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16. Abstract

The purpose of the augmented Speed Enforcement (aSE) project was to detect and warn speeding vehicles in a work zone and provide warnings to work zone workers. The system developed by Montana State University consists of 28 orange traffic drums (called smart drums or sDrums) that were positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, it synchronously flashes the orange lights on top of the drums, warning the driver to slow down and the workers of a speeding vehicle. If the vehicle speed is above a set trigger speed, the system activates a pager system that warns the workers of the speeding vehicle. The results of the project are a system of 30+ smart traffic drums, the system was tested for four weeks on SR 152 near Los Banos, CA. This report presents an evaluation of speed data collected during the Los Banos pilot test to assess the performance of the WTI system.

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aSE Speed Data Evaluation for the Western Transportation Institute System

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U.S. Department of Transportation

Research and Innovative Technology Administration

Final Report

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EXECUTIVE SUMMARY

The purpose of this project, augmented Speed Enforcement (aSE), was to detect and warn speeding vehicles in a work zone as well as providing warnings to work zone workers. The project consisted of two systems, one provided by California PATH at UC Berkeley and the other developed by the Western Transportation Institute (WTI) of Montana State University. Either can be deployed independently or they can be deployed together.

The aSE system consists of two systems developed by two research teams with both systems operating in the same work zone. One system developed by California PATH at UC Berkeley has a camera with built in radar to detect and photograph the license plates of speeding vehicles. Upon detecting a speeding vehicle the vehicle's license number and speed are recorded and displayed on a changeable message sign. The same data is transmitted to the Maintenance Zone Enhanced Enforcement Program (MAZEEP) California Highway Patrol (CHP) officer located in the work zone. The MAZEEP will use the patrol car's radar system to verify the vehicle speed and determine whether or not to issue a citation.

The second system was developed by WTI. It consists of 28 orange traffic drums that are positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, it flashes the orange lights on top of the drums, warning the driver to slow down and the workers of a speeding vehicle. Also, if the vehicle speed is above a pager set speed, the system triggers a pager system that warns the workers and MAZEEP of the speeding vehicle. The WTI system was dubbed the smart drum (sDrum) system.

With the assistance of the California Department of Transportation (Caltrans), the systems were deployed for eight weeks near Los Banos, CA on SR 152 to evaluate the effectiveness and deployability of the aSE system.

The aSE system was planned to be evaluated by an independent party but due to contractual issues that did not occur. WTI was asked to do an evaluation and this document details that evaluation using speed data from the iCones and WTI sDrums.

An evaluation of the average speed as well as the number of speed reads greater than or equal to 60 mph for iCone is documented in this report. Pairs of iCones were evaluated for each week of deployment to determine if the percentage of speed reads greater than or equal to 60 mph dropped or increased as the vehicle traveled through the work zone. These percentages were also compared at individual iCone locations for times in which the systems were present versus the baseline consisting of neither system (cone delineated maintenance work zone closure, but no technologies present).

Where differences in the percentages are statistically significant and in portions of the work zone impacted by both systems, the general indication is that the configurations consisting of both systems, the PATH system alone, and the WTI system alone all showed improvement, demonstrated by reduced percentages of speeds 60 mph or greater over the baseline. This is what would be expected. However, there are also statistically significant differences in the percentages at locations preceding the systems, which indicate that other factors should be considered and engineering judgment should be applied in order to make valid comparisons and conclusions, and decisions about prospects for further deployment.

1. INTRODUCTION

Speeding is a primary factor contributing to major injury and fatality crashes in rural area highway work zones. Automated Speed Enforcement (ASE) detects speed violators and automatically processes speeding citations, but there can be legal barriers for some jurisdictions to implement ASE. Augmented Speed Enforcement (aSE), which is based on similar technologies, utilizes the information about detected violators to notify an onsite CHP officer to manually identify and stop the speeder. The development of aSE was conducted with funding from the Research and Innovative Technology Administration (RITA) in the United States Department of Transportation.

The aSE system consists of two systems developed by two research teams with both systems operating in the same work zone. One system developed by California PATH at UC Berkeley has a camera with built in radar to detect and photograph the license plates of speeding vehicles. Upon detecting a speeding vehicle the vehicle's license number and speed are recorded and displayed on a changeable message sign. The same data is transmitted to MAZEEP located in the work zone. The MAZEEP will use the patrol car's radar system to verify the vehicle speed and determine whether or not to issue a citation.

The second system was developed by the Western Transportation Institute (WTI) of Montana State University. It consists of 28 orange traffic drums that are positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, it flashes the orange lights on top of the drums, warning the driver to slow down and the workers of a speeding vehicle. Also, if the vehicle speed is above a pager set speed, the system triggers a pager system that warns the workers and MAZEEP of the speeding vehicle. The WTI system was dubbed the smart drum (sDrum) system.

The aSE systems were deployed on California SR-152 east of Los Banos, CA. The speed limit on SR-152 is 65 mph which was reduced to 55 mph in the work zone. The PATH system was configured to display speeds of 56 mph and above. The sDrum system lights were configured to flash for speeds of 60 mph and above and pages for speeds of 75 mph and above.

To evaluate the aSE system performance iCones were deployed along with the aSE systems. See Figure 1. The six iCones were furnished by Caltrans and deployed for eight weeks by PATH and Caltrans maintenance personnel. The eight weeks consisted of one week intervals where an individual system, both systems or neither system was deployed and extended from May 14th through July 13th, 2012. Each iCone collected speed data that was transmitted back to the manufacturer's iCone servers along with the cones GPS coordinates. That data was made available to the project teams by the manufacturer.

The aSE system was planned to be evaluated by an independent party but due to contractual issues the contractor was unable to complete an evaluation. As a result, WTI was asked to do an evaluation and this document details that evaluation using speed data from the iCones and WTI sDrums.

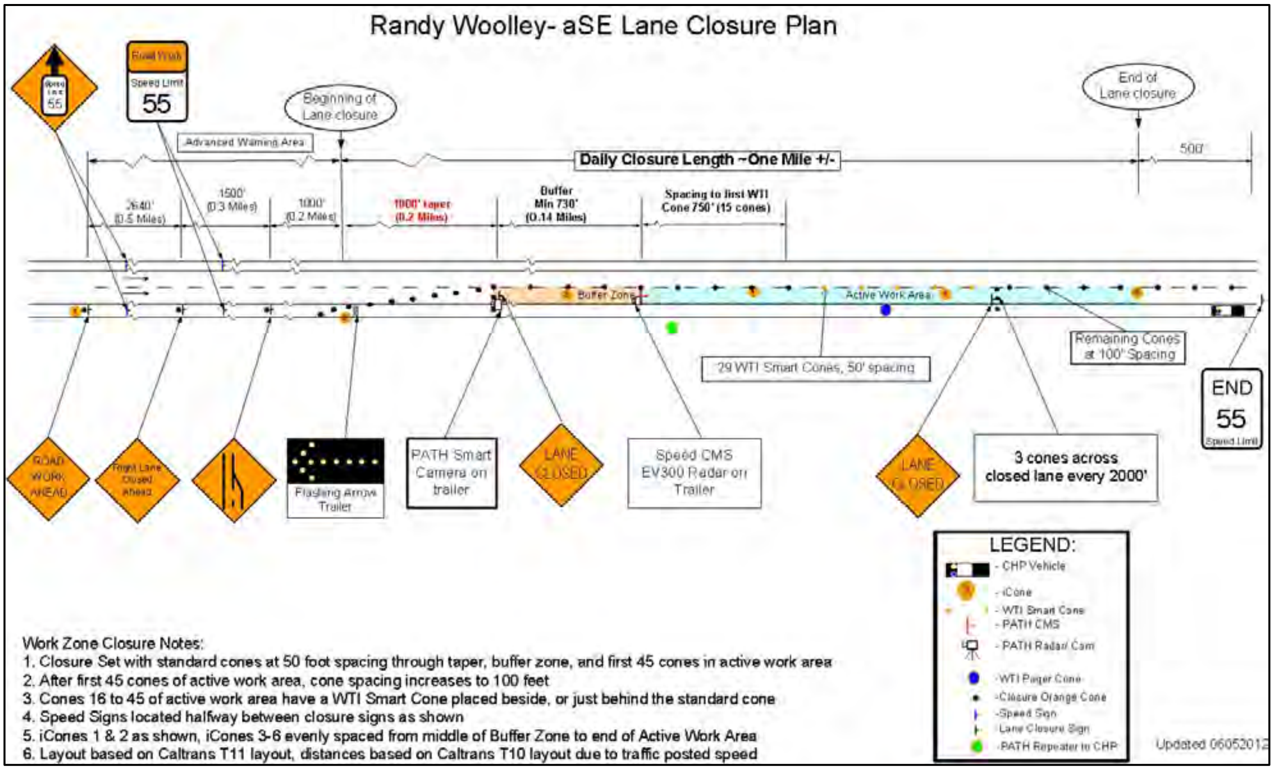


Figure 1: aSE Lane Closure Plan – Caltrans Image

2. METHODOLOGY

The iCone system gives point estimates of vehicle speeds by recording speeds, as reported by integrated radar sensors, on each individual iCone. Since the radar sensors can make multiple reads for a single vehicle, an attempt is made to isolate a single reading per vehicle by logging a reading, then ignoring further readings for a period of 500ms, and then repeating the cycle starting at the next non-zero speed reading. This is only an approximation since multiple reads per vehicle will occur if (slow moving) vehicle is detected by the sensor for a period of more than 500ms. Similarly, if during a 500ms off interval a second vehicle passes the sensor, that vehicle will pass undetected. The latter could happen in situations where a high-speed vehicle is following close behind another high-speed vehicle. Further, the iCone system tallies readings into bins corresponding to 5 mph intervals. Statistics are then reported based on the bin tallies rather than the raw speed values.

Similarly, the WTI sDrums record speeds via radar sensors on master and logger drums. The sDrum system logs every radar sensor reading. Similar to that for the iCone, the raw data from the sDrums does not provide an indication of individual vehicles. After the fact, it might be possible to approximate a data stream with one reading per vehicle. However, recognizing that such an approach would be only an approximation, the WTI team chose to analyze the sDrum data in its raw form, with no attempt to characterize speeds for individual vehicles.

For both data collected via iCones and via WTI sDrums, speed reads less than 30 mph were omitted since such reads generally corresponded to worker vehicles or local farm equipment. The principal measurement compared was the percentage of radar reads greater than or equal to 60 mph, which corresponds to the trigger point for the WTI system. Since the PATH system used 56 mph as a trigger point, this threshold corresponds to speeds in which both systems would be triggered to provide feedback to drivers and corresponds to the lower bound of an iCone bin. Note again that the posted speed limit for the work zone was 55 mph.

Data was grouped by hour and analyzed by week since the location of the work zone and the position of the iCones varied considerably across the testing weeks but was relatively consistent within individual weeks. Only periods in which all 6 iCones had readings were used for analysis of the iCone data (although one day in which the first iCone logged a location abnormally far from the work zone is included). Only periods in which all 4 WTI sDrums had readings were used for analysis of the sDrum data.

Table 1 shows the work zone configurations by week and Figure 2 shows the positions of the iCones by day and week relative to the second iCone, since that iCone was most consistent in its placement relative to the work zone. Note the variation in the positions of the iCones relative to the second iCone.

The iCones are identified in order: iCone 1 precedes the work zone, iCone 2 corresponds to the beginning of the taper, iCone 3 corresponds to the middle of the buffer zone, iCones 4 and 5 were generally within the portion of the work zone covered by the WTI system, and iCone 6 was generally at the end of the work zone.

Table 1: Work Zone Configuration by Week

Week	Dates	Configuration
1	5/14 – 5/18/2012	WTI only
2	5/21 – 5/24/2012	both
3	5/30 – 6/1/2012	PATH only
4	6/4 – 6/8/2012	baseline - neither
5	6/11 – 6/15/2012	WTI only
6	6/18 – 6/22/2012	both
7	6/25 – 6/29/2012	PATH only
8	7/9 – 7/13/2012	baseline - neither

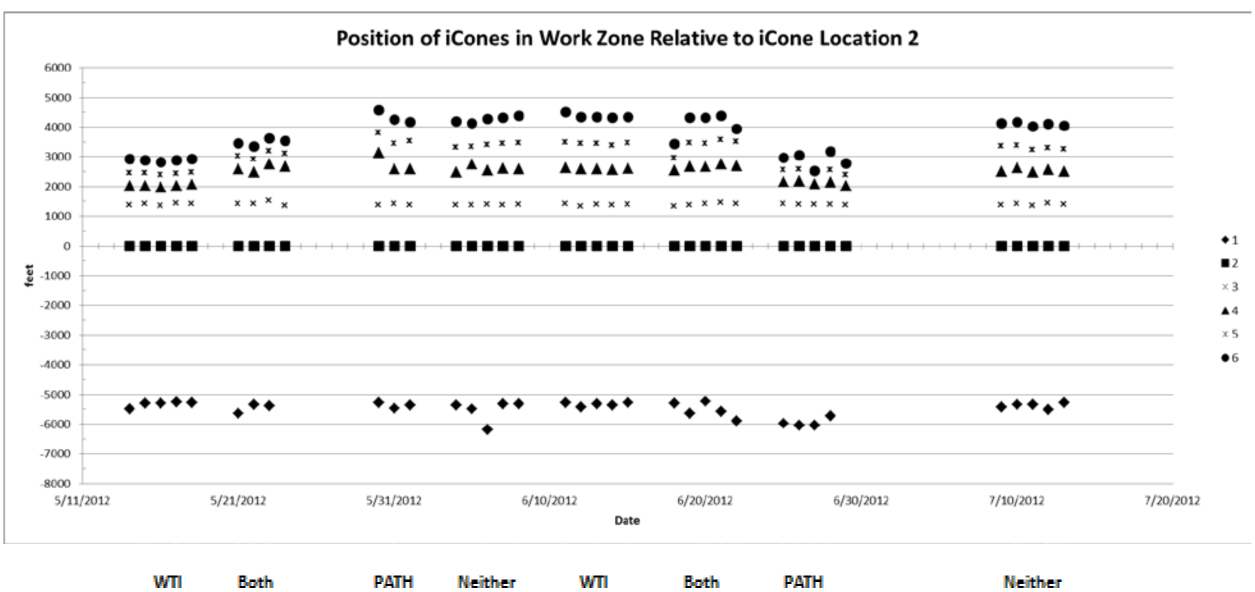


Figure 2: Positions of iCones by Day and Week Relative to iCone Location 2

No attempt was made to align and compare the data from the iCones to that from the sDrums directly, particularly since they were generally deployed at different locations within the work zone, with the sDrums deployed in a relatively small segment in the work zone. The same general trend of slowing throughout the work zone can be seen in both systems. We note that the radar used for the sDrum system indicates +/-0.5% of reading accuracy. iCone accuracy was unknown to the authors and could not be found at the time this document was written.

Our general hypothesis is that the individual and combined systems result in a lower percentage of vehicles with excessive speed (≥ 60 mph) in the treatment area for the systems when compared to a baseline work zone without either system present. As a result, the average overall speed will be reduced in the presence of the systems, although the reduction will be relatively small if most vehicles are not traveling at excessive speed.

Our analysis is divided into two portions: 1) analysis of iCone data and 2) analysis of sDrum data.

3. RESULTS

3.1. Analysis of iCone Data

The iCone data is analyzed both by week and by configuration. The reasoning behind this approach is that conditions, including relative placement of iCones, varied noticeably across weeks and less within individual weeks.

3.1.1. Average Speed

In this section, we present average speeds by iCone location grouped first by week and subsequently by configuration. Several things must be noted in conjunction with this data. First, the iCone data is binned into 5 mph intervals and averages are computed on the binned data. As such, precision is lost and the accuracy of these averages is decreased. Further, both systems attempt to reduce the speed of only those traveling over 56 mph for the PATH system and those traveling over 60 mph for the WTI system. In the portions of the work zone in which these systems were deployed, many if not most of the vehicles were traveling at speeds below these thresholds and would have been unaffected by the systems. So, even if the systems were 100% effective in getting drivers to reduce their speeds to below these thresholds, the resulting decrease in average overall speed could be relatively small. Finally, since the PATH system uses a lower threshold than the WTI system, the PATH system would be expected to influence a greater percentage of all vehicles than the WTI system, resulting in a greater decrease in average overall speed. This should be taken into account if attempting to compare the systems directly.

When broken down by week, average speeds decrease as vehicles progress through the work zone. This is not surprising. See Table 2.

Table 2: Average Speed by Week and iCone Location (mph)

		iCone Location					
Week	**Configuration**	**1**	**2**	**3**	**4**	**5**	**6**
1	**WTI**	61.78	54.88	52.75	52.14	52.14	51.70
2	**both**	62.58	55.47	51.30	51.15	51.04	50.66
3	**PATH**	63.64	55.62	53.12	53.17	53.44	53.38
4	**baseline**	62.67	55.97	54.29	53.99	53.71	52.53
5	**WTI**	62.86	56.18	53.57	52.73	52.99	52.97
6	**both**	62.69	55.70	52.43	52.45	52.09	52.92
7	**PATH**	62.23	55.49	52.40	51.46	51.83	51.88
8	**baseline**	63.43	55.70	54.10	54.24	53.34	52.11

There are several cases shown in the table where average speed increases by small amounts between subsequent locations. Further note that there are differences of as much as 1 mph between identical configurations during different weeks. For instance, there was an average speed of 54.88 mph during Week 1 and an average speed of 56.18 mph during Week 5 at iCone location 2. The WTI system alone was deployed during both of these weeks and would not have influenced speeds at that location, so the difference in speeds may be an indication of other factors unrelated to the WTI system that could influence results at subsequent locations. In particular, during Week 1, the work zone was located in close proximity to Los Banos where-as during Week 5 it was located well outside Los Banos. Further, WTI staff has noted the CHP was located at the front of the work zone with lights flashing at least part of Week 1. With this qualification we note that at locations that could be influenced by either or both systems, iCone locations 3, 4 and 5, average speeds during both baseline weeks were greater than average speeds during other weeks.

Table 3 shows average speeds by configuration and Table 4 shows the change in average speed for each non-baseline configuration versus the baseline. The greatest decreases in average speed versus the baseline occurred when both systems were in place. At iCone locations 3 and 4, there was a decrease of approximately 2.4 mph and a decrease of nearly 2 mph at iCone location 5. The WTI system showed a decrease of 1.7 mph at iCone location 4 while the PATH system showed a decrease of almost 1.9 mph. In fact, there was a decrease in speed at all locations for all configurations when compared to the baseline except for the PATH system at location 6. This includes iCone locations 1 and 2, which would not be impacted by either system. Again, this may indicate that other factors that could influence results.

