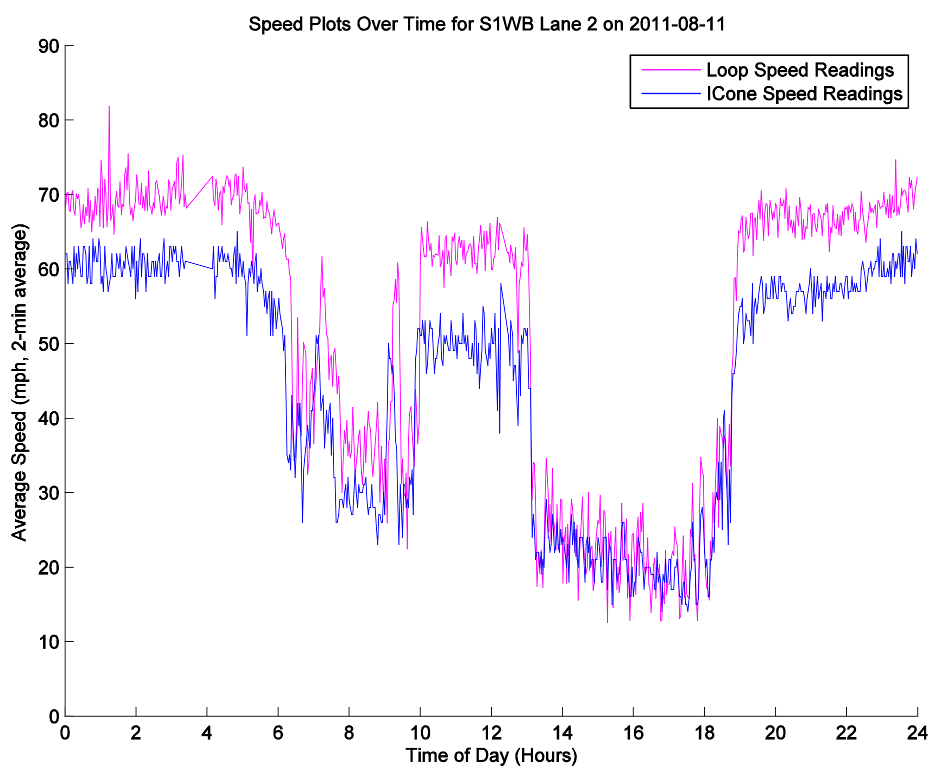

Figure 11: Lane 2 Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

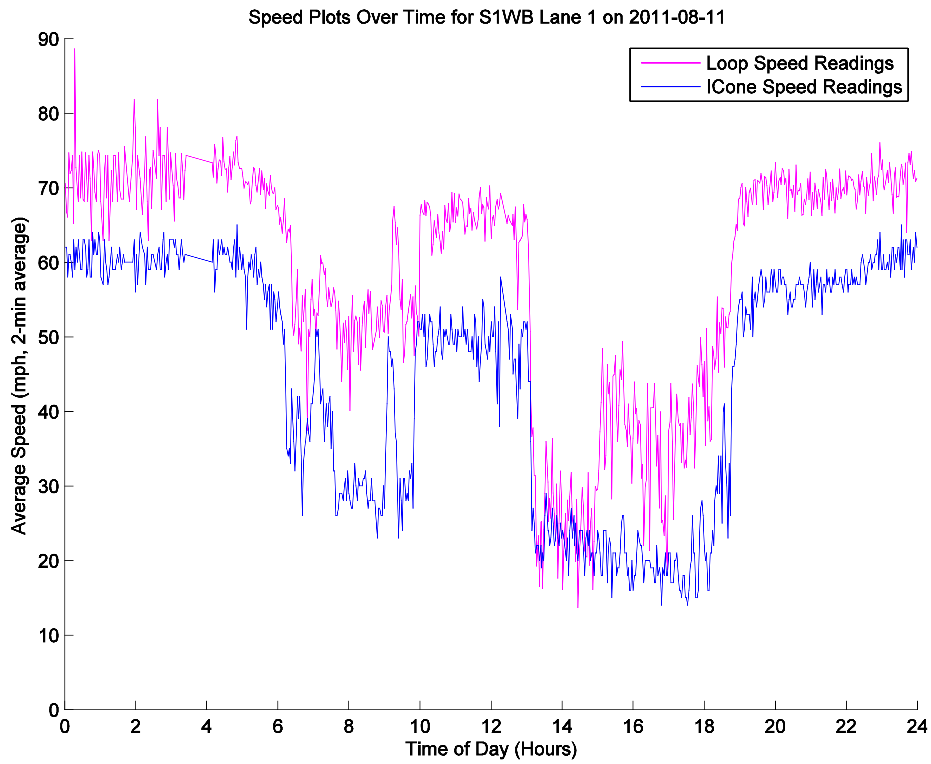

Figure 12: Lane 1 Loop speed vs iCone speed at Station 1 westbound, Aug 11, 2011

These plots are of the two-minute iCone and loop speed values, either by lane or by site. The X-axis is time of day starting at midnight, the Y-axis is speed in miles/hour. The blue line is iCone data and the purple line is loop data. These plots are for station 1 westbound for the date Thursday Aug 11, 2011, but are consistent with the values at the other three analyzed sites and for all dates. It is apparent from this sequence of plots that the further you move from the right-hand side of the roadway, where the iCone was deployed, the greater the difference of the speed values. There are small gaps in the plots around 4 AM when no data was received due to BHL loop system maintenance.

5.3 ICONE VS LOOP SPEED ERROR PLOTS

While the speed plots are suggestive of the divergence of iCone speed values from loop speed values as the number of lanes between the iCone and loops increases, the divergence can be seen more dramatically using plots of the average error. What follows are a series of plots of the average error as described at the beginning of section 5.

These plots aggregate the speed values and calculate the average error across 30-minute periods. Data for all seven days is included, with each circle representing the average error for a single time period on a single day – and either for a single lane or for all lanes at the site. Color coding represents which condition the values for the period represent – blue for "Congested", red for "Normal", or green for "Free-flow" as described in section 5.1. As values for a full week are plotted together, there are as many as seven individual circles for each time period. The X-axis is time of day starting at midnight and the Y-axis is average error for the 30-minute period in miles/hour. Note that average error can be both positive and negative. In this analysis, a positive error indicates that the iCone reported a *slower* speed than the loop detectors. This first series of plots focuses on station 1 westbound for comparison with the speed plots in section 5.2. The first plot shows the difference between the iCone and an all-lanes loop speed and could be compared with Figure 7. The subsequent five plots break out the error value by lane.