Somewhat surprisingly, the average speed at iCone location 6 during the baseline weeks is slightly less than for the weeks in which the PATH system was deployed and only slightly greater than for weeks in which the WTI system was deployed. And, the average speed between iCone 5 and iCone 6 dropped by over 1 mph during the baseline, while there was a slight increase between these two iCones for the PATH system, a small decrease for the WTI system and an even smaller decrease for BOTH systems. We speculate for lack of a better explanation that perhaps CHP was positioned at the end of the work zone for a greater portion of the time during the baseline than during other testing.

Table 3: Average Speed by Configuration and iCone Location (mph)_

	iCone Location					
Configuration	1	2	3	4	5	6
both	62.65	55.58	51.79	51.73	51.55	51.48
WTI	62.31	55.56	53.09	52.41	52.56	52.16
PATH	62.88	55.54	52.67	52.22	52.41	52.52
baseline	63.06	55.84	54.19	54.10	53.51	52.35

Table 4: Average Change in Speed versus Baseline by Configuration and iCone Location (mph)

	iCone Location					
Configuration	1	2	3	4	5	6
both	-0.41	-0.26	-2.40	-2.37	-1.96	-0.87
WTI	-0.76	-0.28	-1.10	-1.70	-0.96	-0.19
PATH	-0.18	-0.30	-1.53	-1.88	-1.11	0.17

Due to concerns about calculations on the binned iCone data and also because of the differences noted above at iCone locations 1, 2 and 6, further analysis is merited. In subsequent sections, we analyze percentages relative to 60 mph to better investigate the impact on vehicles in the target range for the WTI system.

3.1.2. Behavior of Drivers as They Traverse the Work Zone

In this section, we investigate the behavior of drivers as they approach and drive through the work zone. To do so, **we compare the percentage of speed reads greater than or equal to 60 mph at each iCone location and by changes between subsequent iCone locations by week**. According to the speeds measured and recorded by the iCones, the percentage of reads at or above 60 mph generally decreased as drivers approached and traversed the work zone (see Figure 3 and Figure 4). At full highway speed prior to the work zone, between 60 to 70 percent of the reads are 60 mph or greater. In general, approximately 10 percent or less of the reads at iCones 3, 4, 5 and 6 are 60 mph or greater. Thus, it can be seen that most drivers reduce their speed to below 60 mph prior to or upon entering the work zone. Note that we are using hourly percentages.

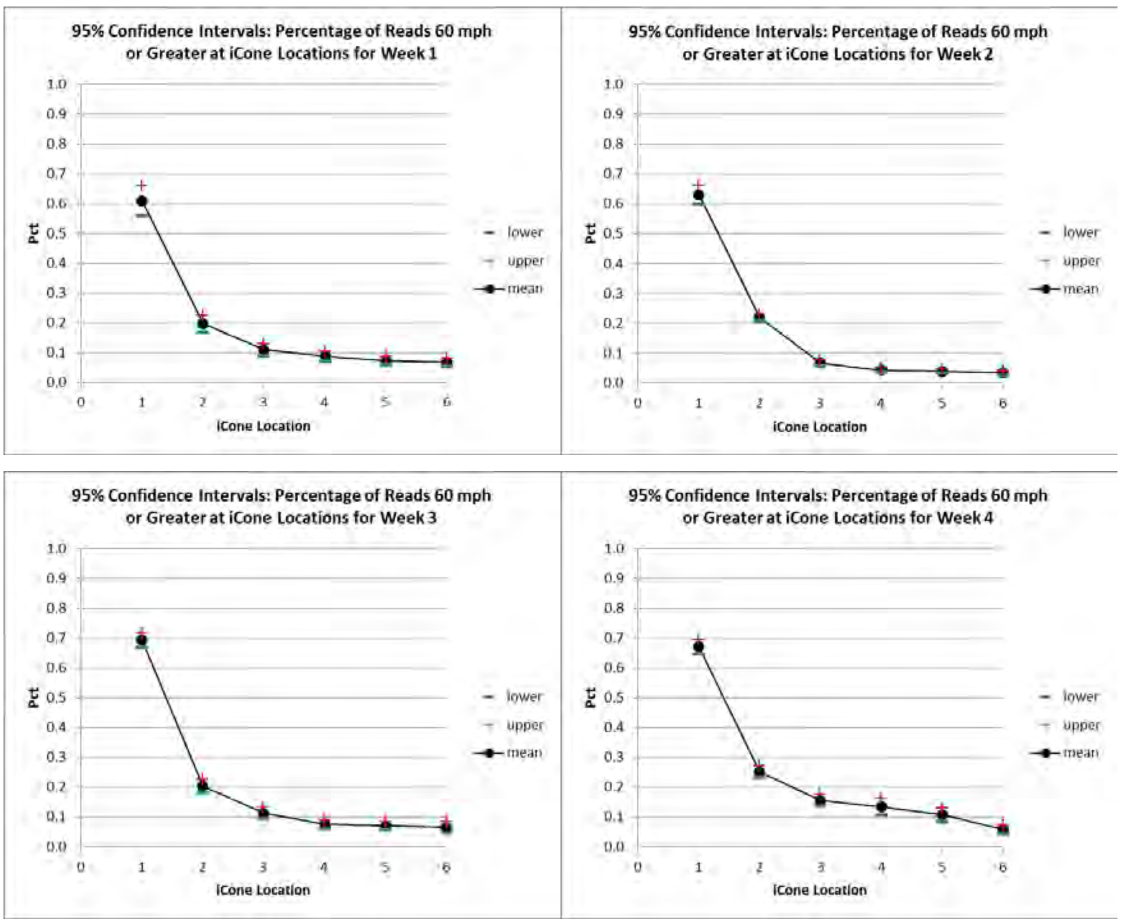


Figure 3: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by iCones by Week (Week 1 – Week 4)

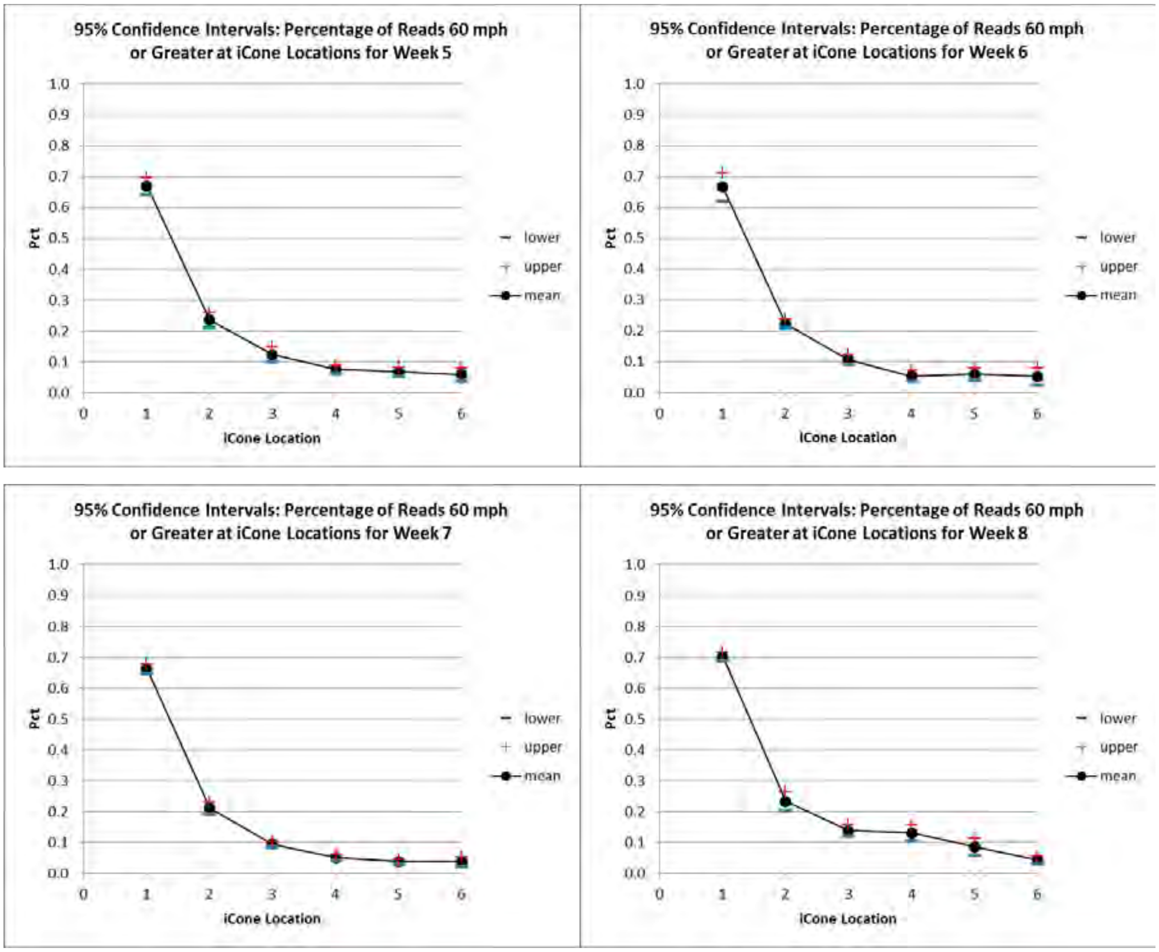


Figure 4: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by iCones by Week (Week 5 – Week 8)

We further note that during baseline weeks 4 and 8, the percentages are higher at iCone locations 2, 3, 4 and 5 than during weeks in which one or both of the systems was in place. Later in this report we show that these differences are statistically significant.

There is noticeable variation in the percentage of reads of 60 mph or greater at the various iCone locations when broken down by week (see Figure 5). In the subsequent Discussion section, we provide a number of factors that may have contributed to this variability.

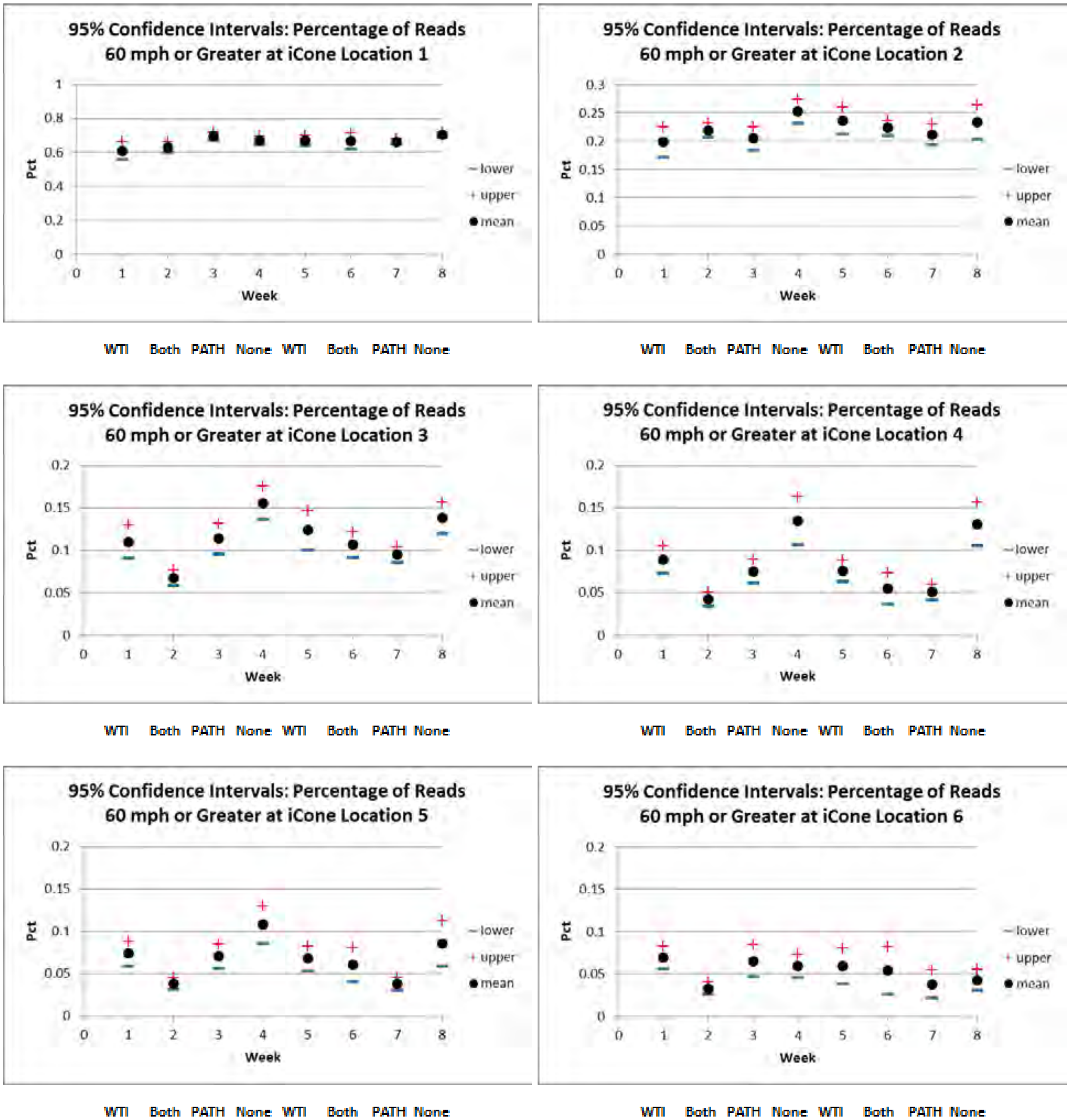


Figure 5: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by iCones by Location

In the remainder of this section, we investigate the difference between subsequent iCones in percentage of speed reads measure that are greater than or equal to 60 mph. For instance, if the percentage of speed reads at iCone location 1 was 0.6 and at iCone location 2 was 0.2, then the difference is 0.4, indicating that there were 40% less overall speed reads greater than or equal to 60 mph.

Statistical significance tests were used to determine if the reduction in speed between subsequent iCone locations were significant at the 95% level. One-tailed, paired sample t-tests were performed to determine if there were significant differences in the mean percentage of speed reads greater than or equal to 60 mph between subsequent iCone locations – i.e., was there a reduction (or increase) in the rate between the subsequent locations. Associated 95% confidence intervals were also determined. Tests for normality of the data were not conducted.

To help the reader to better understand the rationale and method for using statistical significance tests on this data, we present a brief analysis of the change in hourly percentage of reads 60 mph or greater between iCone locations 3 and 4 to illustrate our approach and interpretation of the results. The plot in Figure 6 shows 95% confidence intervals for these hourly percentages. The mean (average) shows the overall average of these percentages, and is indicated by black circles in the plot. The + and – symbols in the plots show the upper and lower extremes of the 95% confidence intervals for this data. These encapsulate the variance of the hourly percentages and are interpreted to show that with 95% confidence, the true mean of hourly data for the various weeks would fall within the range between these upper and lower extremes. For week 5, for instance, we have a (sample) mean change of percentage of approximately -0.048, a reduction. The upper extreme corresponds to a percentage change of approximately -0.03, also a reduction, and the lower extreme corresponds to approximately -0.066. So, we interpret this by saying that with 95% confidence, the change in hourly percentage of reads 60 mph or greater between iCone locations 3 and 4 is between -0.03 and -0.066. In other words, we are 95% confident that there was a reduction of between approximately 3% and 7%. This is more informative than stating that that the (sample) mean reduction was 4.8% since it further gives an indication of the variability of the data.

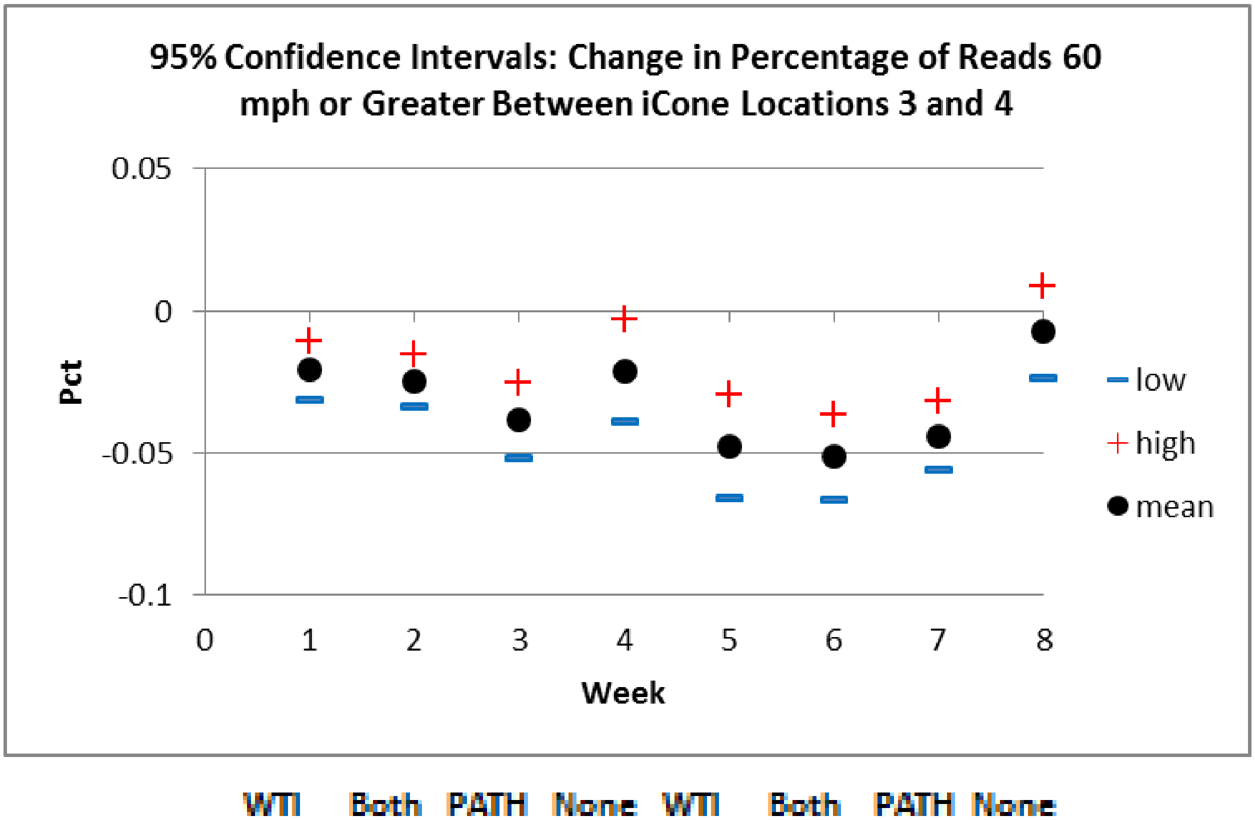


Figure 6: Confidence Interval Plots for Change in Hourly Percentage of Reads 60 mph or Greater between iCones 3 and 4 by Week

A t-test can be used to further formalize these results. See Table 5. Here we list the same 95% confidence intervals and also provide the t-test p-value. A t-test is used to examine a "null hypothesis" and determine whether or not we can reject this null hypothesis with a given level of confidence. For this situation, we examine the null hypothesis that for a given week, the mean hourly change in percentage of reads 60 mph or greater between iCone locations 3 and 4 is 0, unchanged. We use a 95% confidence level. The p-value represents the probability that the null hypothesis is valid. If this probability is less than 0.05 (5%), then we can reject the null hypothesis with 95% confidence. If this probability is greater than or equal to 0.05, then we cannot reject the null hypothesis.

In Table 5, we see a p-value of 0.173 for week 8. This tells us that we cannot reject the null hypothesis of a zero mean for that week. This makes sense, particularly when looking at Figure 6. The (sample) mean for the week was just slightly below zero and the 95% confidence interval for that week overlaps not only with zero but with positive values. Therefore, we cannot say that during week 8, there was a reduction in speed between iCone locations 3 and 4. The p-values for all other weeks, however, have p-values less than 0.05, indicating that we can reject the null hypothesis of a zero mean for weeks 1 through 7. We then can say, with 95% confidence, that there was a reduction in speed between iCone locations 3 and 4.

Table 5: Confidence Intervals and t-test Results for Change in Hourly Percentage of Reads 60 mph or Greater between iCones 3 and 4. (The null hypothesis is that the mean is zero.)

			95% Confidence Interval			
Location	Config.	Week	lower	mean	upper	t-test p value
3-4	WTI	1	-0.031	-0.021	-0.011	**0.000**
3-4	both	2	-0.034	-0.025	-0.016	**0.000**
3-4	PATH	3	-0.052	-0.039	-0.025	**0.000**
3-4	neither	4	-0.039	-0.021	-0.003	**0.011**
3-4	WTI	5	-0.066	-0.048	-0.030	**0.000**
3-4	both	6	-0.067	-0.052	-0.036	**0.000**
3-4	PATH	7	-0.056	-0.044	-0.032	**0.000**
3-4	neither	8	-0.024	-0.007	0.009	0.173

In a manner similar to that shown in the prior example and by observing the t-test values in Table 6 and the confidence intervals and means shown in Table 6 and Figure 7, we make the following observations with 95% confidence regarding the change in hourly percentage of reads 60 mph or greater between iCones:

- The reduction between iCones 1 and 2 was determined significant for every test week. Since these iCones were located prior to both systems, the systems played no role in this reduction.
- The reduction between iCones 2 and 3 was determined significant for every test week. Since these iCones were located prior to both systems, the systems played no role in this reduction.
- Between iCones 3 and 4, there was a significant reduction for all but week 8, a baseline week. In other words, there was a significant reduction for every week in which either or both systems were installed, and also for one of the baseline weeks, week 4.
- Between iCones 4 and 5, the reduction was significant for Weeks 1 (WTI), 4 (baseline), 5 (WTI), 7 (PATH) and 8 (baseline), but not for Weeks 2 (both), 3 (PATH) and 6 (both). Since these iCones are downstream from the PATH system, it may be the case that little or no further reduction in speed is occurring on this segment, although the WTI system could still have an influence.
- And, between iCones 5 and 6, the reduction was significant for Weeks 2 (both), 4 (baseline) and 8 (baseline), but not for Weeks 1 (WTI), 3 (PATH), 5 (WTI), 6 (both) or 7 (PATH). It is unclear why there would be a significant difference during baseline weeks over this segment. We speculate that it may be related to the location of CHP. Since these iCones are downstream from the PATH system and at the end of or beyond the WTI system, it may be the case that little or no further reduction in speed is occurring on this segment due to either system.

While there was generally a reduction in percentages of speed reads at or above 60 mph between subsequent iCones, these results demonstrate the difficulty in assessing the impact of the systems from this data alone. See Table 6 and Figure 7.

Table 6: Confidence Intervals and t-test Results for Change in Hourly Percentage of Reads 60 mph or Greater between iCones. (The null hypothesis is that the mean is zero.)

			95% Confidence Interval			
Location	Config.	Week	lower	mean	upper	t-test p value
1-2	WTI	1	-0.461	-0.411	-0.361	**0.000**
1-2	both	2	-0.445	-0.411	-0.377	**0.000**
1-2	PATH	3	-0.517	-0.489	-0.461	**0.000**
1-2	neither	4	-0.453	-0.419	-0.385	**0.000**
1-2	WTI	5	-0.466	-0.433	-0.401	**0.000**
1-2	both	6	-0.489	-0.442	-0.396	**0.000**
1-2	PATH	7	-0.469	-0.451	-0.433	**0.000**
1-2	neither	8	-0.494	-0.469	-0.444	**0.000**
2-3	WTI	1	-0.107	-0.088	-0.068	**0.000**
2-3	both	2	-0.165	-0.151	-0.138	**0.000**
2-3	PATH	3	-0.105	-0.091	-0.076	**0.000**
2-3	neither	4	-0.115	-0.096	-0.077	**0.000**
2-3	WTI	5	-0.130	-0.113	-0.095	**0.000**
2-3	both	6	-0.129	-0.117	-0.104	**0.000**
2-3	PATH	7	-0.136	-0.117	-0.097	**0.000**
2-3	neither	8	-0.112	-0.095	-0.079	**0.000**
3-4	WTI	1	-0.031	-0.021	-0.011	**0.000**
3-4	both	2	-0.034	-0.025	-0.016	**0.000**
3-4	PATH	3	-0.052	-0.039	-0.025	**0.000**
3-4	neither	4	-0.039	-0.021	-0.003	**0.011**
3-4	WTI	5	-0.066	-0.048	-0.030	**0.000**
3-4	both	6	-0.067	-0.052	-0.036	**0.000**
3-4	PATH	7	-0.056	-0.044	-0.032	**0.000**
3-4	neither	8	-0.024	-0.007	0.009	0.173
4-5	WTI	1	-0.024	-0.015	-0.007	**0.000**
4-5	both	2	-0.010	-0.004	0.001	0.069
4-5	PATH	3	-0.016	-0.004	0.007	0.220
4-5	neither	4	-0.043	-0.027	-0.011	**0.001**
4-5	WTI	5	-0.014	-0.008	-0.002	**0.008**
4-5	both	6	-0.002	0.006	0.013	0.061
4-5	PATH	7	-0.024	-0.012	-0.001	**0.020**
4-5	neither	8	-0.055	-0.045	-0.035	**0.000**
5-6	WTI	1	-0.013	-0.005	0.003	0.111
5-6	both	2	-0.009	-0.006	-0.002	**0.002**
5-6	PATH	3	-0.017	-0.006	0.006	0.155
5-6	neither	4	-0.066	-0.049	-0.031	**0.000**
5-6	WTI	5	-0.029	-0.009	0.012	0.188
5-6	both	6	-0.018	-0.007	0.004	0.094
5-6	PATH	7	-0.014	-0.001	0.013	0.465
5-6	neither	8	-0.067	-0.043	-0.019	**0.001**

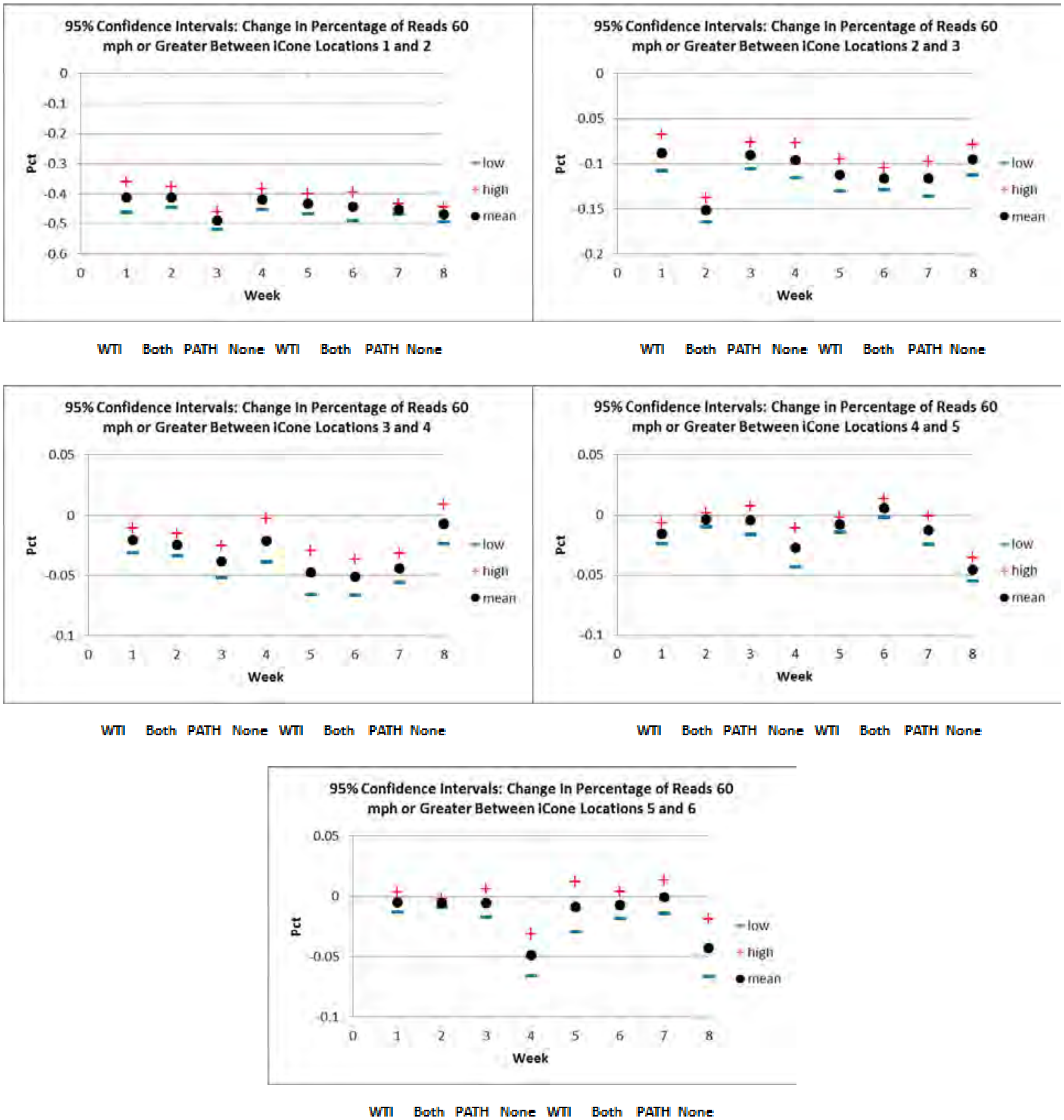


Figure 7: Confidence Interval Plots for Change in Hourly Percentage of Reads 60 mph or Greater between iCones by Week

3.1.3. Behavior of Drivers in Conjunction with Different Warning Configurations through Direct Comparison of Percentages of Speed Reads Greater than or Equal to 60 mph

In this section, we compare the percentage of speed reads greater than or equal to 60 mph at each iCone location by configuration. In particular, we compare the various configurations in which one or both of the systems were present to the baseline configuration of no system.

95% confidence intervals of percentage of speed reads greater than or equal to 60 mph at the various iCone locations were computed and one-tailed, two-sample unequal variance t-tests were performed to determine if there were significant differences in the mean percentage of speed reads greater than or equal to 60 mph at each iCone location by each pair of configurations. Since the t-tests are used here to determine if the means from two different groups are equal rather than determine if the mean from a single group is zero, we present a brief example of how we interpret these results.

In Figure 8 we show 95% confidence interval plots for hourly percentage of reads 60 mph or greater measured by iCones by configuration at iCone location 3. We can see that the baseline configuration shows the highest percentage of reads 60 mph or greater of the group at approximately 0.15. The configuration of both systems shows the lowest percentage at approximately 0.09, and the other two configuration have percentages a little above 0.1.

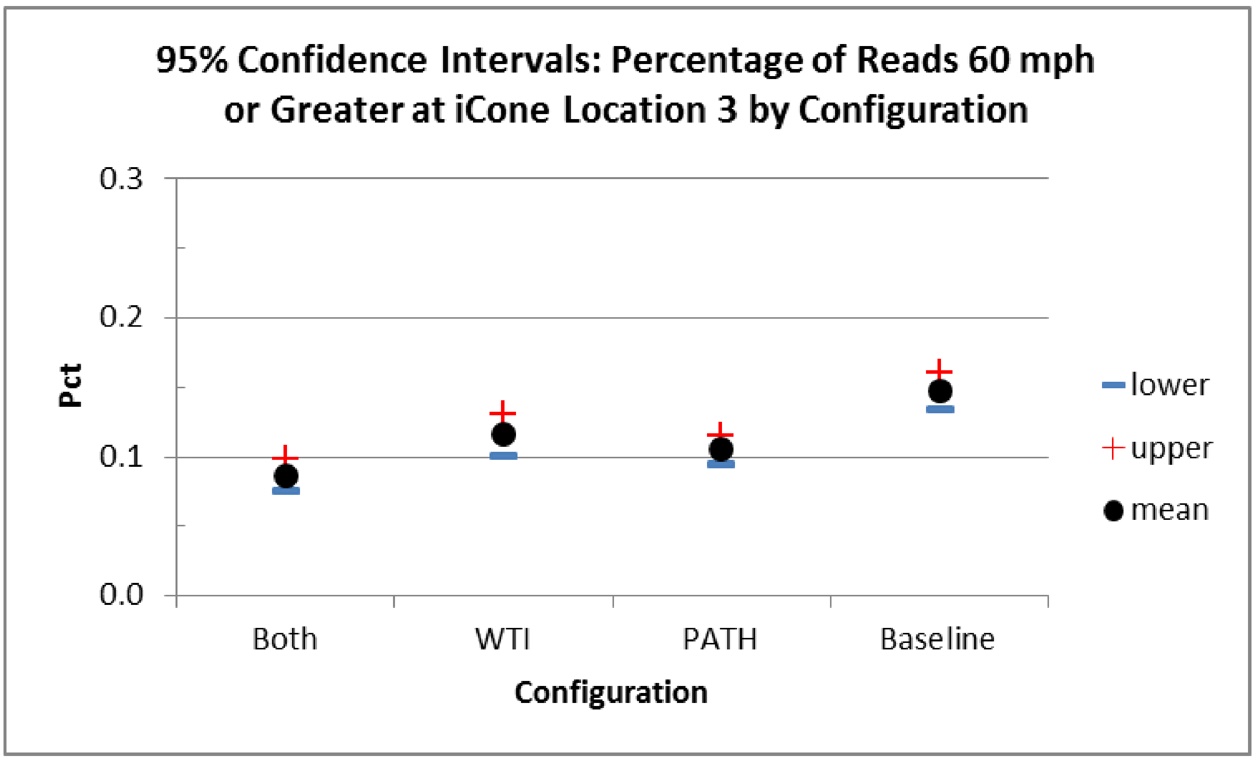


Figure 8: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by iCones by Configuration at iCone Location 3

Table 7 shows p-values for t-tests comparing the various configurations to determine if there is a difference in the percentage of reads 60 mph or greater at iCone location 3. These tests add weight to the casual observations we might make in looking at the plots in Figure 8, so that we can attempt to make conclusions with confidence. Again, we formulate a null hypothesis for the t-test which, in this case, is that the mean percentage of reads 60 mph or greater is the same for a given pair of configurations. I.e., there is no difference in the percentages for the given pair. In Table 7, we see that the p-value for the WTI-only configuration as compared to the PATH-only configuration is 0.1172. This value is greater than 0.05. So, we cannot reject the null hypothesis that the mean percentages for these configurations are different. In other words, we cannot distinguish one system as better than the other in this case. However, all of the remaining p-values for other pairs of configurations are less than 0.05. So we can say with 95% confidence that all of the other pairs exhibit a statistically significant difference in percentages. In particular, we can say that the baseline configuration had a greater percentage of reads 60 mph or greater at iCone location 3 than all other configurations, since there is a statistically significant difference between the mean for the baseline and that for all of the other configurations, and since the (sample) mean for the baseline is greater than that for all other configurations.

Table 7: t-test p-values Comparing Percentage of Reads 60 mph or Greater at iCone Location 3 for Pairs of Configurations. (The null hypothesis is that there is no difference between the means of the configuration pairs.)

		Location #
Configurations Compared		3
both	baseline	**0.0000**
WTI	baseline	**0.0008**
PATH	baseline	**0.0000**
both	PATH	**0.0084**
WTI	PATH	0.1172
both	WTI	**0.0011**

Following the methodology shown above, we use the 95% confidence intervals of percentage of speed reads greater than or equal to 60 mph at the various iCone locations broken down by configuration, as shown in Figure 9, and the one-tailed, two-sample unequal variance t-test results for which p-values are shown in Table 8 to make the following observations:

At Location 1, no significant difference is shown between the rates for the configuration with both systems and the configuration with just the WTI system. Also, no significant difference is shown between the rates for the configuration with neither system and the configuration with just the PATH system. However, all other combinations (both versus PATH, both versus baseline, WTI versus PATH, and WTI versus baseline) show a significant difference between the rates. Since Location 1 precedes the work zone, these results do not show differences between the effectiveness of the systems but rather differences in the characteristics of traffic prior to entry into the work zone during periods in which the various configurations were tested. With 95% confidence we can say that a greater percentage of radar reads indicating speeds greater than or equal to 60 mph occurred during times when the PATH system alone and the baseline configuration of no system were present versus times in which both the PATH system and the WTI system or the WTI system alone were present. We present this comparison because it shows that free-flow traffic was likely not homogeneous across the periods in which the systems and baseline were evaluated.

At iCone location 2, there was a significant difference between the rates for the configurations in which either or both of the systems are present versus the baseline configuration. However, there is no significant difference between the percentages when comparing pairs of configurations in which either or both of the systems were in place. Location 2 for iCones corresponded to the beginning of the taper and preceded both of the systems for configurations in which one or both were deployed, so these results do not indicate differences in the effectiveness of the various configurations. It should be noted that the presence of the CHP vehicle at the beginning of the work zone may have influenced readings at this location. The CHP vehicle was located at the beginning of the work zone on some days but at the end on other days. There is no complete record indicating when CHP was at the beginning versus the end, so it is not possible to isolate the impact of the CHP vehicle on driver behavior.

iCone location 3 corresponded to the middle of the buffer zone and generally coincided with the location of the PATH CMS when it was present, and preceded the WTI system by approximately 730 ft. As such, the PATH system might influence the behavior of drivers at this location, but the WTI system would not. At iCone location 3, there is a significant difference between the rates for all pairs of configurations except for the comparison of the WTI only and PATH only configurations. As such, we might conclude that both the WTI and PATH systems performed better than the baseline of no system. Further, we might conclude that both systems together performed better than either system individually and better than the baseline. However, since location 3 preceded the WTI system, the WTI system could not have had an impact measured at this location unless drivers were reacting to the lights that were at least 730 ft. ahead of them.

iCone locations 4 and 5 were generally within the portion of the work zone covered by the WTI system. As such, the WTI system could influence behavior of drivers at these locations, as could the PATH system. At iCone location 4, there is a significant difference between the mean rates for all pairs of configurations. As such, and taking into account the relative order of the means for the configurations, one might infer that the most effective configuration relative to rates at this location was the configuration including both systems. Next would be the configuration with the PATH system alone, followed by the configuration with the WTI system alone. All of these configurations showed significant differences from the baseline. At iCone location 5, all pairs of configurations showed a significant difference in means except for the configuration in which both systems were present as compared to the PATH only configuration. These two configurations show better rates than the WTI only configuration and the WTI only configuration shows better performance than the baseline configuration at location 5.