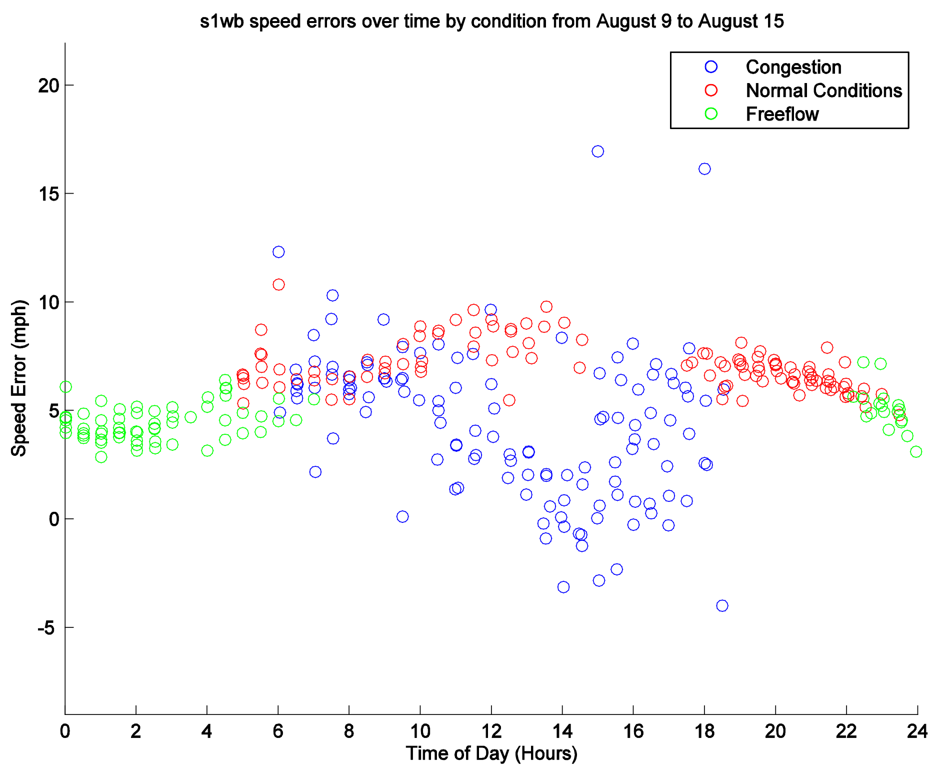

Figure 13: All Lanes, Full-week average error values by time and condition at Station 1 westbound

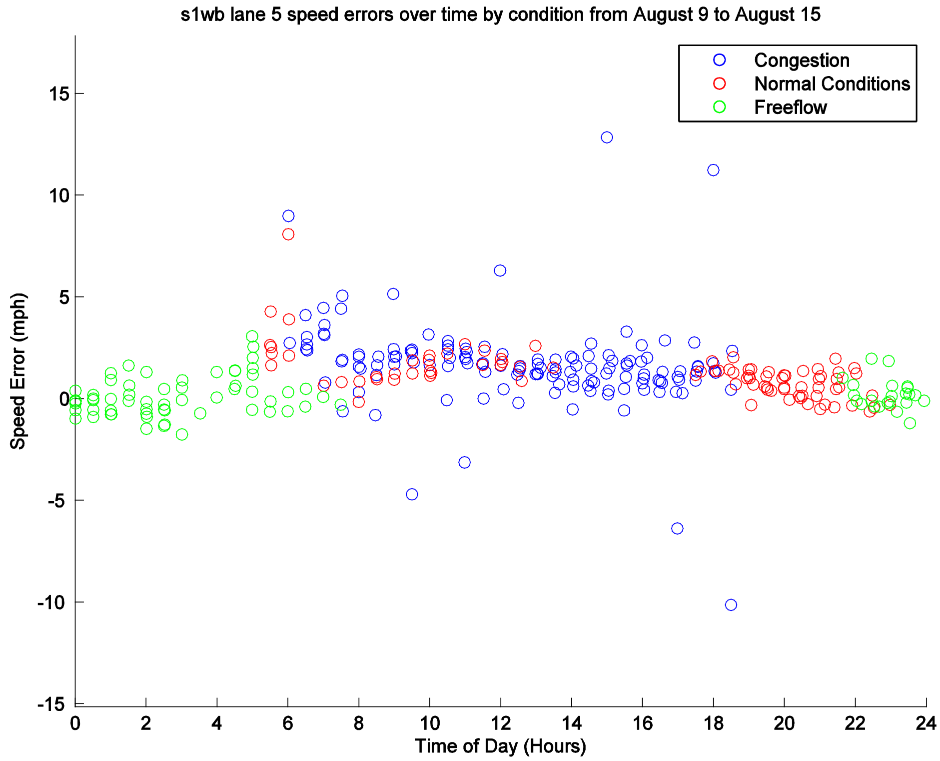

Figure 14: Lane 5, Full-week average error values by time and condition at Station 1 westbound

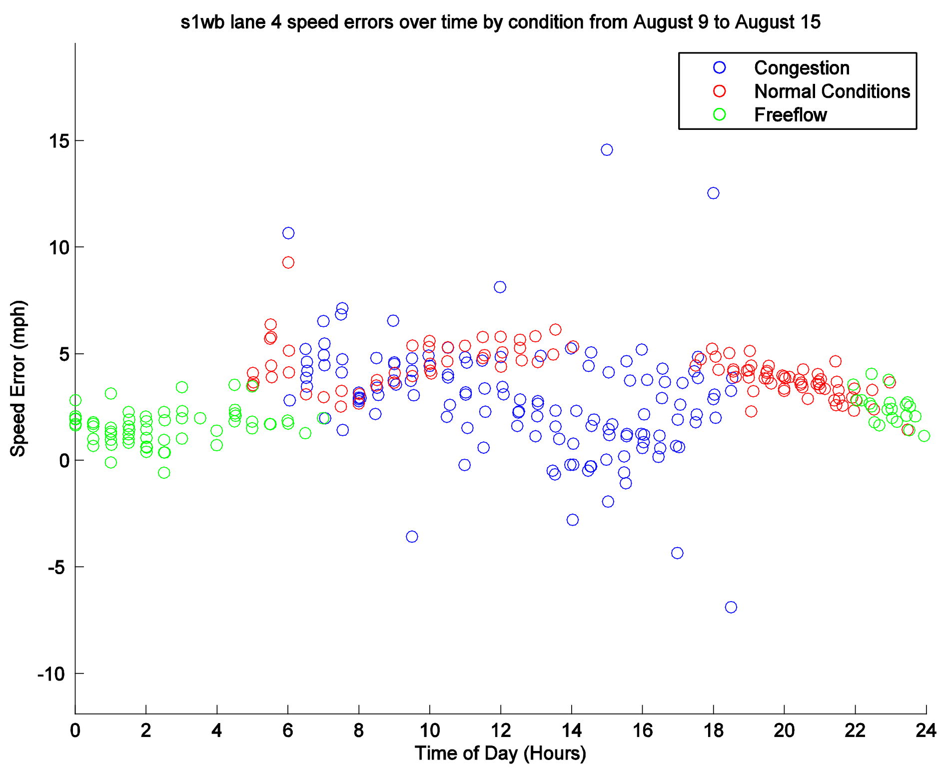

Figure 15: Lane 4, Full-week average error values by time and condition at Station 1 westbound

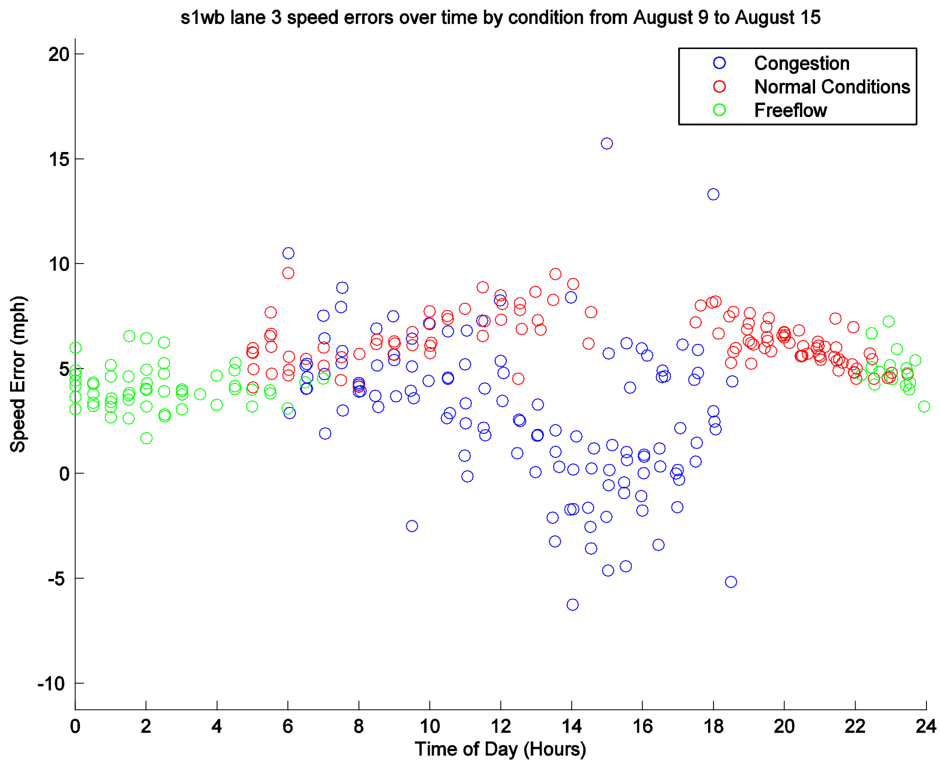

Figure 16: Lane 3, Full-week average error values by time and condition at Station 1 westbound

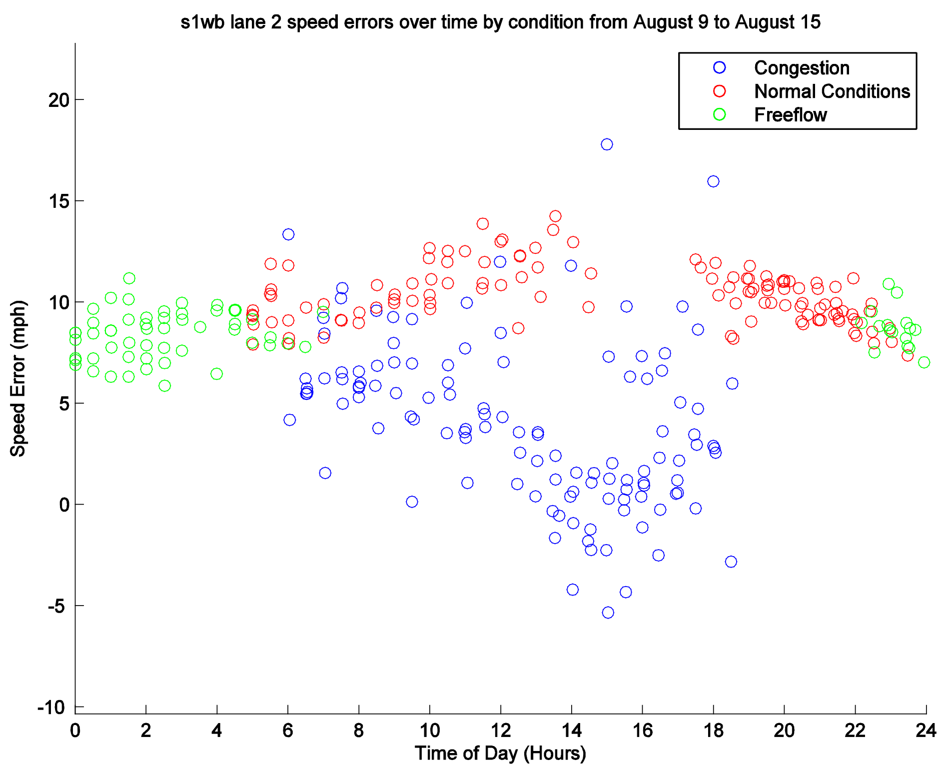

Figure 17: Lane 2, Full-week average error values by time and condition at Station 1 westbound

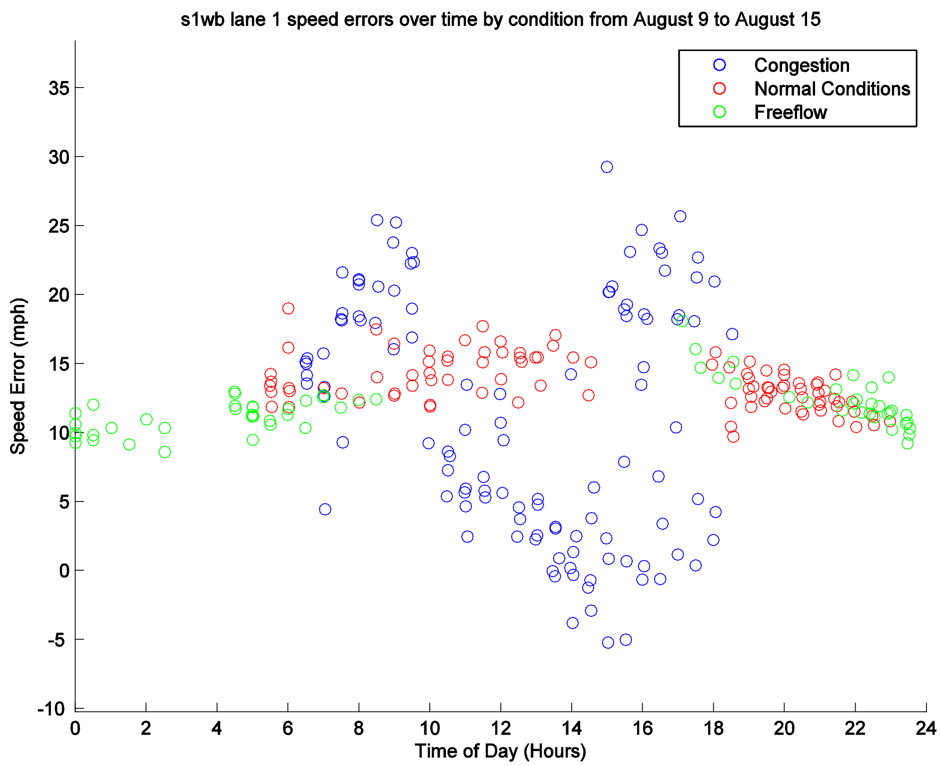

Figure 18: Lane 1, Full-week average error values by time and condition at Station 1 westbound

As was observed with the speed plots in Section 5.2, the average speed error across condition and day was significantly lower (near 0 mph) in the lane furthest to the right (lane 5), closest to the iCone. Average error ranged from 10 to 15 mph between the iCone and the left lane (lane 1), except during mid-day congestion. During mid-day congestion, speeds in all lanes are lower as well as more similar (see the plots in Section 5.2). This means that speeds in the "slow" lanes, as reported by loops or iCones are more likely to match the speeds in the "fast" lanes.