During most weeks, iCone location 6 was generally at the end of the work zone and, as such both the WTI system and the PATH system could possibly influence the behavior of drivers at this location, although direct influence at this point is less likely since drivers will have passed through both systems upon reaching this point. Further, the presence of the CHP vehicle at the end of the work zone might influence readings at this location. The only configuration pairs that yielded a significant difference in rates were the WTI system versus the baseline and the WTI system versus both systems. Since the mean for the WTI only configuration was greater than that for any of the other configurations, we might infer that it performed worse than the baseline and worse than the configuration with both systems, but we cannot conclude that it performed worse than the PATH-only configuration. Again, the presence of CHP at the end of the work zone on certain days but not others may have influenced this result. Referring back to Figure 2, we note that iCone Location 6 did vary significantly relative to iCone Location 2 across weeks during pilot testing.

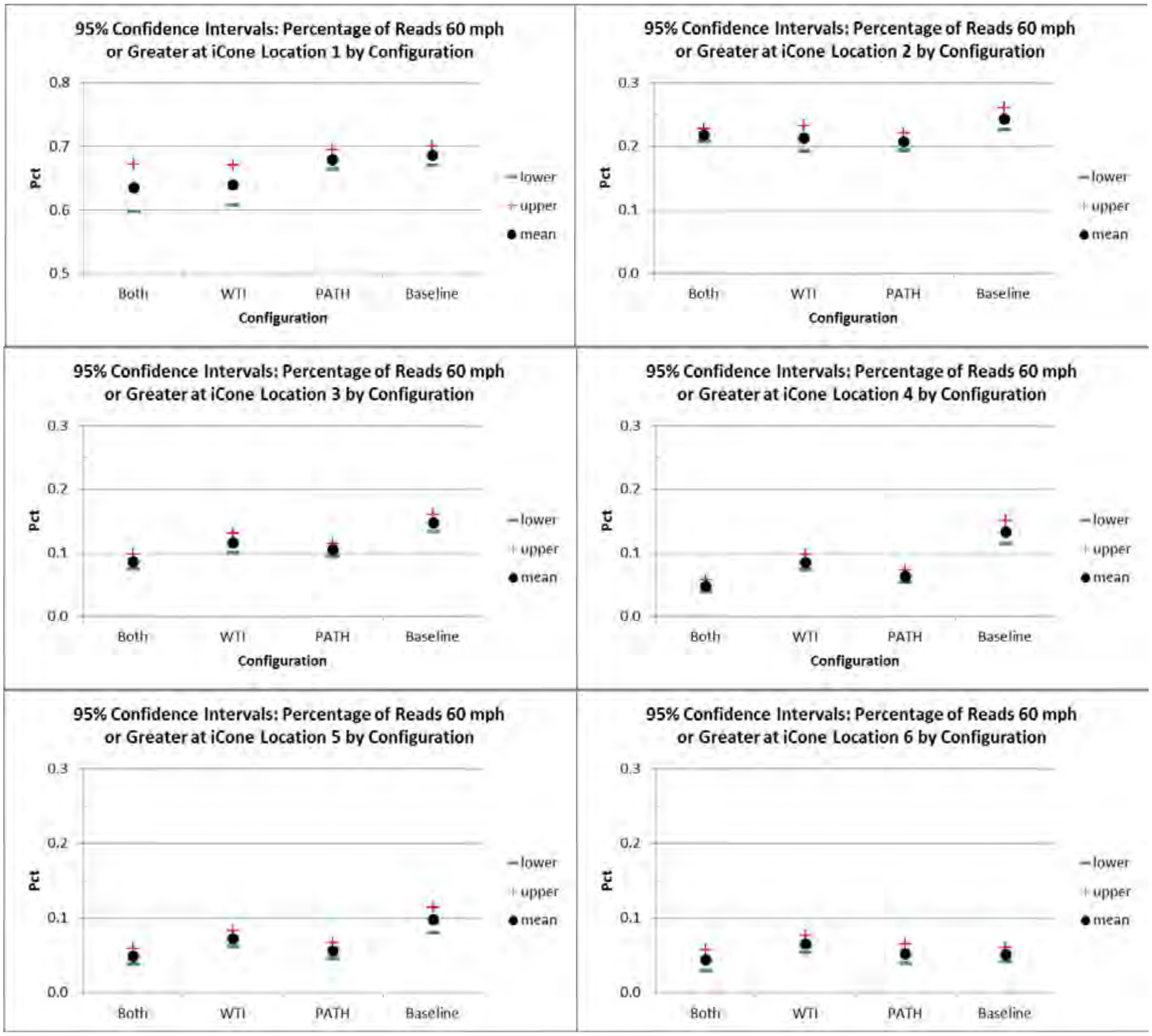


Figure 9: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by iCones by Location and Configuration

Table 8: t-test p-values Comparing Percentage of Reads 60 mph or Greater at iCones for Pairs of Configurations. (The null hypothesis is that there is no difference between the means of the configuration pairs.)

		Location #					
Configurations Compared		1	2	3	4	5	6
both	**baseline**	**0.0064**	**0.0060**	**0.0000**	**0.0000**	**0.0000**	0.1596
WTI	**baseline**	**0.0038**	**0.0105**	**0.0008**	**0.0000**	**0.0064**	**0.0253**
PATH	**baseline**	0.2699	**0.0006**	**0.0000**	**0.0000**	**0.0000**	0.4496
both	**PATH**	**0.0141**	0.0879	**0.0084**	**0.0100**	0.1675	0.1631
WTI	**PATH**	**0.0103**	0.3287	0.1172	**0.0017**	**0.0109**	0.0601
both	**WTI**	0.4266	0.3057	**0.0011**	**0.0000**	**0.0008**	**0.0060**

3.1.4. Behavior of Drivers in Conjunction with Different Warning Configurations through Comparison of Percentage Change in Speed Reads Greater than or Equal to 60 mph

In this section, we compare the percentage of speed reads greater than or equal to 60 mph between subsequent iCone locations in a different way than in the prior sections. In prior sections, we compared the percentage of speed reads greater than or equal to 60 mph relative to the number of overall speed reads. For instance, if there were 100 speed reads at iCone location 1 and of those, 20 were greater than or equal to 60 mph, then in prior sections this would be reported as 20% of the overall speed reads. Similarly, if there were 100 speed reads at iCone location 2 and of those, 10 were >= 60 mph, then this would be reported as difference of 10% percent of the overall speed reads and the difference between the two locations would be reported as a 10% reduction. I.e., 10% less of the overall speed reads fall in the critical region.

In this section, we measure the percentage change in speed reads between subsequent iCone locations as a relative percentage. This is a subtle but important difference. Here, regardless of what the percentages are relative to the overall counts (all readings, regardless of >= 60 mph and <60 mph), we attempt to determine the percentage change in behavior of those in the critical region of 60 mph or greater. For instance, if 20 reads >= 60 mph are recorded at iCone location 1 and 10 reads greater than or equal to 60 mph are recorded at iCone location 2, then there is a 50% percentage reduction, regardless of the overall number of reads. As opposed to the prior measures which represent the overall behavior of drivers, this measure may better represent the behavior of individual drivers who fall in the critical region of behavior that we wish to reduce their speeds.

95% confidence intervals of percentage change of speed reads greater than or equal to 60 mph between the various iCone locations are shown broken down by configuration in Figure 10. One-tailed, two-sample unequal variance t-tests were performed to determine if there were significant differences in the percentage changes of speed reads greater than or equal to 60 mph between each pair of subsequent iCone locations and by each pair of configurations. Tests for normality of the data were not conducted. The p-values for these t-tests are shown in Table 9.

From these plots and t-tests, we observe the following:

Between iCone locations 1 and 2, there is a significant difference in the percentage changes when compared by configuration between both systems and the PATH system alone, between the WTI system and the PATH system, and between the PATH system and neither system. There is, however, no significant difference between both systems and the WTI system, between both systems and neither system and between the WTI system and no system. As discussed in the previous sections, these iCones precede both systems, thus the systems could not have had an impact on driver behavior. Other factors had to have contributed to these differences, and these other factors could influence behavior observed subsequently.

Between iCone locations 2 and 3, all comparisons of configurations result in a significant difference in percentage changes, except the comparison of WTI only to PATH only. The baseline configuration had the least change and the configuration consisting of both systems had the greatest change. As noted previously, neither system would influence drivers at location 2 and only the PATH system would influence drivers at location 3. Thus, the PATH system may be significantly changing behavior between locations 2 and 3, but other factors may be responsible as well.

Between iCone locations 3 and 4, all comparisons of configurations result in a significant reduction in percentages except the comparison of both systems to PATH only. The baseline configuration had the least change and the configuration consisting of both systems along with the configuration of PATH only had the greatest reduction. All configurations with one or both of the systems showed a change in driver behavior when compared against the baseline. Both systems could influence driver behavior in this segment, so it does appear that both systems significantly change behavior between locations 3 and 4, although other factors may contribute to this difference.

Between iCone locations 4 and 5, all comparisons of configurations result in a significant reduction in percentages except the comparison of WTI only to PATH only. Interestingly, the baseline configuration had the greatest change and the configuration consisting of both systems had the least reduction. All configurations with one or both of the systems showed a change in driver behavior when compared against the baseline, but this time the baseline showed greater reductions. Further, the configuration of both systems showed, on average, an increase rather than a decrease. The WTI only and PATH only configurations showed only a small decrease. It is unclear why the baseline of neither system would result in greatest positive change in behavior along this segment and why the configuration of both systems may result in a negative change.

Between iCone locations 5 and 6, all comparisons of configurations result in a significant reduction in percentages except the comparison of both to PATH only and the comparison of WTI only to PATH only. On this segment, here, even more so than on the prior segment the baseline configuration shows the greatest (positive) change of all configurations and the baseline configuration is significantly different than all other configurations. The presence of CHP at the end of the work zone might contribute to this, although it is unclear why it would differ when compared to other configurations and it is also unclear, as mentioned elsewhere in the document, as to whether CHP was at the end of the work zone throughout the baseline periods. It was observed that CHP was at the front of the work zone at other times during pilot testing.

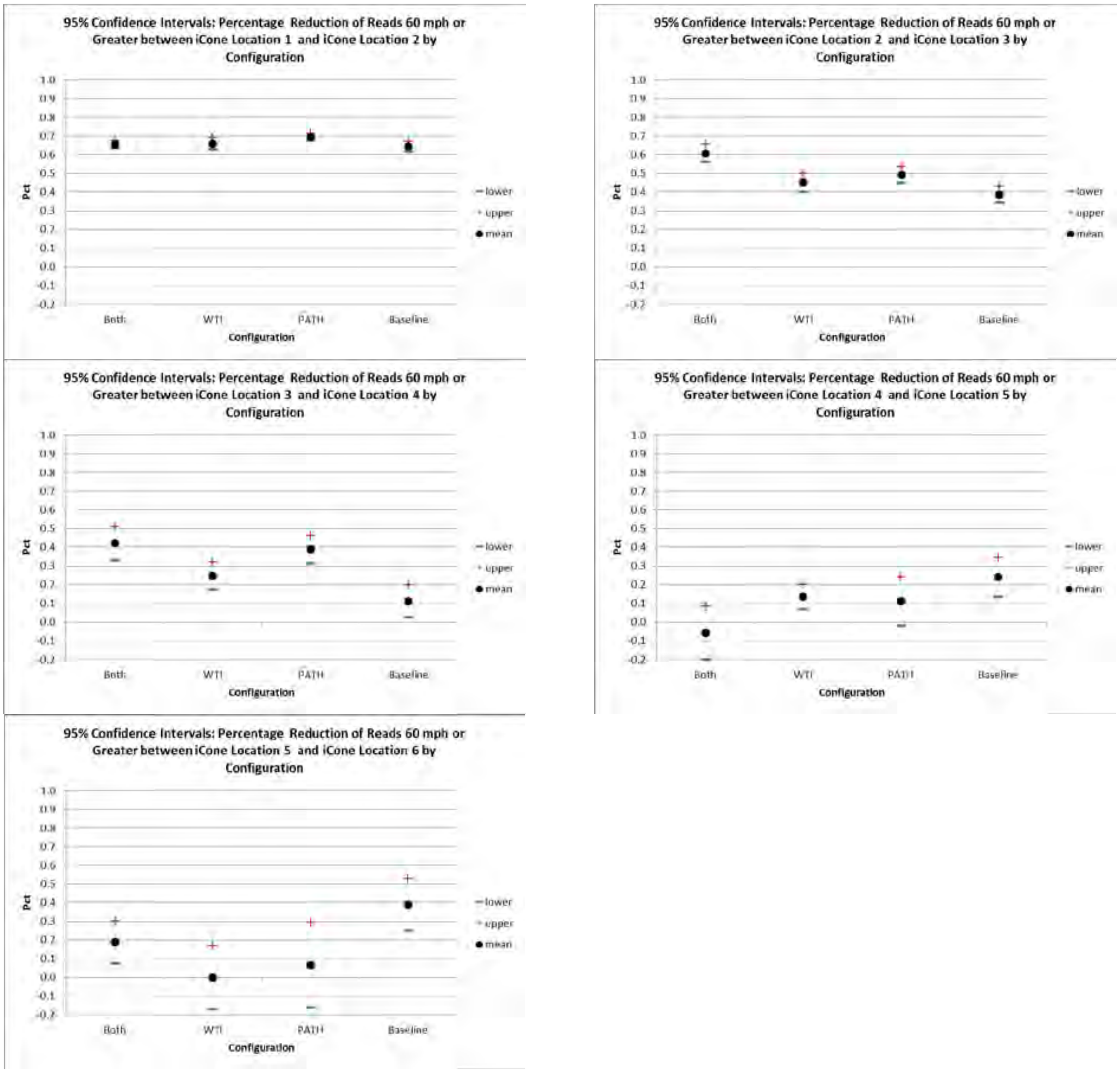


Figure 10: Confidence Interval Plots for Hourly Percentage Decrease of Reads 60 mph or Greater between Subsequent iCones by Configuration

Table 9: t-test p-values Comparing Hourly Percentage Decrease of Reads 60 mph or Greater between Subsequent iCones for Pairs of Configurations. . (The null hypothesis is that there is no difference between the means of the configuration pairs.)

		iCone Pair #'s				
Configurations Compared		1 -> 2	2 -> 3	3 -> 4	4 -> 5	5 -> 6
both	**WTI**	0.4323	**0.0000**	**0.0015**	**0.0083**	**0.0322**
both	**PATH**	**0.0025**	**0.0002**	0.2758	**0.0385**	0.1654
both	**neither**	0.2184	**0.0000**	**0.0000**	**0.0006**	**0.0126**
WTI	**PATH**	**0.0280**	0.1156	**0.0039**	0.3666	0.3125
WTI	**neither**	0.2220	**0.0284**	**0.0088**	**0.0485**	**0.0003**
PATH	**neither**	**0.0010**	**0.0005**	**0.0000**	0.0602	**0.0084**

3.2. Analysis of WTI sDrum Data

Speeds recorded by the WTI sDrums provide information about the portion of the work zone covered by the WTI sDrums only. Generally, they show a reduction in reads of speeds at or greater than 60 mph as drivers traversed this portion of the work zone, although Week 2 shows a small reduction followed by a small increase. See Figure 11. The WTI sDrum data is only available for weeks in which the WTI system was deployed. Here, we analyze percentage of overall speed reads greater than or equal to 60 mph.

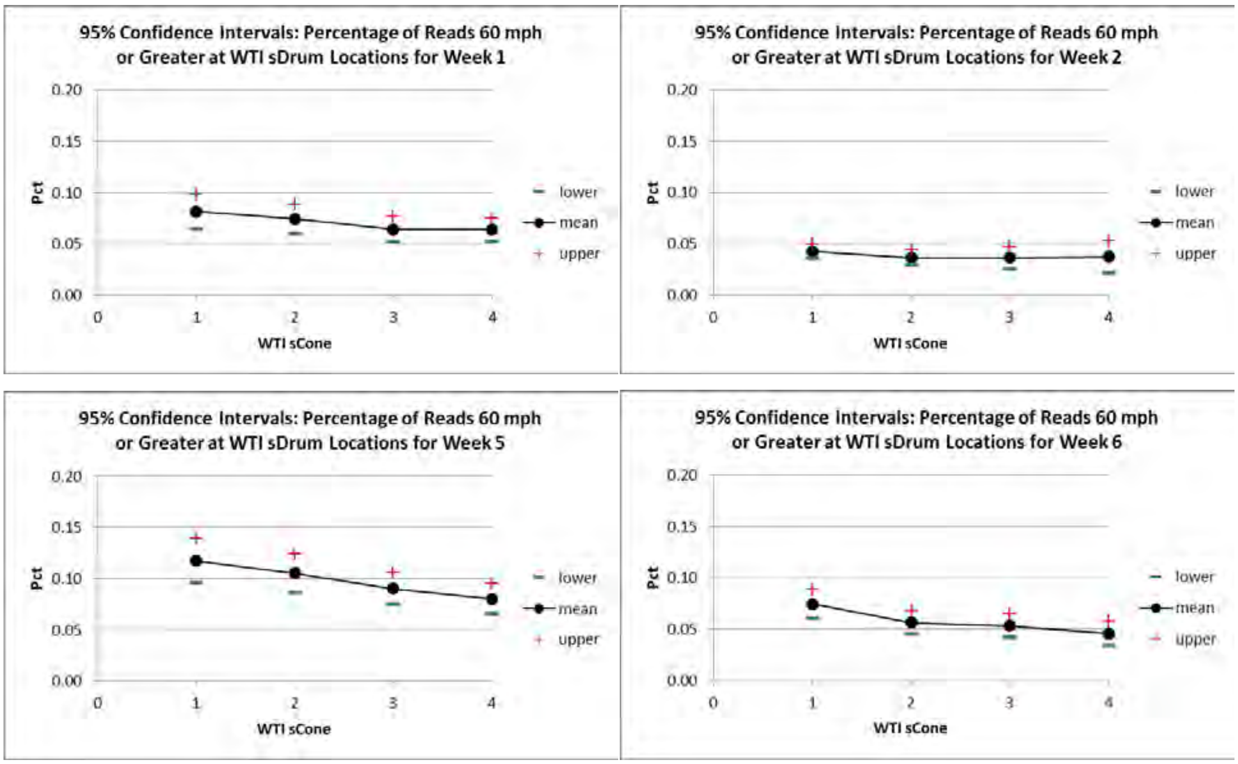


Figure 11: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by WTI sDrums

There was variation in the percentages for each WTI sDrum across the four weeks that the WTI system was deployed. The rates appear lower during weeks 2 and 6, which are weeks in which both systems were deployed. See Figure 12.