Similar plots are available for each of the other stations, but a set of plots for the by-lane average error for all four stations follows and provides further support for the observation that an iCone tends to report average speeds most accurately for the lane closest to it. In these plots, single circles represent the same 30-minute average error as in the plots by station, but values for all four stations are plotted together on a single graph.

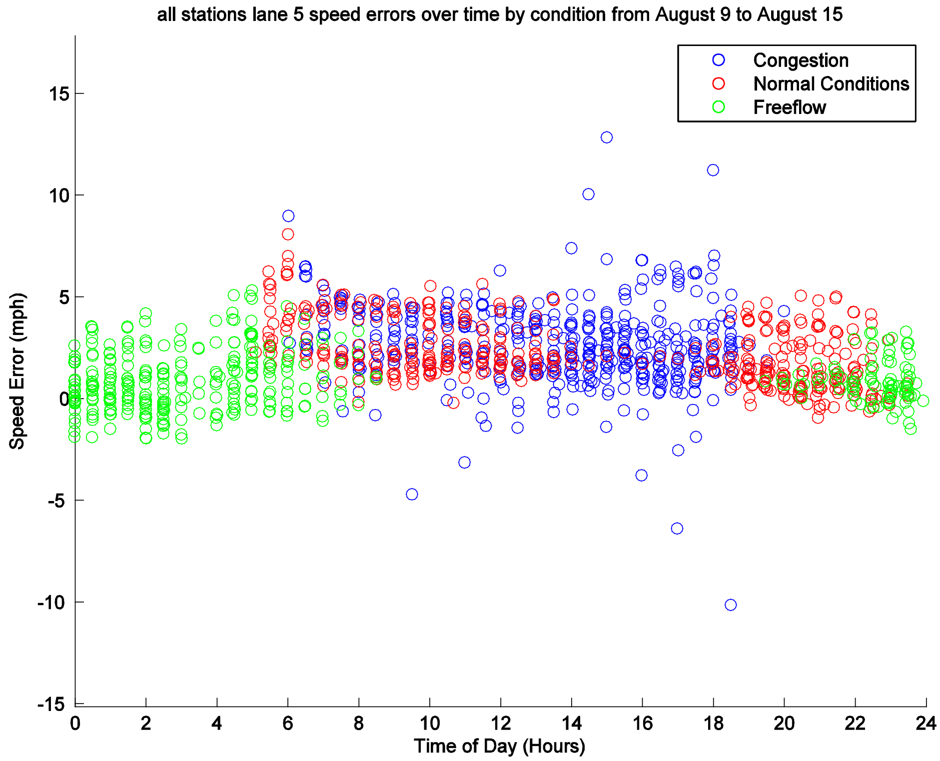

Figure 19: Lane 5, Full-week average error values by time and condition at all stations

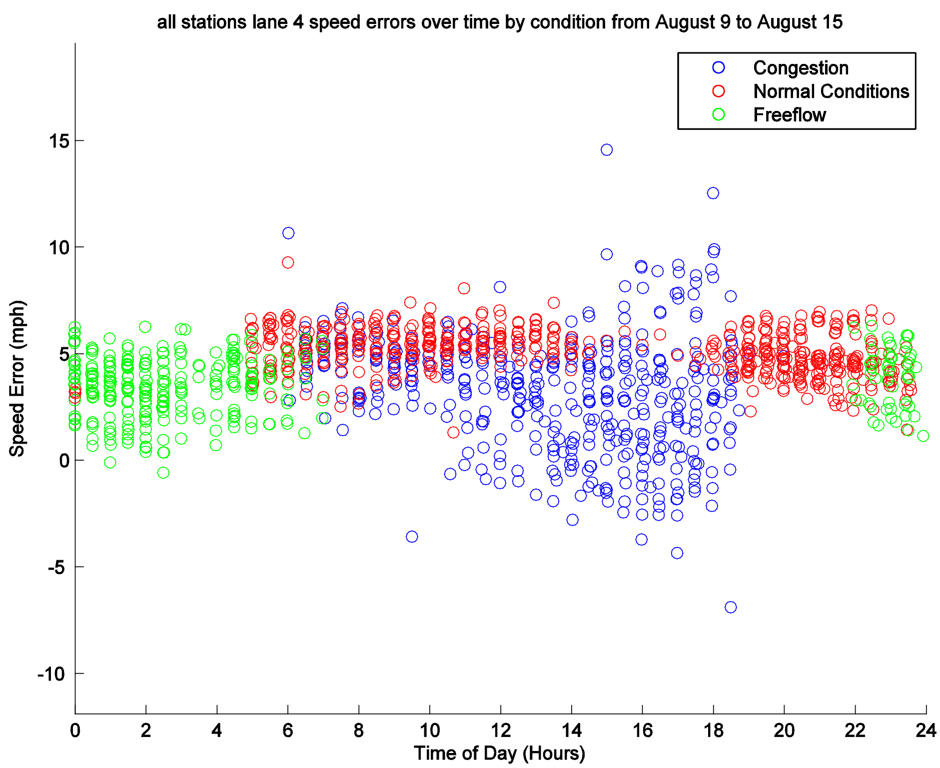

Figure 20: Lane 4, Full-week average error values by time and condition at all stations

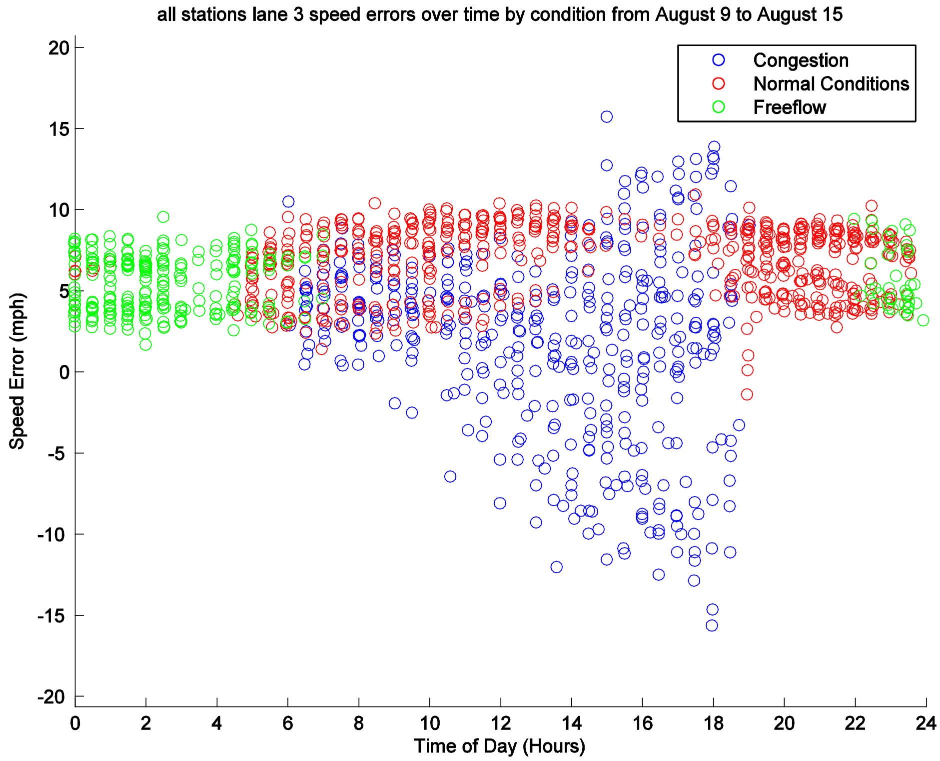

Figure 21: Lane 3, Full-week average error values by time and condition at all stations

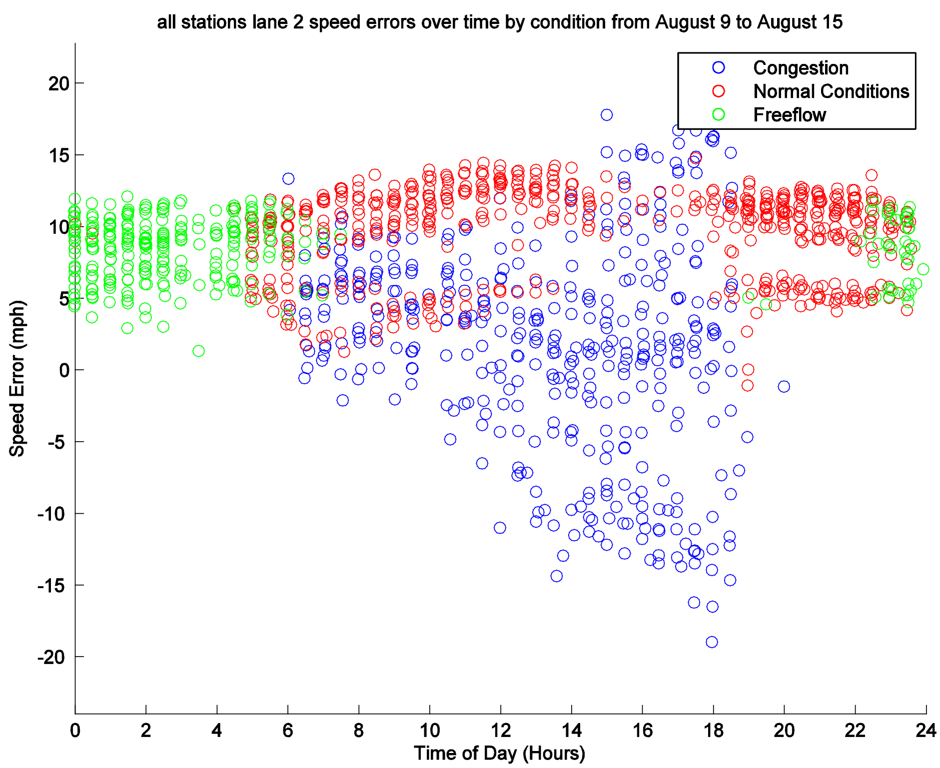

Figure 22: Lane 2, Full-week average error values by time and condition at all stations

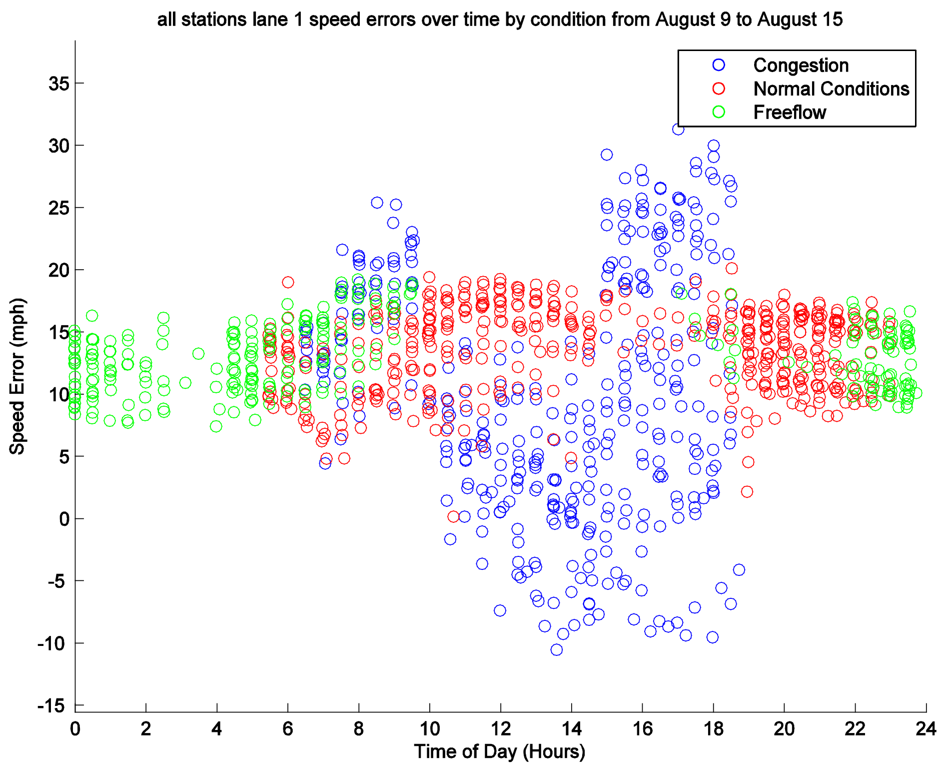

Figure 23: Lane 1, Full-week average error values by time and condition at all stations

5.4 ICONE AND LOOP VEHICLE COUNT PLOTS

The differences between iCone and loop speed values by lane is well demonstrated by the data, but speed is not the only value that an iCone produces. It also provides a count of individual vehicle speed observations that its firmware uses to produce the two-minute average speeds (this is different than iCone's results when configured to collect "count" data). It should be noted that the iCone is not attempting to detect every vehicle when deployed in "speed" mode – it picks one "good" value for every radar sweep of its field of view. As configured in these tests the iCones could have up to 48 such sweeps in every two-minute period, so the maximum number of detections in any two-minute window is 48. Further, not every radar sweep produces a "good" reading – some are excluded because the radar data is too noisy.