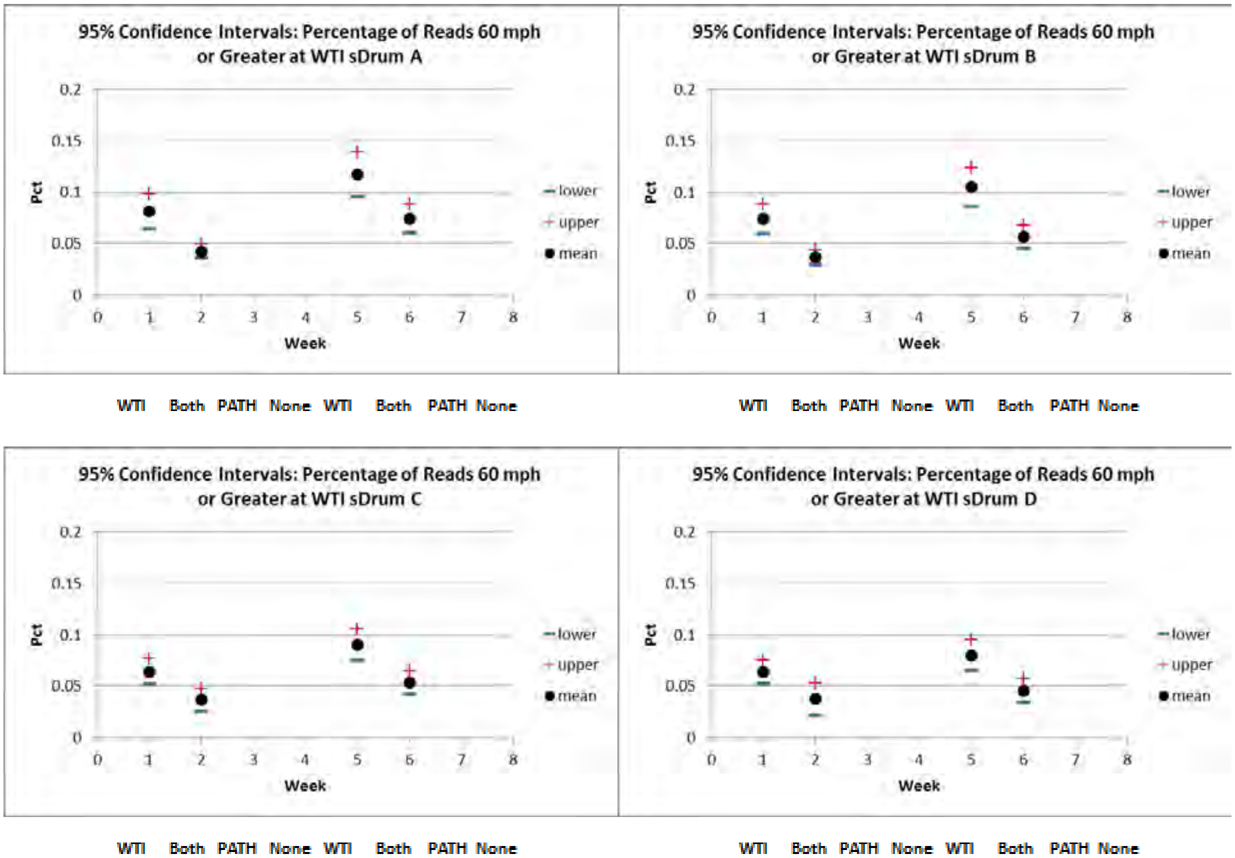


Figure 12: Confidence Interval Plots for Hourly Percentage of Reads 60 mph or Greater Measured by WTI sDrums by Week

Statistical significance tests were used to determine if the reduction in rates between subsequent sDrum locations were significant at the 95% level. Associated 95% confidence intervals were also determined. At this level, rate reduction between sDrums A and B were determined to be significant for all four weeks in which the WTI system was deployed. Rate reduction between sDrums B and C were determined to be significant for Weeks 1, 5 and 6, but not for week 2. Rate reduction between sDrums C and D were determined to be significant for Weeks 5 and 6 but not for Weeks 1 and 2. And, rate reduction between sDrums A and D were determined to be significant for Weeks 1, 5 and 6 but not for Week 2. See Figure 13, Figure 14, Table 10 and Table 11. As such, it appears that drivers reduced their speeds, at least initially, when the WTI system was present, but it is difficult to further assess the impact of the systems.

Table 10: Confidence Intervals and t-test Results for Change in Hourly Percentage of Reads 60 mph or Greater between WTI sDrums. (The null hypothesis is that the mean is zero.)

		95% Confidence Interval			
Location	Week	lower	mean	upper	t-test p value
A-B	1	-0.0117	-0.0070	-0.0024	**0.0022**
A-B	2	-0.0100	-0.0060	-0.0019	**0.0030**
A-B	5	-0.0198	-0.0120	-0.0042	**0.0024**
A-B	6	-0.0233	-0.0180	-0.0127	**0.0000**
B-C	1	-0.0175	-0.0103	-0.0030	**0.0348**
B-C	2	-0.0073	-0.0001	0.0070	0.4843
B-C	5	-0.0495	-0.0370	-0.0246	**0.0000**
B-C	6	-0.0072	-0.0034	0.0005	**0.0400**
C-D	1	-0.0062	-0.0004	0.0055	0.4513
C-D	2	-0.0058	0.0008	0.0073	0.4056
C-D	5	-0.0165	-0.0099	-0.0033	**0.0028**
C-D	6	-0.0136	-0.0074	-0.0011	**0.0124**

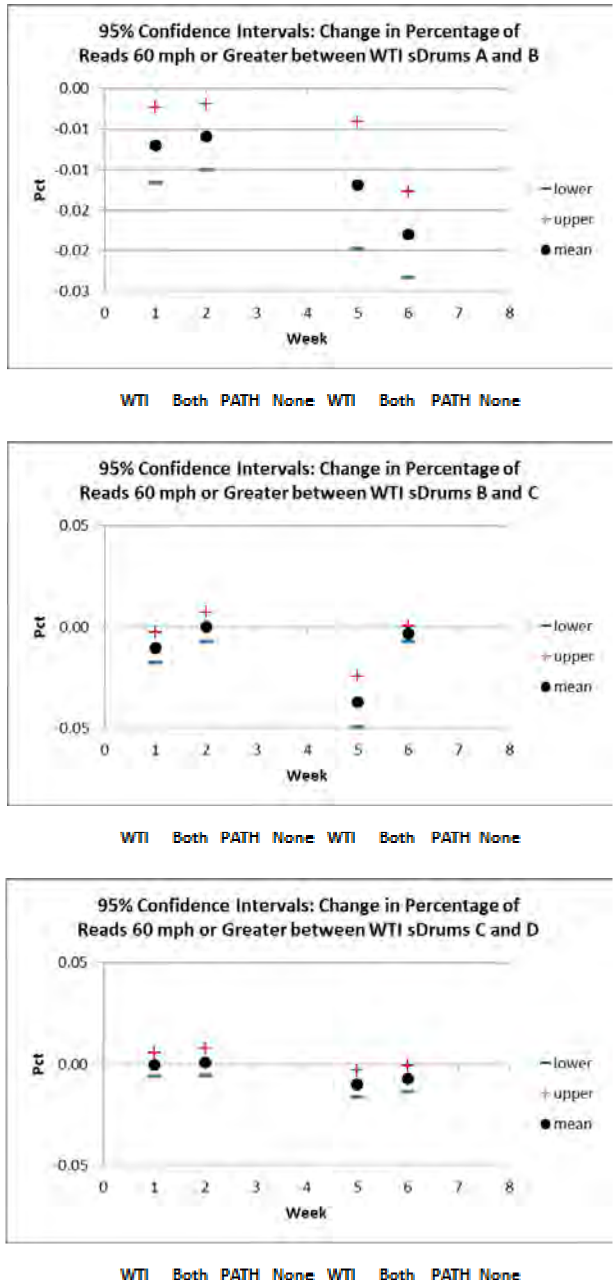


Figure 13: Confidence Interval Plots for Change in Hourly Percentage of Reads 60 mph or Greater between WTI sDrums by Location

Table 11: Confidence Intervals and t-test Results for Change in Hourly Percentage of Reads 60 mph or Greater between First and Last WTI sDrums

		95% Confidence Interval			
Location	Week	lower	mean	upper	t-test p value
A-D	1	-0.0326	-0.0176	-0.0027	**0.0111**
A-D	2	-0.0205	-0.0053	0.0099	0.2359
A-D	5	-0.0355	-0.0250	-0.0146	**0.0000**
A-D	6	-0.0378	-0.0288	-0.0198	**0.0000**

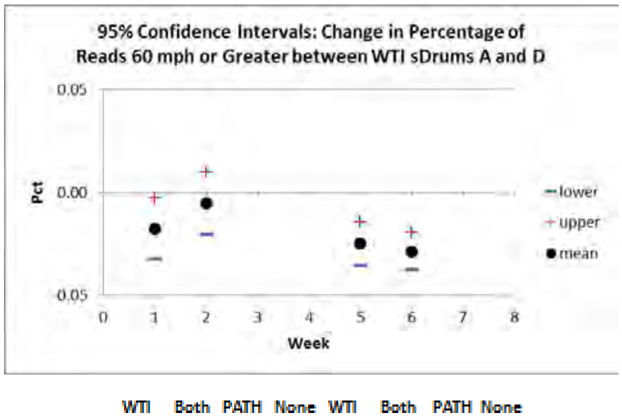


Figure 14: Confidence Interval Plot for Change in Hourly Percentage of Reads 60 mph or Greater between First and Last WTI sDrums

4. DISCUSSION

There were a number of issues making evaluation of the aSE systems effectiveness challenging. The following sections discuss those issues.

4.1. Multiple speed readings per vehicle

Both the iCone radar and WTI's radar produced multiple speed readings per vehicle. In an effort to minimize multiple readings per vehicle the iCone radar was configured to record a speed then sleep for ½ second before recording another speed. Although the exact number of multiple speed reads is not known a quick look at the iCone data showed several instances of four reads per vehicle.

The WTI radar produced speed readings approximately every 400 milliseconds consequently there were multiple speed readings per vehicle. For a vehicle traveling alone there were four to about 18 speed readings per vehicle, depending on the vehicle's speed and radar signature and the radar's range. The radar data showed drum B's radar range was noticeably greater (typically 50% more readings) than the other radars which may have biased its data.

Note, from viewing video along with the corresponding radar speed readings a car tucked in between two trucks is not identifiable in the speed data.

4.2. Radar offset

The vehicle must be in a direct line (collision course) with the radar to measure the exact speed. A small offset is acceptable and clearly necessary to measure speed safely with radar. Radar works by measuring the frequency shift (Doppler Shift) of the vehicle's reflected signal, then calculating the speed from the frequency shift. If the vehicle is significantly offset from a direct line, the cosine effect comes into play causing the radars speed reading to be lower than the actual speed.[1] As a result, speed readings for a given vehicle traveling at a constant speed will be closest to actual when the vehicle is furthest from the radar and will be furthest from and lower than actual when the vehicle is closest to the radar.

4.3. Traffic entering and leaving the closure via side roads

A cross road or side road was within the closure area for many deployment locations. Traffic was entering and leaving the closure area which caused the number of readings per radar to differ slightly. At a few closure locations a major arterial was located just before or after the closure, affecting speeds.

4.4. MAZEEP location

MAZEEP's location varied significantly during the first week of deployment, from in the taper to back off the road at the end of the closure. Also, the patrol car's emergency lights were illuminated sometimes and not other times, which may have affected vehicle speeds.

Generally from June 11 - 22 MAZEEP was parked at the end of the closure with external emergency lights illuminated but several MAZEEP vehicles did not have external emergency lights. The authors do not know where MAZEEP was located during PATH alone and baseline deployments.

4.5. Maintenance worker and researcher location within the work zone

The location of the maintenance workers in the closure varied during the day as their work progressed. Generally they started at the beginning of the closure in the morning and worked their way towards the end of the closure. Occasionally, due to side road issues or short days, the closure remained in the same or nearly the same location for a second day and the crew started where they had left off the previous day. The researchers noted traffic appeared to slow where maintenance personnel were present.

The number and location of the researchers working in the closure varied from day to day and sometimes hour to hour. As many as four researchers could be troubleshooting a deployed system. Typically the troubleshooting lasted less than 30 minutes per event and may occur several times a day. The attenuator truck was placed near the traffic lane to protect the researchers when they were working on the system. The researchers noted vehicles and personnel in the closed lane, especially near the traffic lane, appeared to slow traffic.

4.6. Maintenance trucks located in the closed lane

The attenuator truck was occasionally parked in the closed lane for extended periods of time which appeared to slow approaching traffic. The cone truck was periodically used to setup toppled cones and was occasionally parked in the closed lane.

4.7. iCone pointing variation

During the first week of deployment the iCones were first pointed at a 10 degree angle to the direction of traffic but soon changed to a 20 degree angle in an attempt to reduce multiple speed reads per vehicle. The 20 degree angle reduces speed readings from actual speeds by approximately 4% from the cosine effect.

4.8. iCone and sDrum location variation

The iCone locations varied on the roadway from the middle of the closed lane to the outside edge of the shoulder. During the May 14 – 24 deployment the iCones were mainly in the center of the closed lane. During the second deployment from June 11 – 22 they were mainly against the edge of the closed lane.

Relative to the closure, the iCones were repositioned occasionally after initial deployment although after reviewing the iCone GPS data it was determined that by 1 PM the iCones were in their final location of the day. They were also sporadically spaced differently than the plan shown in Figure 1. Using screen captures of the iCone website, the location of the iCones at 1PM PDT is shown in Appendix Figures 16 – 44 for the eight weeks of deployment.

Figures 45 – 63

, in the Appendix, show the location of the sDrums in relation to the iCones for the four weeks the sDrum system was deployed. The sDrum locations were obtained from video, still images, and the researcher’s notes and memories. The variation in iCone locations during the four weeks of WTI deployment are noted below:

Table 12: iCone Location Variation

Dates	iCone	Comments
5/14/12–5/24/12	4 – 6	spaced midway between the WTI radar drums
5/17/12	3	outside edge of the shoulder instead of the middle of the closed lane
6/11/12, 6/12/12, 6/14/12, 6/15/12	–	iCones maintained consistent positions relative to the sDrums
6/13/12	3	350 feet before sDrum A and iCone4 was 600 feet after the last sDrum (only 6 sDrums deployed)
6/18/12	4 – 6	not in the same position as previous days
6/20/12	4	located between the first and last sDrum (only 6 sDrums deployed)
6/22/12	6	different location than the previous days

Typical sDrum and iCone locations for May 14 through May 18 are shown in Figure 15.

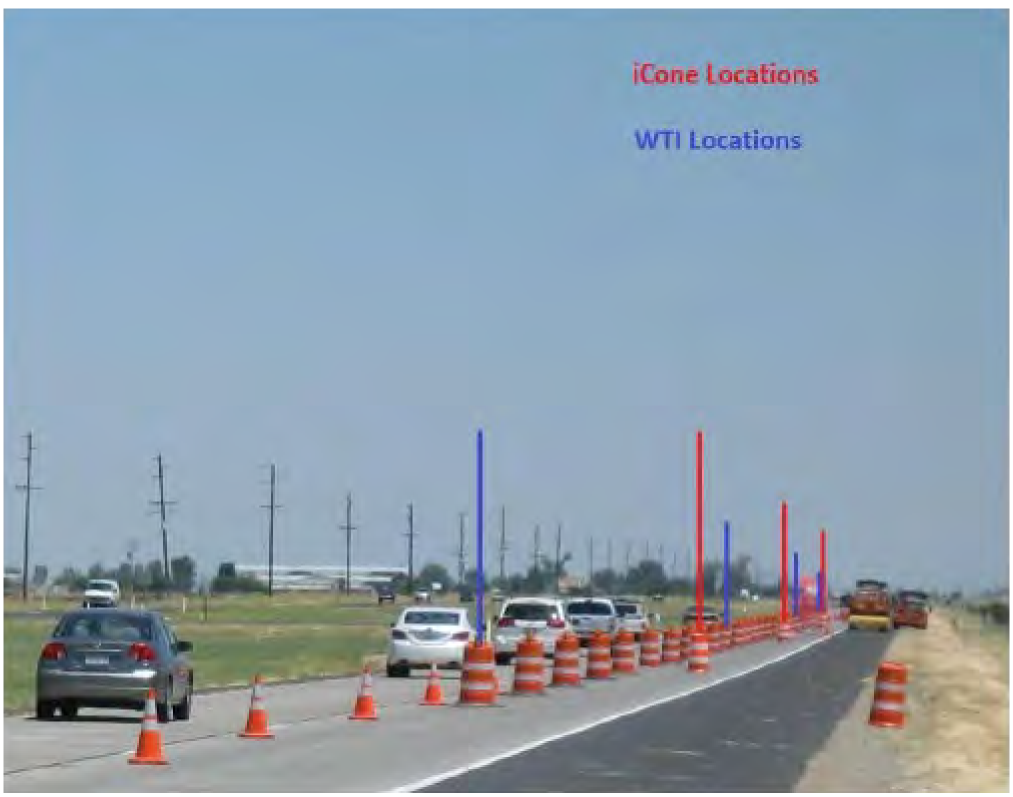


Figure 15: Typical May 14 – 18 iCone and sDrum Locations

Note only six out of the normal 28 sDrums were deployed on 6/13/12 and 6/20/12.

4.9. Different Thresholds for the Two Systems

The threshold for the PATH system was set at 56 mph. The threshold for the WTI system was set at 60 mph. Thus, more drivers would receive warning from the PATH system than from the WTI system and, because of the relative location of the two systems, drivers would receive notification earlier from the PATH system than from the WTI system. Thus, direct comparison of the two systems is questionable.

4.10. Impact of Congestion Versus Free Flow – Traffic Volume

During times of congestion, drivers may be forced to slow by the vehicles in front of them rather than by their own choice of a safe speed. It is unclear if times of congestion versus free flow average out over the pilot testing period or if results for certain configurations may have been biased by such conditions. Times in which the work zone was closer to Los Banos may have resulted in greater congestion and there may have been times in which the traffic volume may have been out of the ordinary. Special events, holiday weekends, closures on nearby roads, etc. could have such an impact. It is unclear if such events had a significant impact on traffic during this study.

5. CONCLUSION

The systems do appear to have an impact on driver behavior as demonstrated by reduced average speeds and reduced percentages of radar reads of vehicle speeds greater than or equal to 60 mph at affected locations in the work zone. For instance, the configuration consisting of both systems showed a reduction in overall average speed of approximately 2.4 mph in the areas affected by both systems. For the configuration consisting of both systems, approximately 40% of vehicles entering this affected area at 60 mph or above reduced their speed to below 60 mph within this same area. For the baseline, there was only a 10% reduction in this portion of the work zone. Where differences in the percentages are statistically significant and in portions of the work zone affected by both systems, the indication is that the configurations consisting of both systems, the PATH system alone, and the WTI system alone all showed improvement, demonstrated by reduced percentages of speeds 60 mph or greater over the baseline consisting of neither system (no treatment). This is consistent with our general hypothesis regarding the expected impact of these systems.

There are also statistically significant differences in the percentages at locations preceding the systems, which indicate that other factors should be considered in order to make valid comparisons and conclusions, since these locations would not have been influenced by either of the systems. And, there are apparent reductions in speed during baseline weeks at the end of the work zone, which indicates that other factors are involved. For instance, the location of the CHP vehicle was sometimes at the beginning of the taper in the work zone and at other times at the end of the work zone during times in which the WTI system was in operation. The work zone itself was not in the same location throughout the evaluation period. Proximity to Los Banos, traffic to and from side roads and variation in the placement of the iCones also may have contributed general variability and specific differences between rates. As such, engineering judgment will be critical prior to deploying these systems, and further study is recommended. And, it must be noted that the systems are prototypes only – further research and development would be necessary prior to production use.