This count does not react to fluctuations in traffic volume in the way that might be expected. What follows are a series of daily comparisons of count values in two-minute periods as reported by the iCone and the loop detectors at Station 1 westbound. These plots provide two-minute loop count values in purple (with the scale to the left) plotted with two-minute iCone count values in blue (with the scale on the right). While the loop counts vary dramatically between different times of day, the iCone's counts do not vary nearly so much. There are several cases where the iCone's count drops significantly during periods of high volume. This may be an indication that congestion produces noisier radar data, making it more difficult for the iCone to select a "good" reading in a given two-minute period.

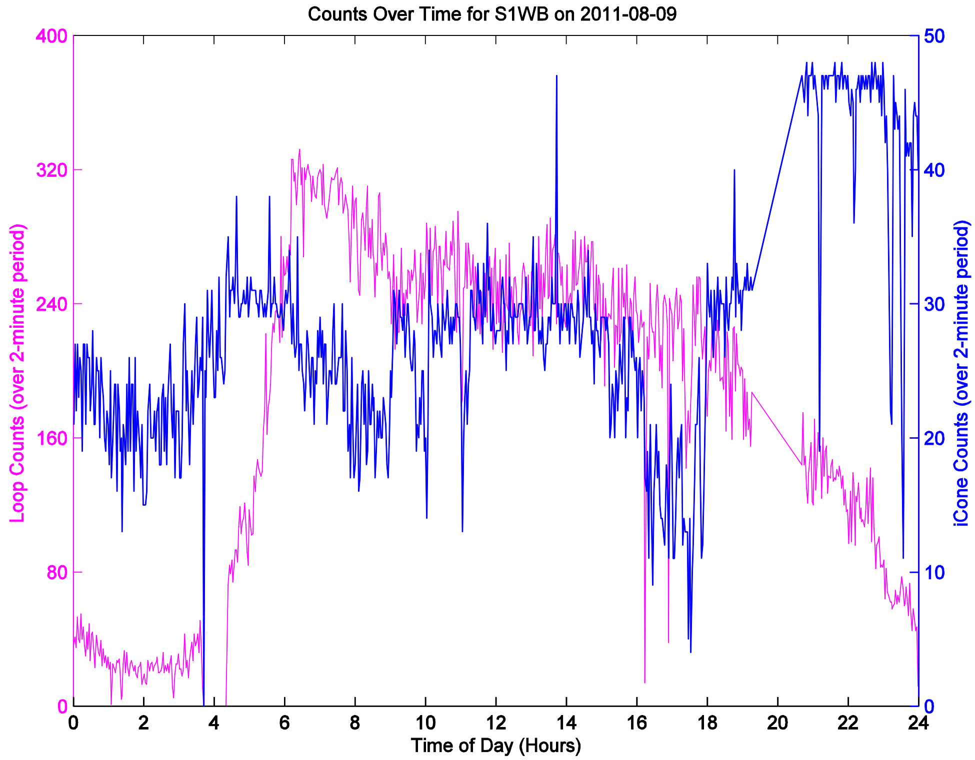

Figure 24: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 9, 2011

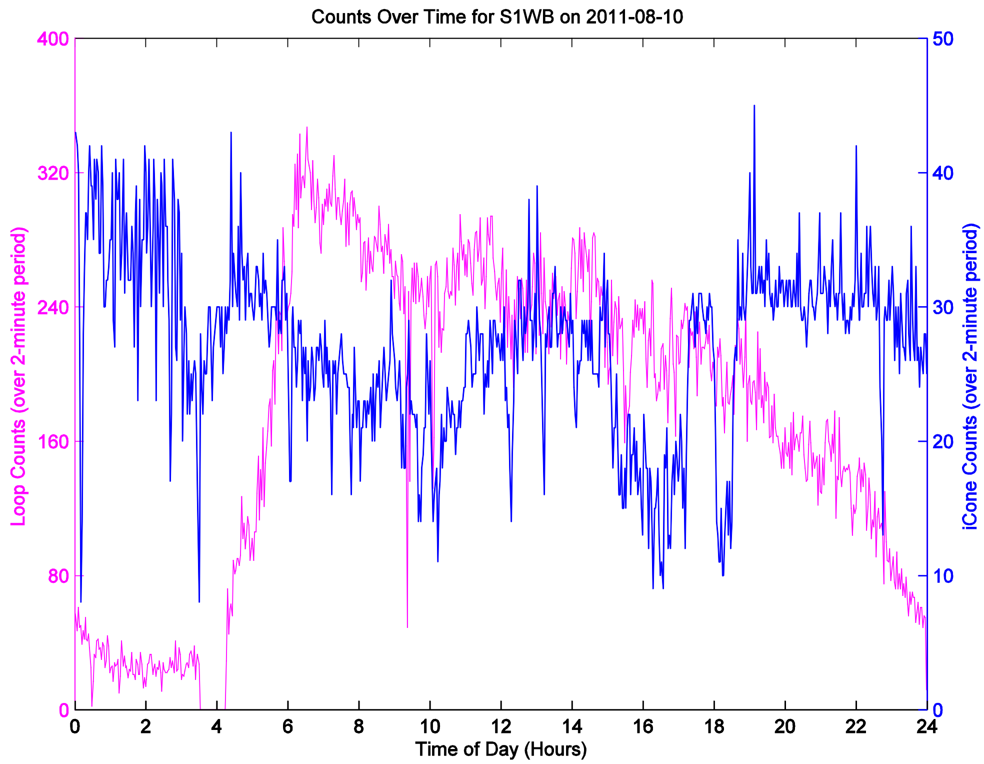

Figure 25: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 10, 2011

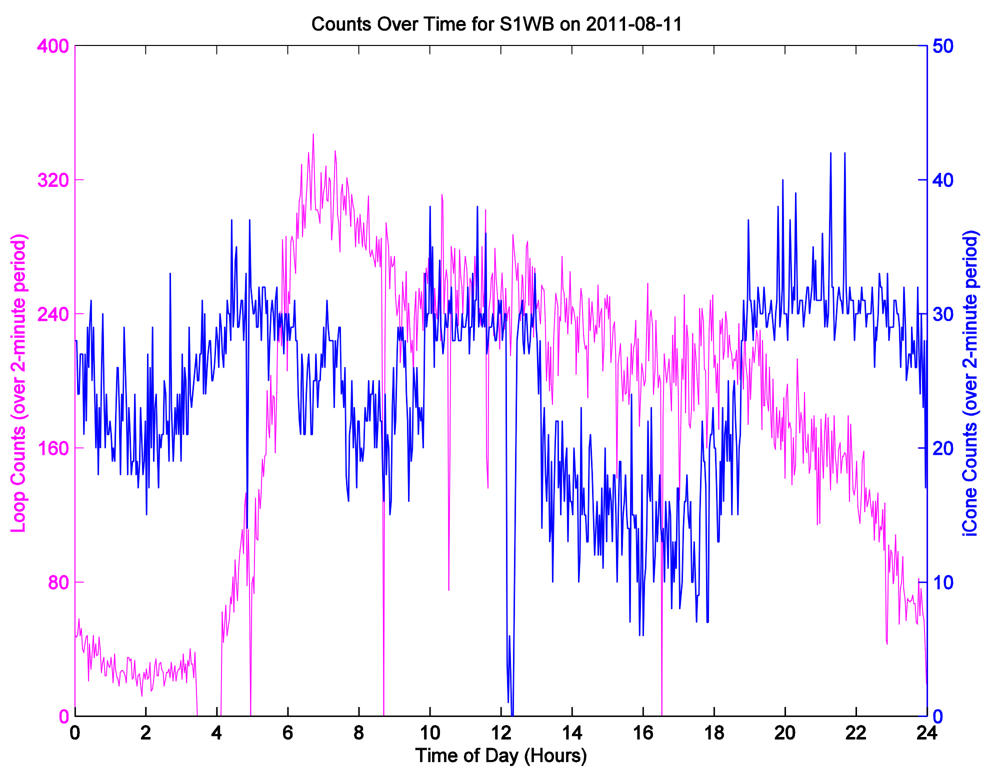

Figure 26: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 11, 2011

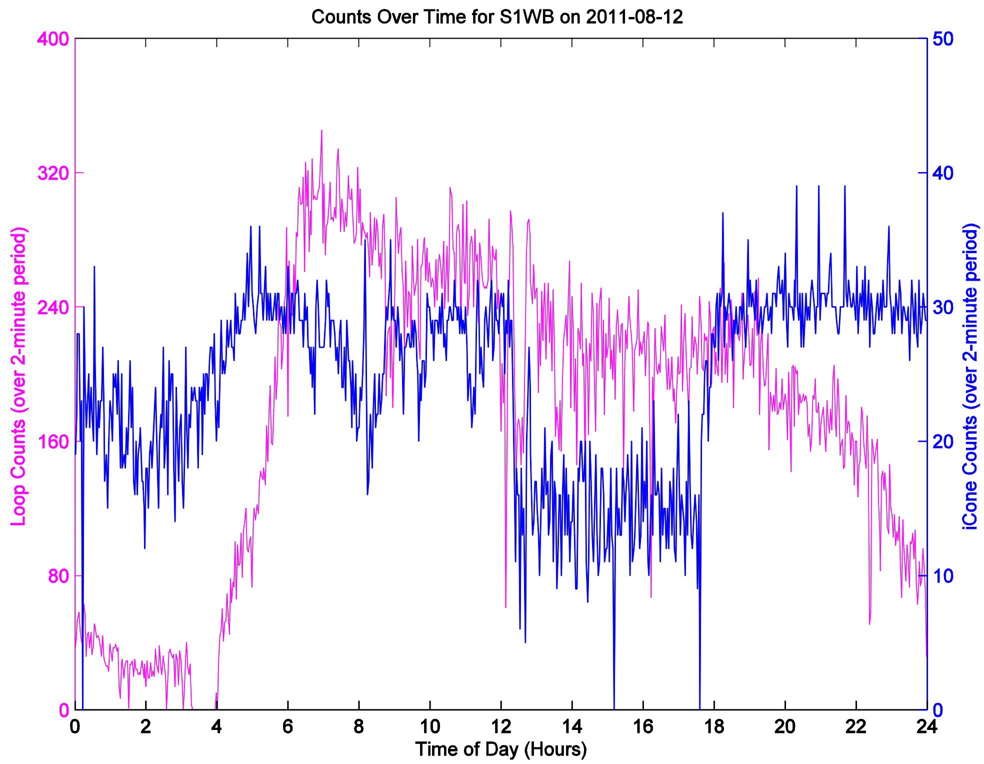

Figure 27: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 12, 2011

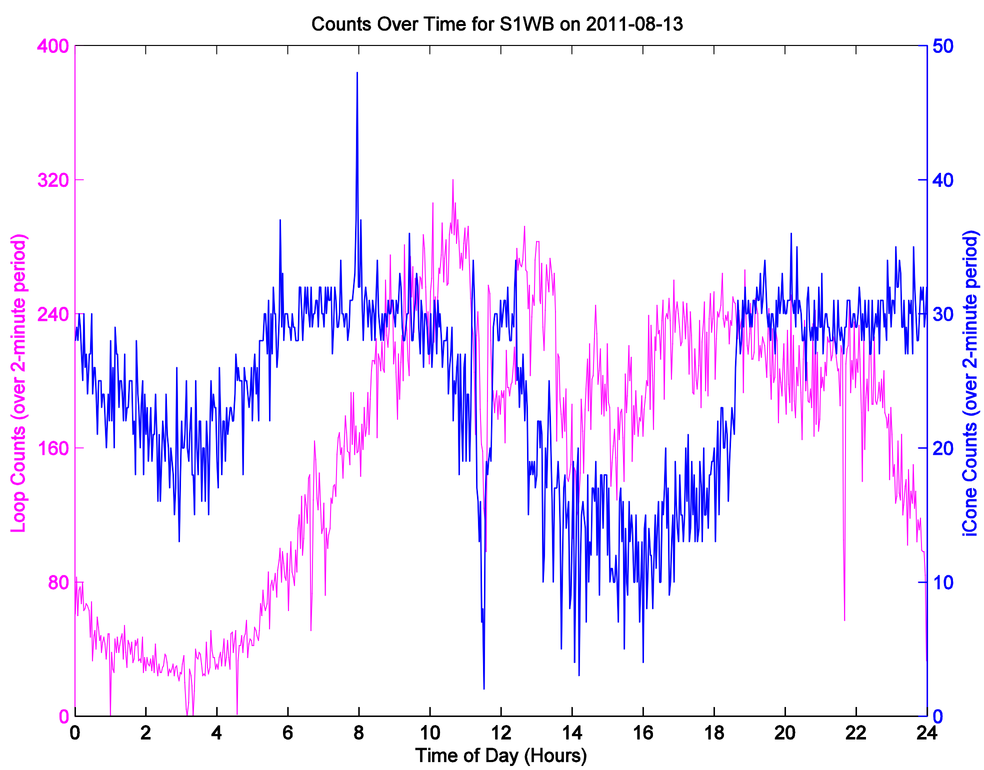

Figure 28: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 13, 2011

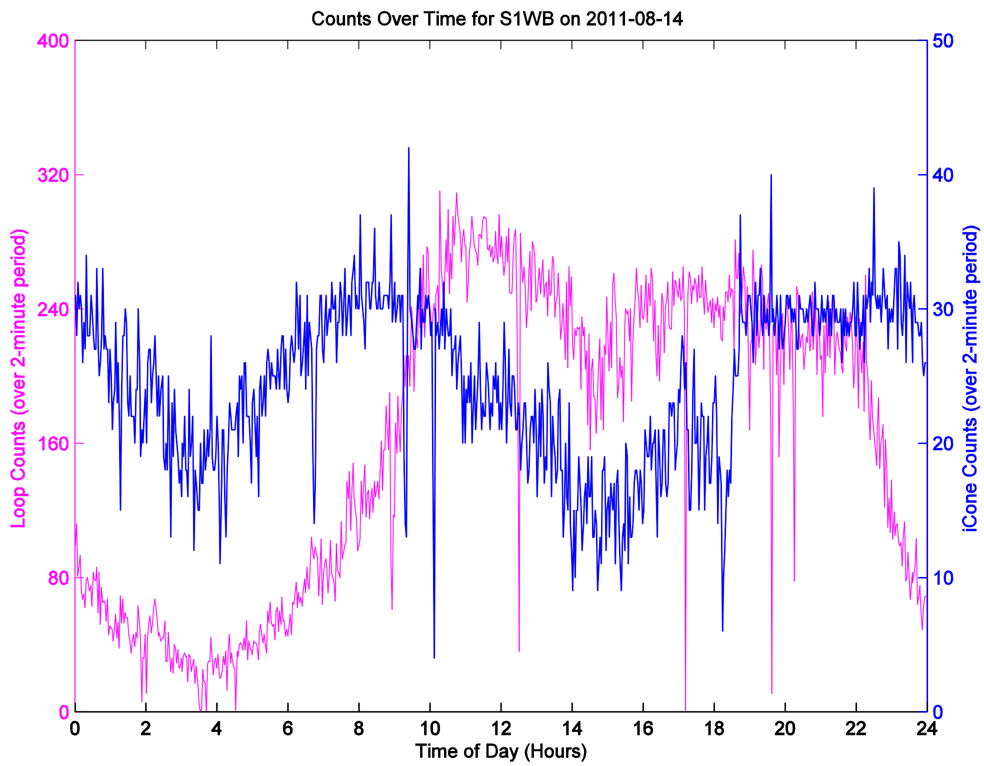

Figure 29: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 14, 2011

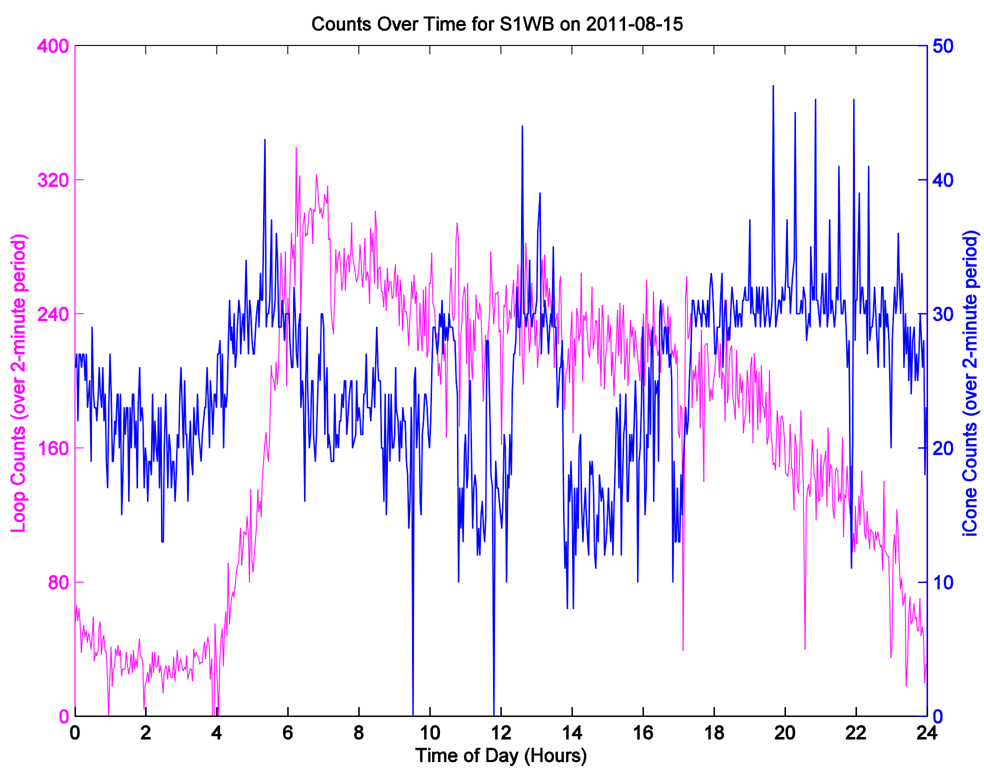

Figure 30: All lanes Station 1 westbound iCone vs loop 2 minute counts Aug 15, 2011