6. APPENDIX

6.1. Daily iCone locations

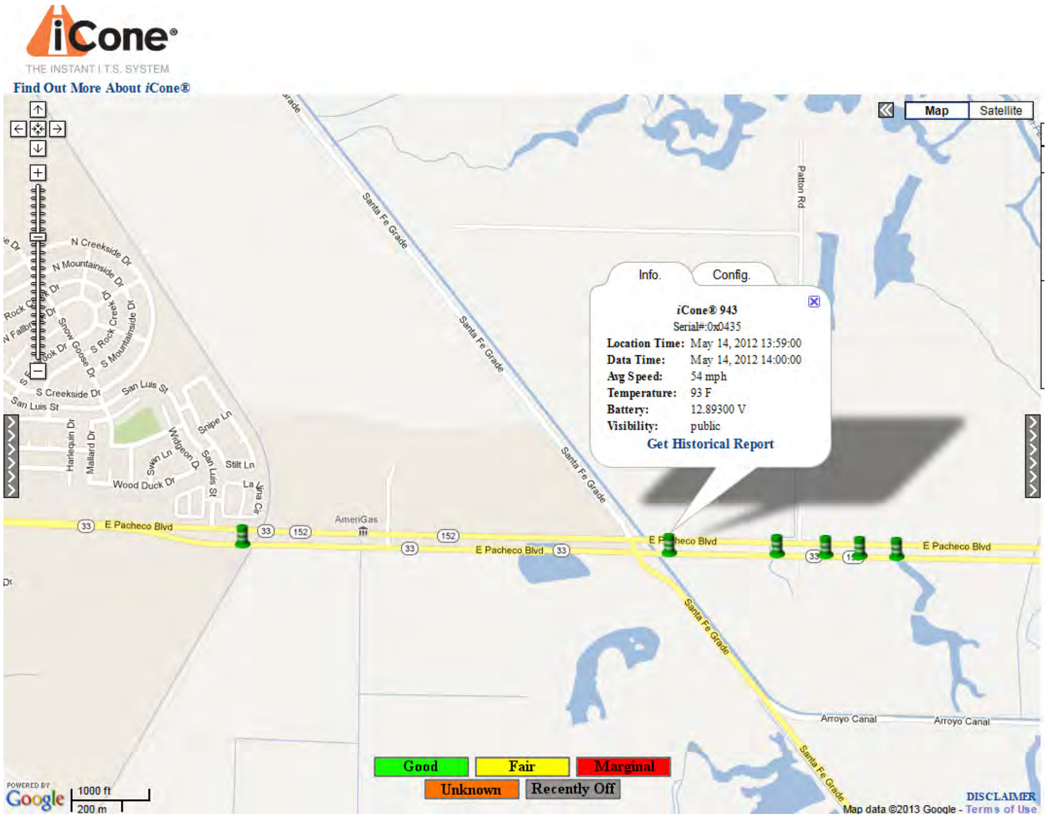


Figure 16: iCone Location Map for 5/14/12 - WTI

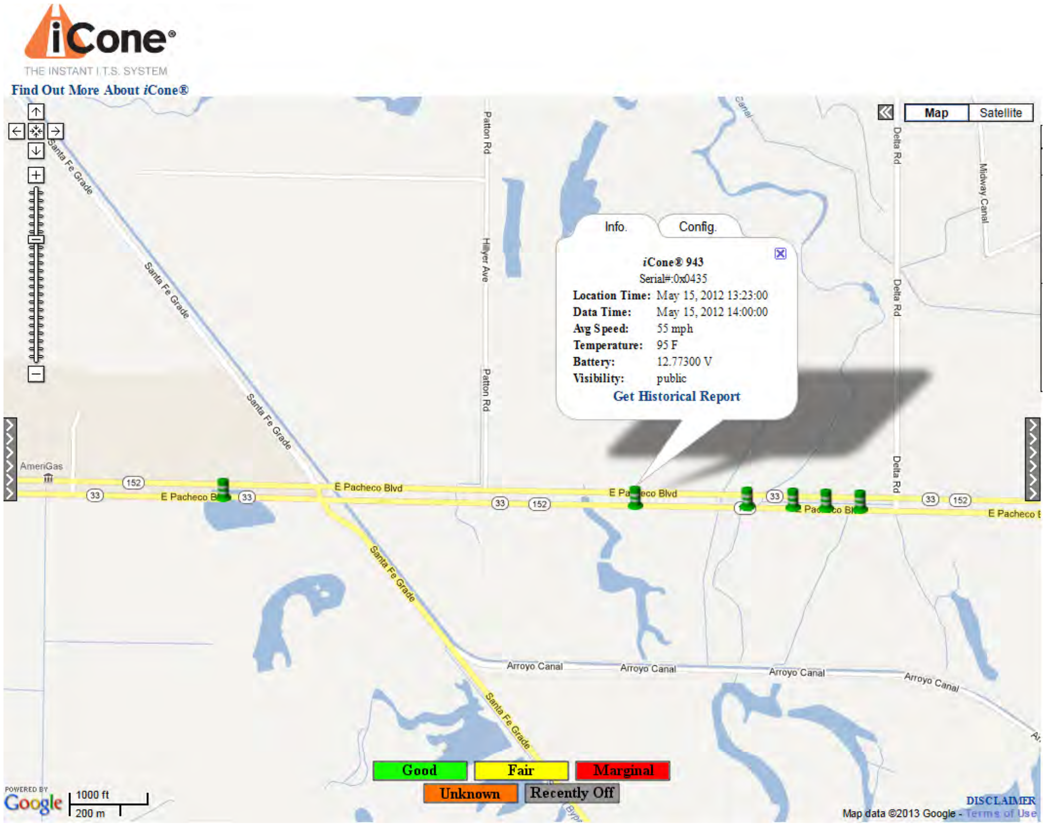


Figure 17: iCone Location Map for 5/15/12 - WTI

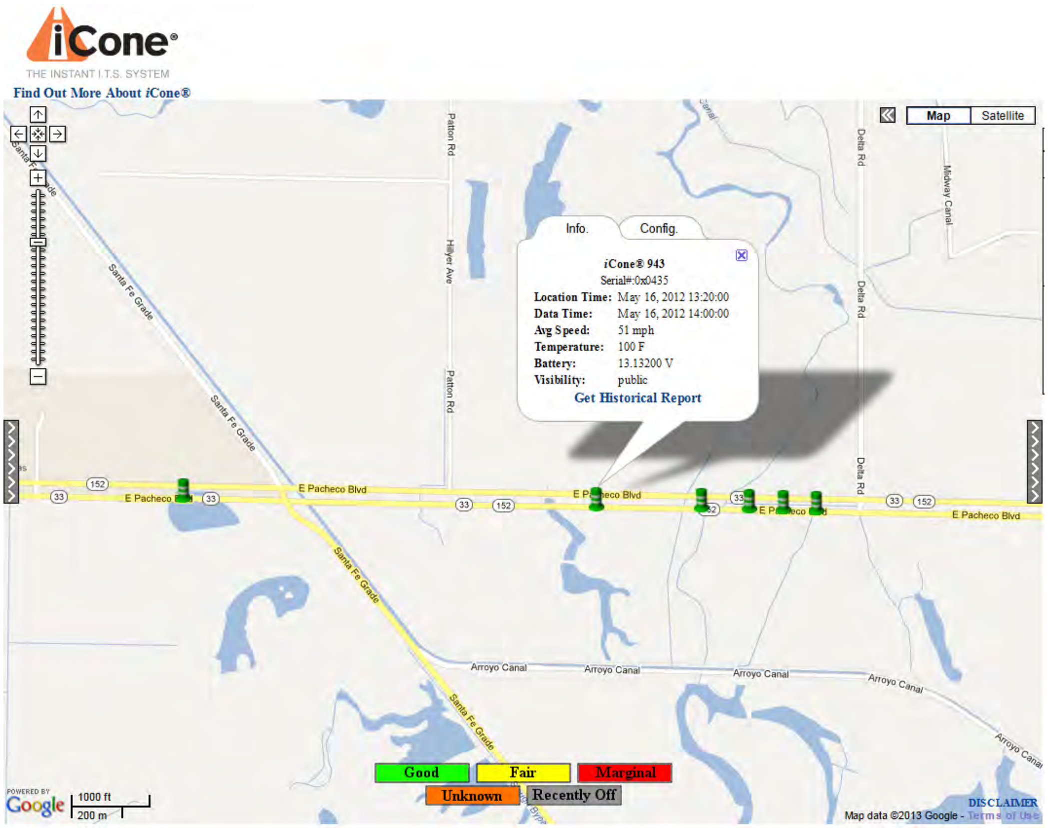


Figure 18: iCone Location Map for 5/16/12 – WTI

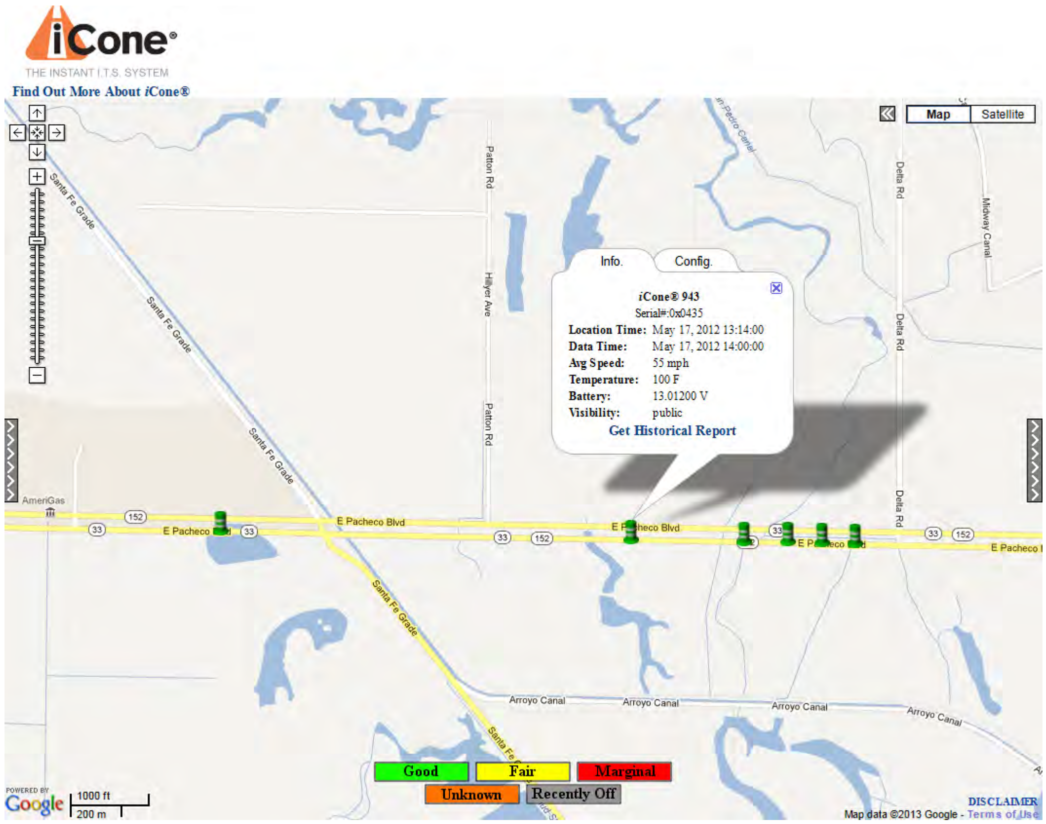


Figure 19: iCone Location Map for 5/17/12 - WTI

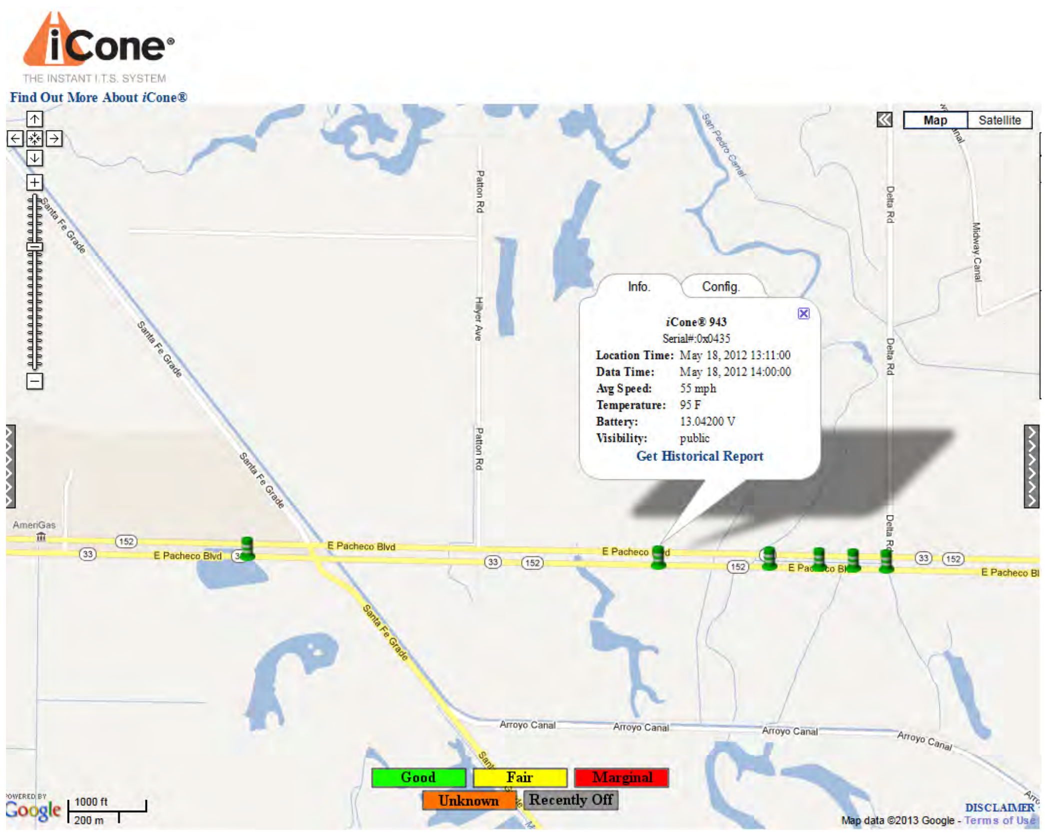


Figure 20: iCone Location Map for 5/18/12 - WTI

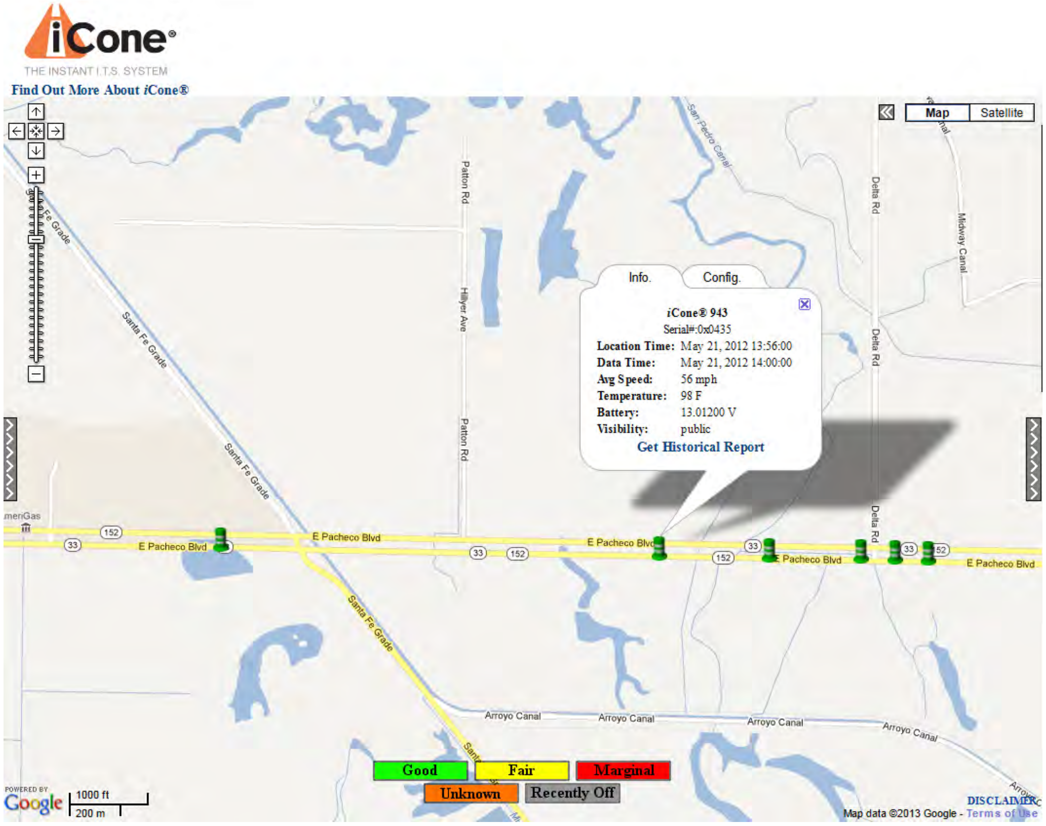


Figure 21: iCone Location Map for 5/21/12 - both

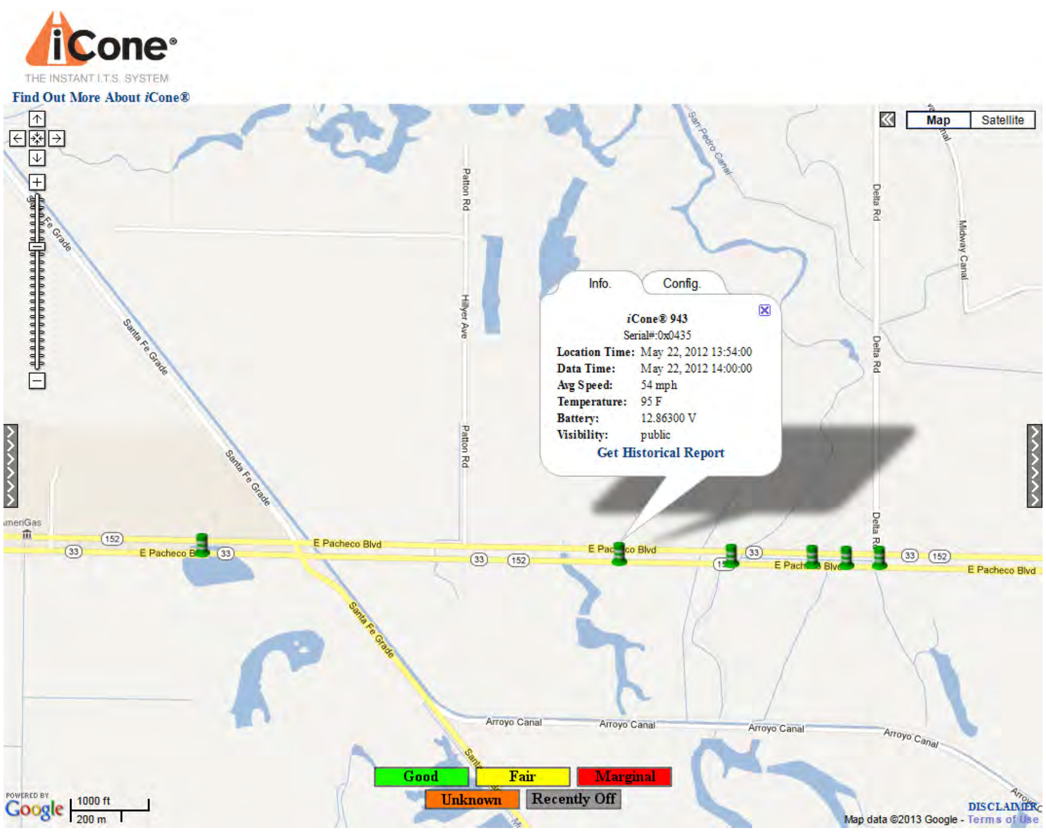


Figure 22: iCone Location Map for 5/22/12 - both

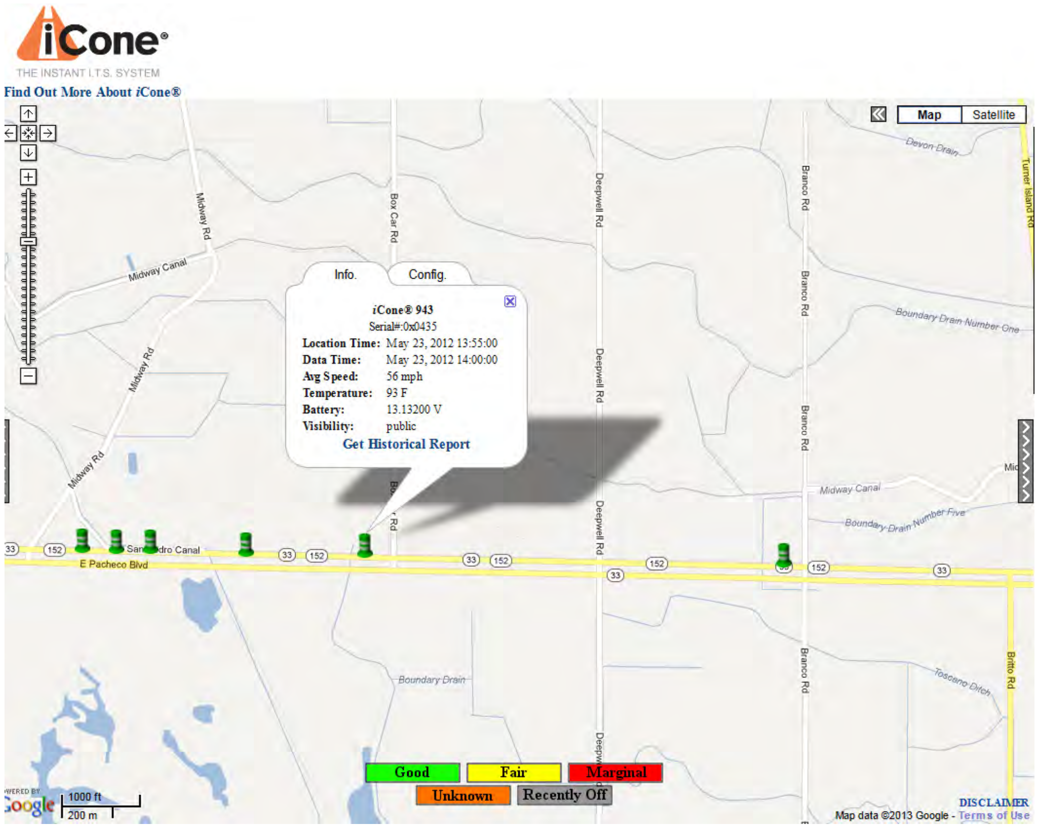


Figure 23: iCone Location Map for 5/23/12 - both

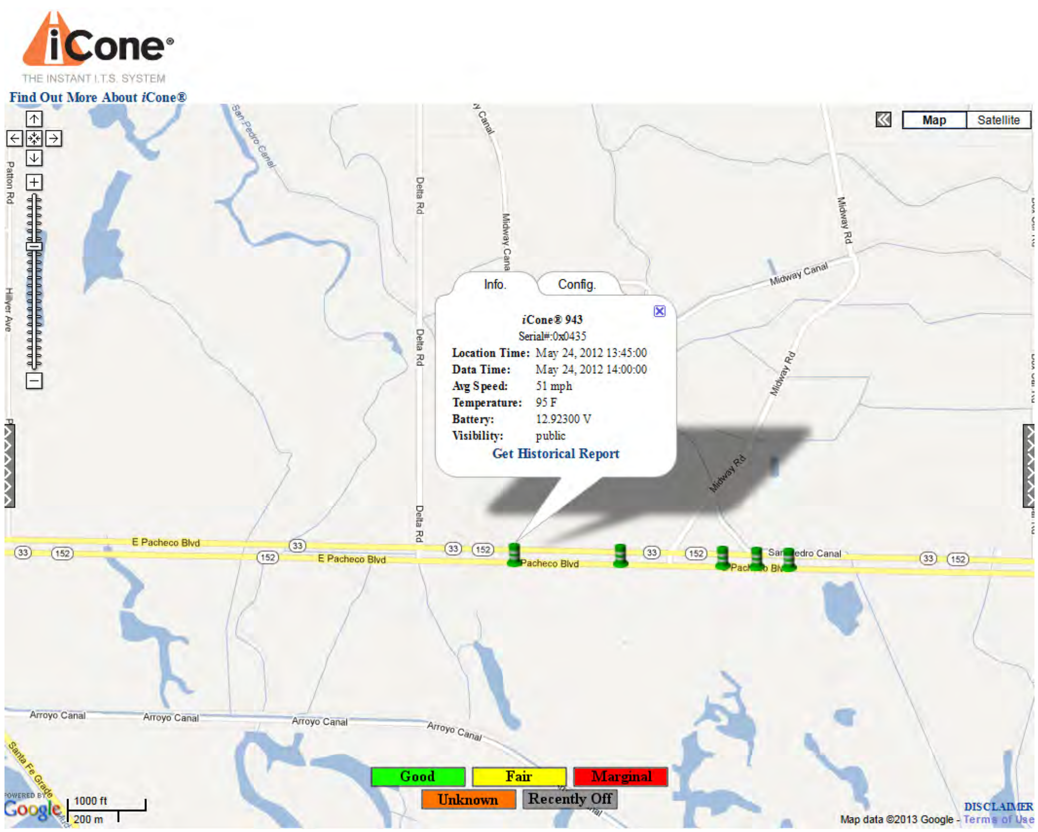


Figure 24: iCone Location Map for 5/24/12 - both

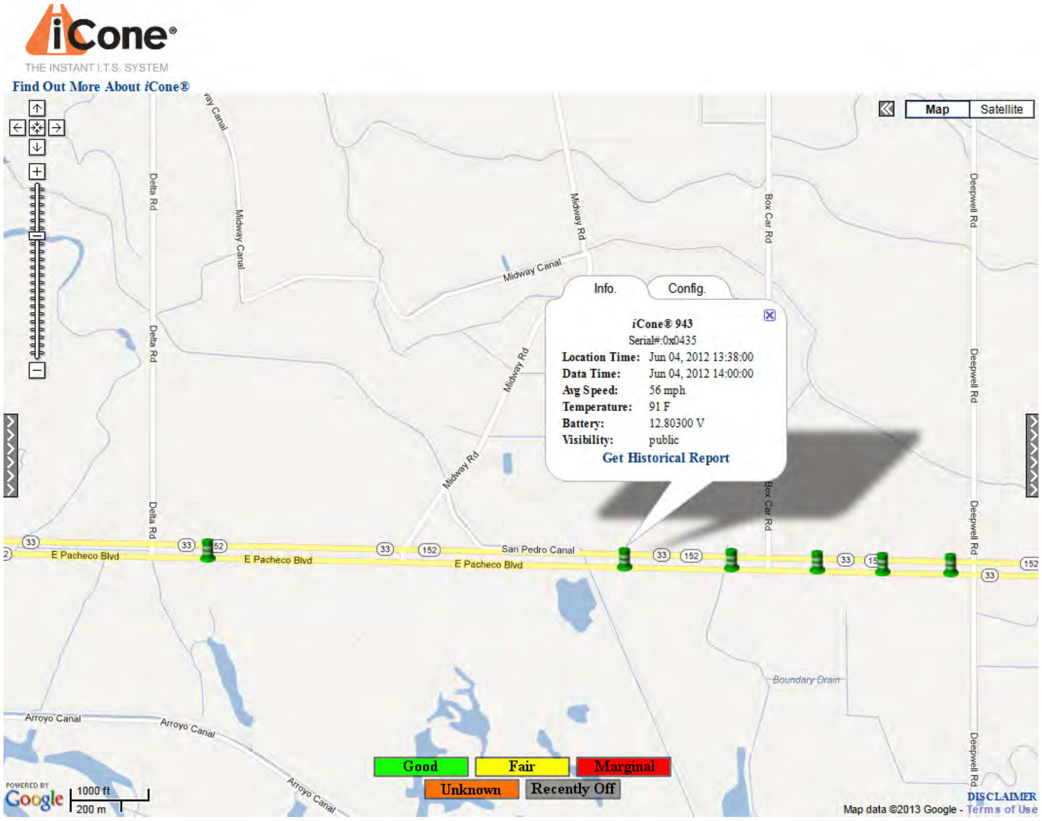