6 CONCLUSIONS

This report presents and discusses a deployment of several iCone portable traffic monitoring units along the Berkeley Highway Lab (BHL) Testbed along I-80 in Berkeley and Emeryville, CA. The sections of highway where the testing was performed are five or six lanes wide and frequently heavily congested. ICone units were deployed for about two months between June and August, 2011 and sent average speed readings every two minutes. Matching data from the BHL dual-loop detectors was used to find comparable ground-truth speed values, and a detailed analysis was performed on data for the week of August 9-15.

Section 5 provides plots for speed and count data provided by both the BHL loop detectors and iCones placed at the same sites, illustrating the iCone's performance. The discussion of these plots notes some of the differences between the characteristics of the detectors, and notes some of the main divergences in the data. On the whole, however, the iCone radar systems do a very good job of measuring traffic speed in nearby lanes. If you look at Figure 8, you will see that the moment-by-moment speed averages from the iCone very closely match values from loop detectors in the nearest lane at BHL station 1 westbound. Figures 14 and 19 display the average error between the loop detectors in the nearest lane at that site and all sites for a full week – and both show very small values across a range of traffic conditions.

While the nearby lane is very well represented by the iCone speed values, the values diverge more significantly in lanes further from the iCone. As shown by Figures 12, 18, and 23, the speed error in the lane furthest from the iCone in the BHL testbed averaged about 15 mph – generally this was lane 1 (furthest to the left), where traffic travels faster than lane 5 (furthest to the right). It is clear that the iCone had a better view of the "slow" lane than the "fast" lane consistently across the four deployment sites analyzed. The best explanation of this result comes from the iCone selecting representative targets on each sweep of its radar – it is likely that the iCones selected most of its "best" targets from the nearest lane – so that this lane is more frequently represented than any other. With many lanes of traffic, vehicles in the near lanes will block the radar's view of the further lanes as the radar is about three to four feet above the road surface in the traffic barrel.

Given the "speed" mode of deployment of the iCones used in this comparison, it is clear that the count values that the iCone provides are not representative of the traffic volume, nor are they meant to be[2]. They do provide perspective regarding the statistical basis of each two-minute speed value the iCone produced, but are not a measure of traffic volume. In fact, it appears that the count values may be less in congested traffic conditions.

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[2] As noted before, iCone units also have a "count" mode of deployment where they are designed to count passing vehicles. The units are not aimed in the same manner in this mode as for speed monitoring, so this study can't address how they perform in "count" mode.