Figure 25: iCone Location Map for 6/4/12 - baseline

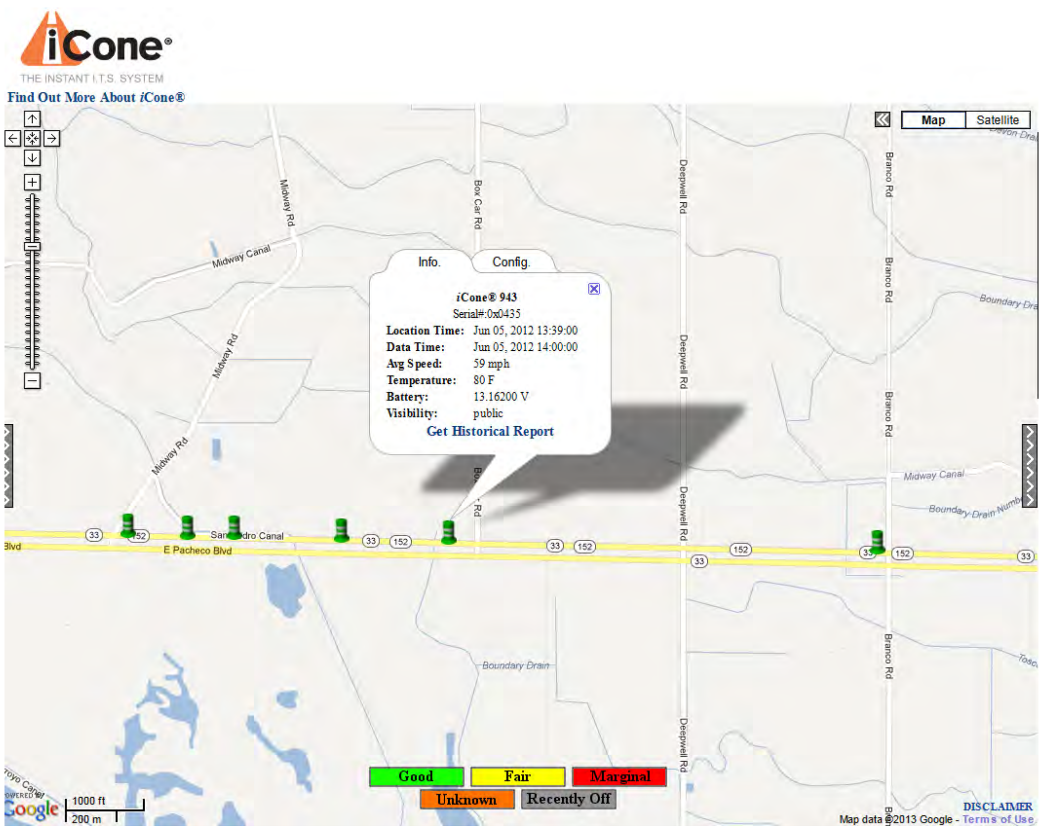


Figure 26: iCone Location Map for 6/5/12 - baseline

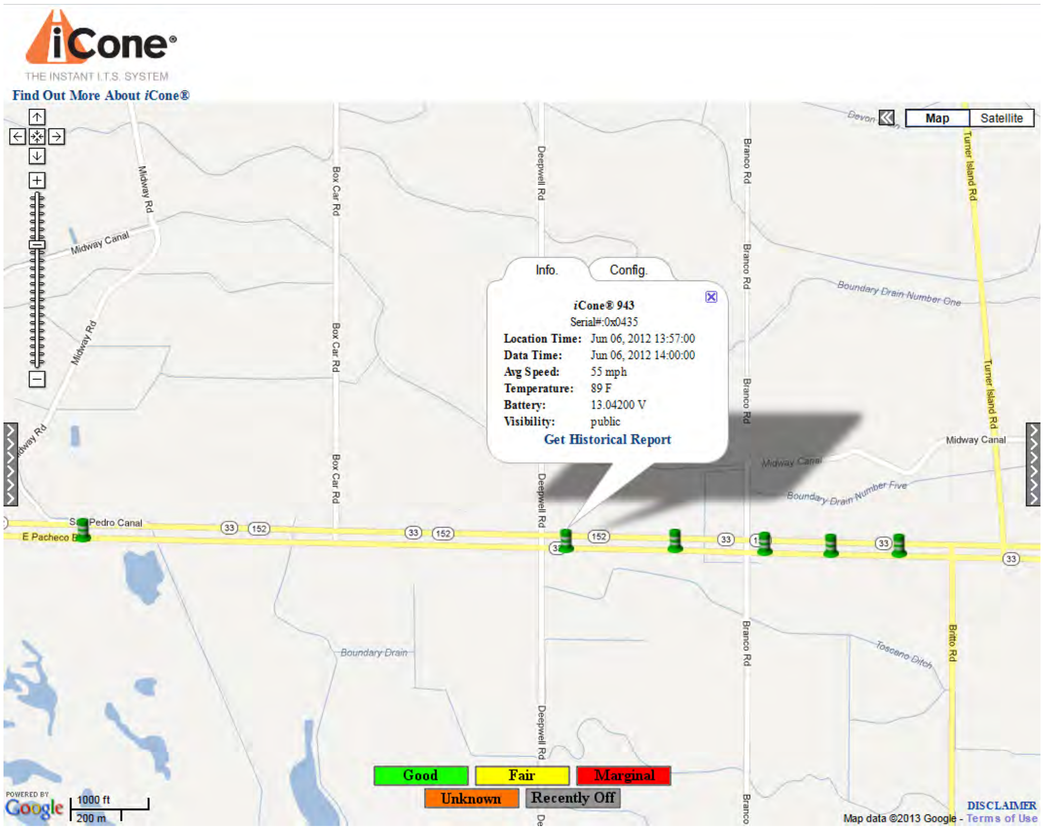


Figure 27: iCone Location Map for 6/6/12 – baseline

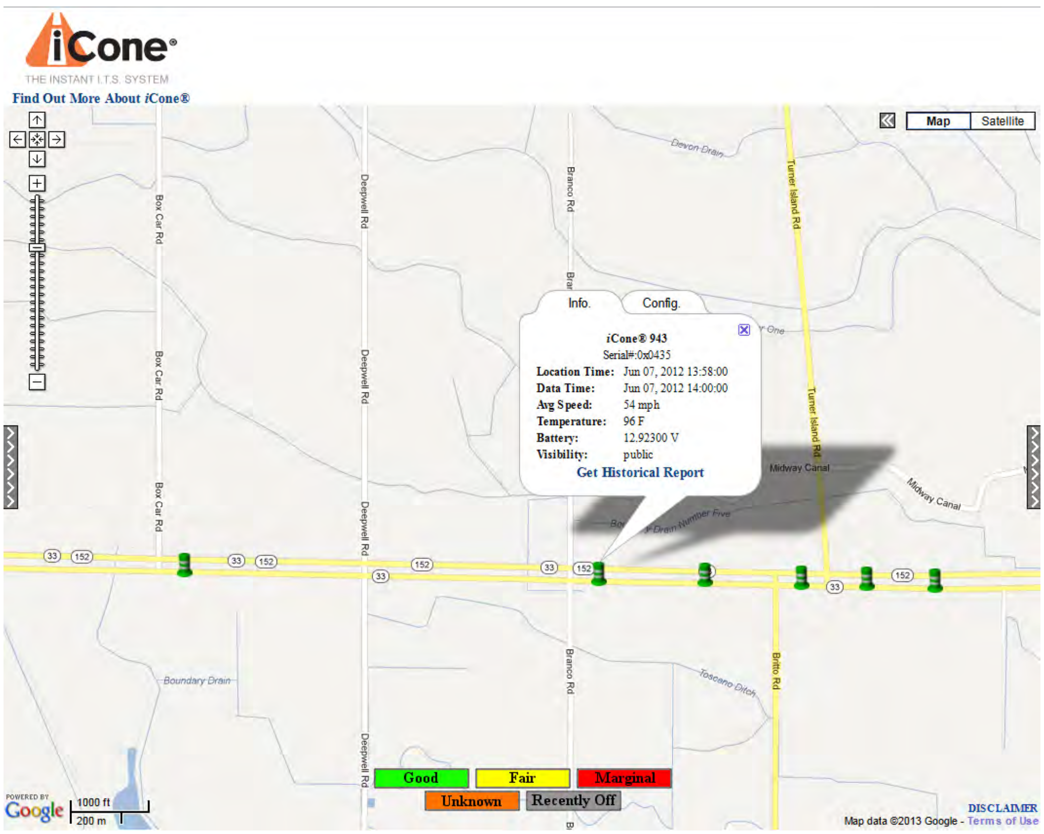


Figure 28: iCone Location Map for 6/7/12 – baseline

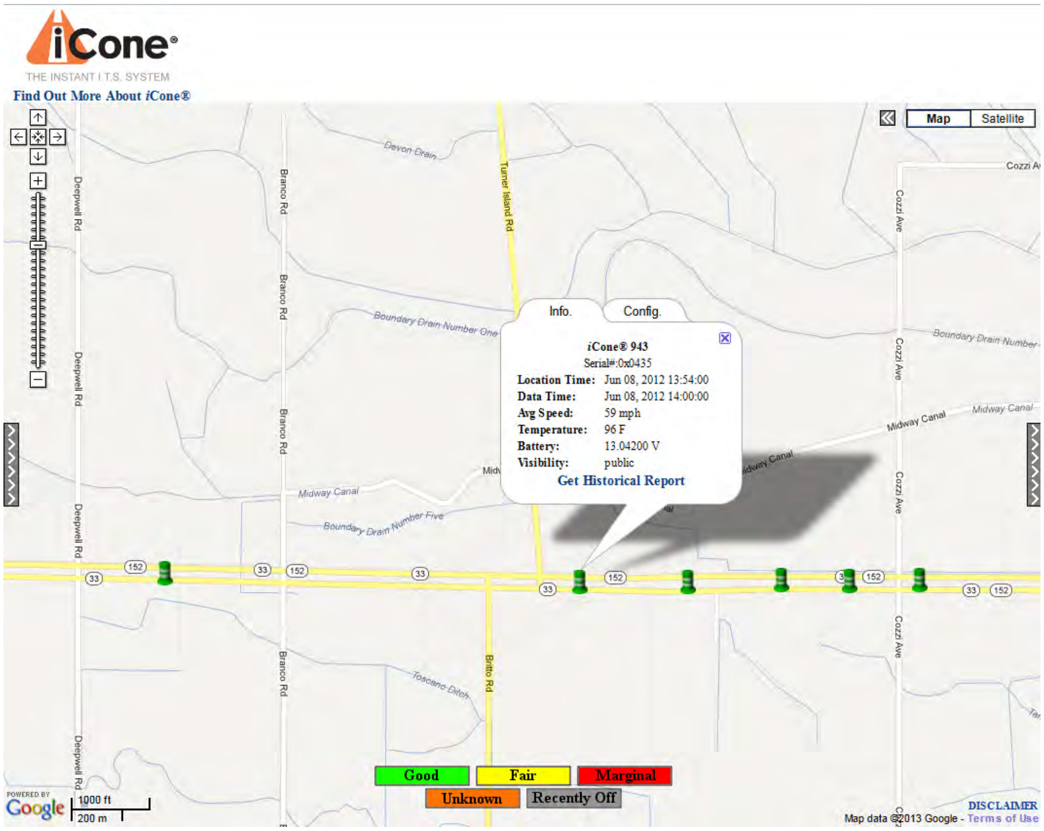


Figure 29: iCone Location Map for 6/8/12 – baseline

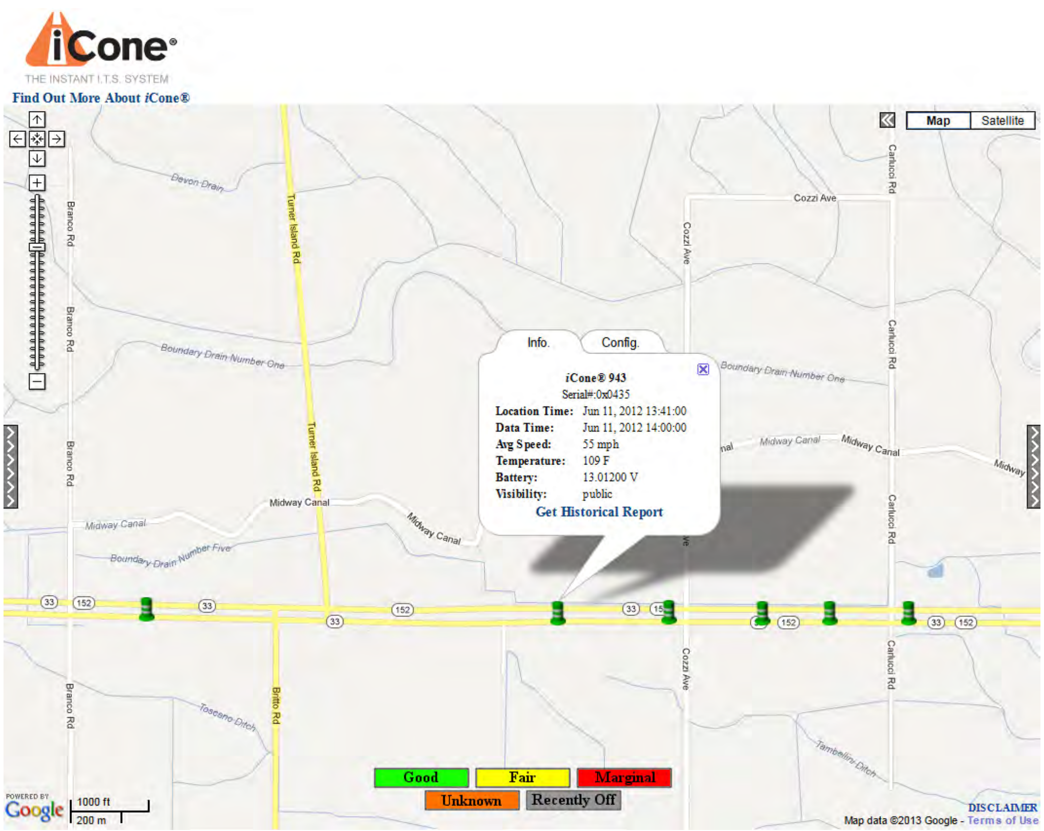


Figure 30: iCone Location Map for 6/11/12 - WTI

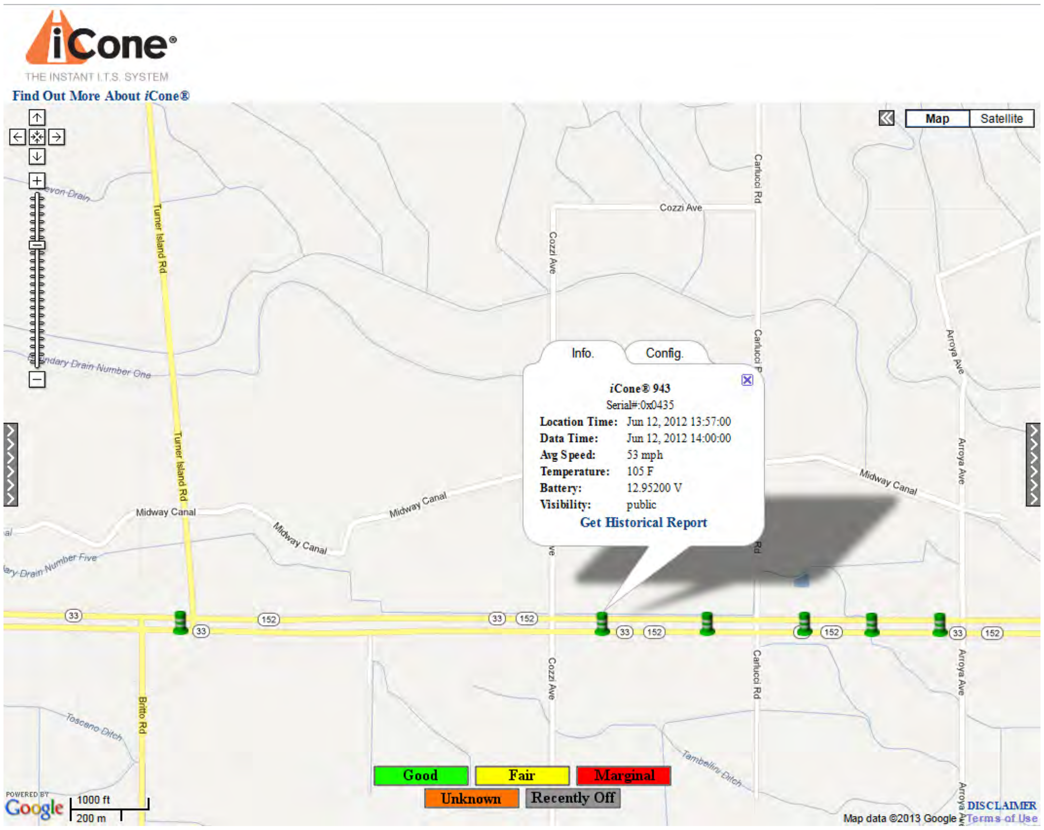


Figure 31: iCone Location Map for 6/12/12 – WTI

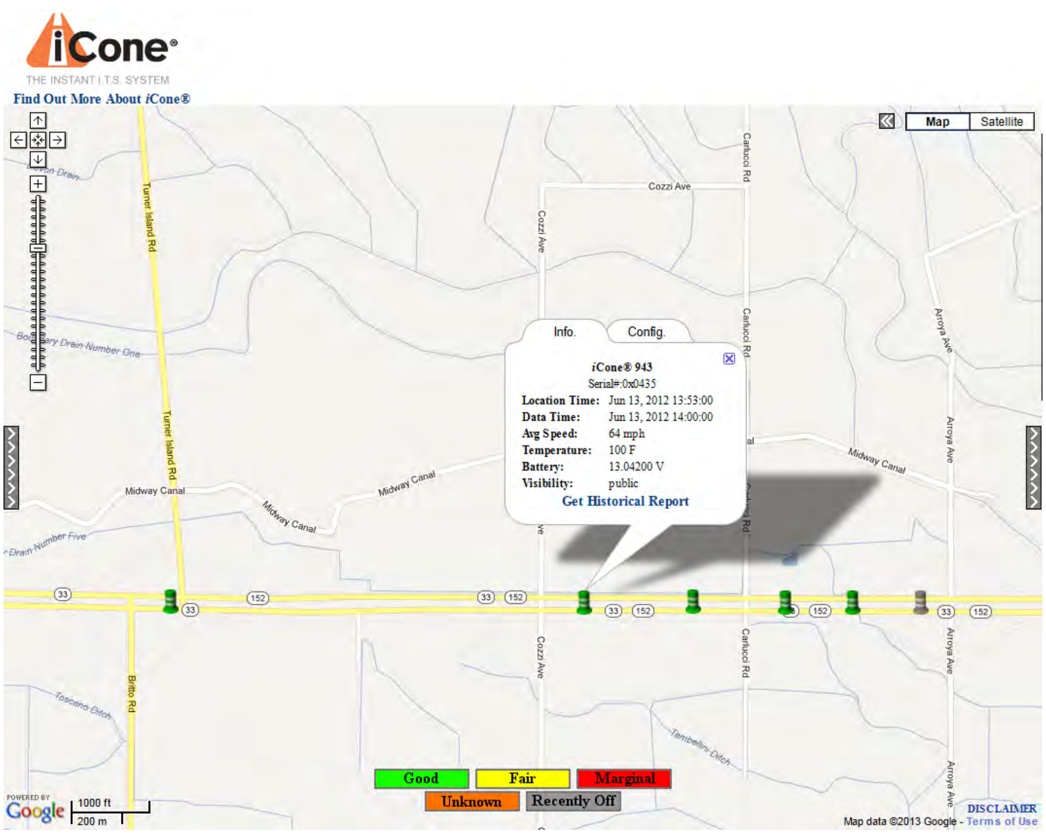


Figure 32: iCone Location Map for 6/13/12 - WTI

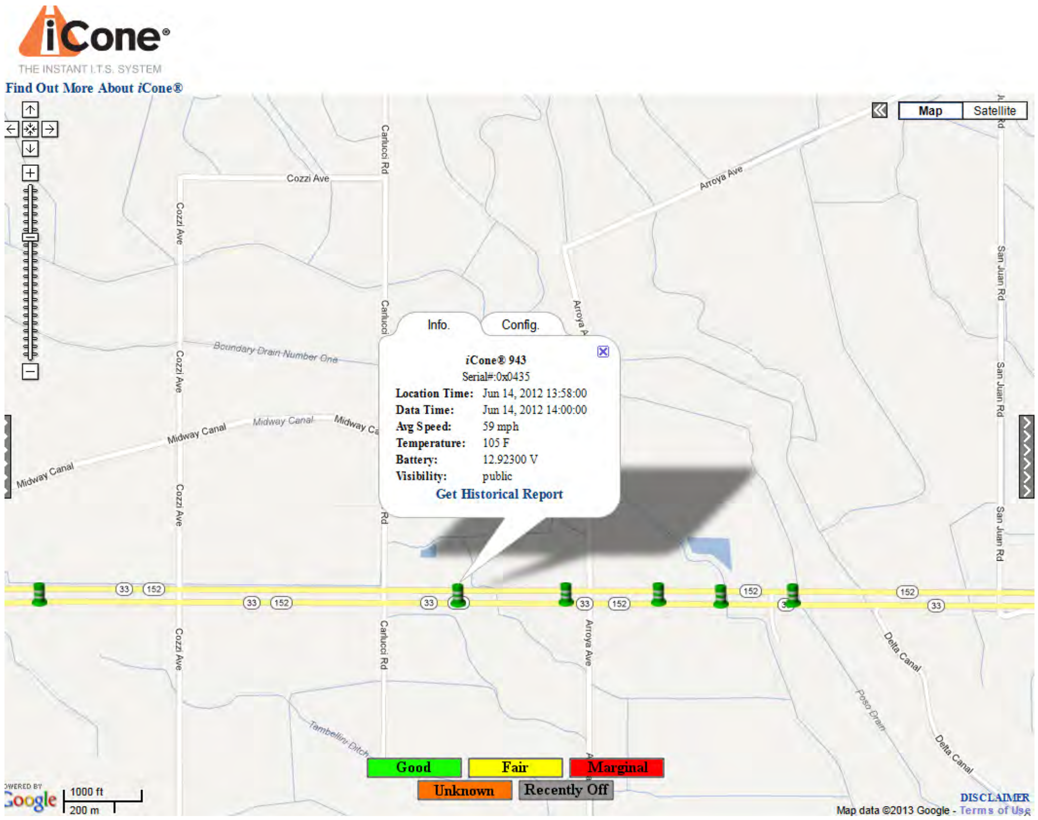


Figure 33: iCone Location Map for 6/14/12 - WTI

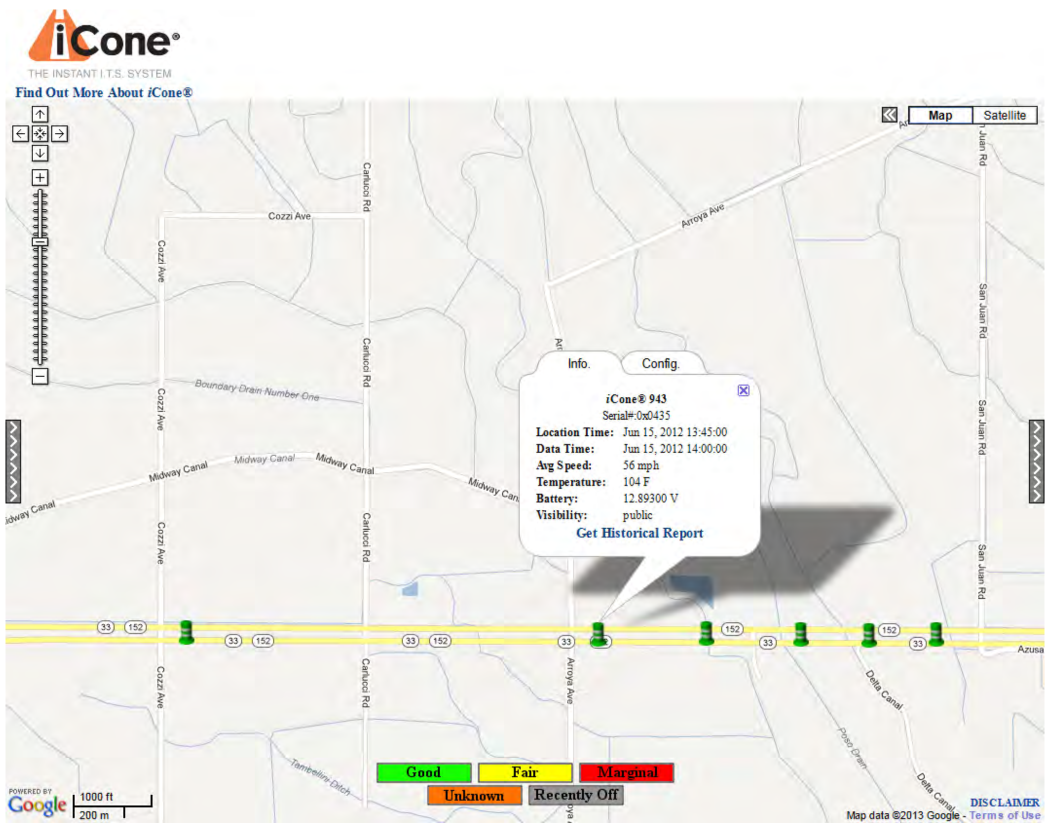


Figure 34: iCone Location Map for 6/15/12 - WTI

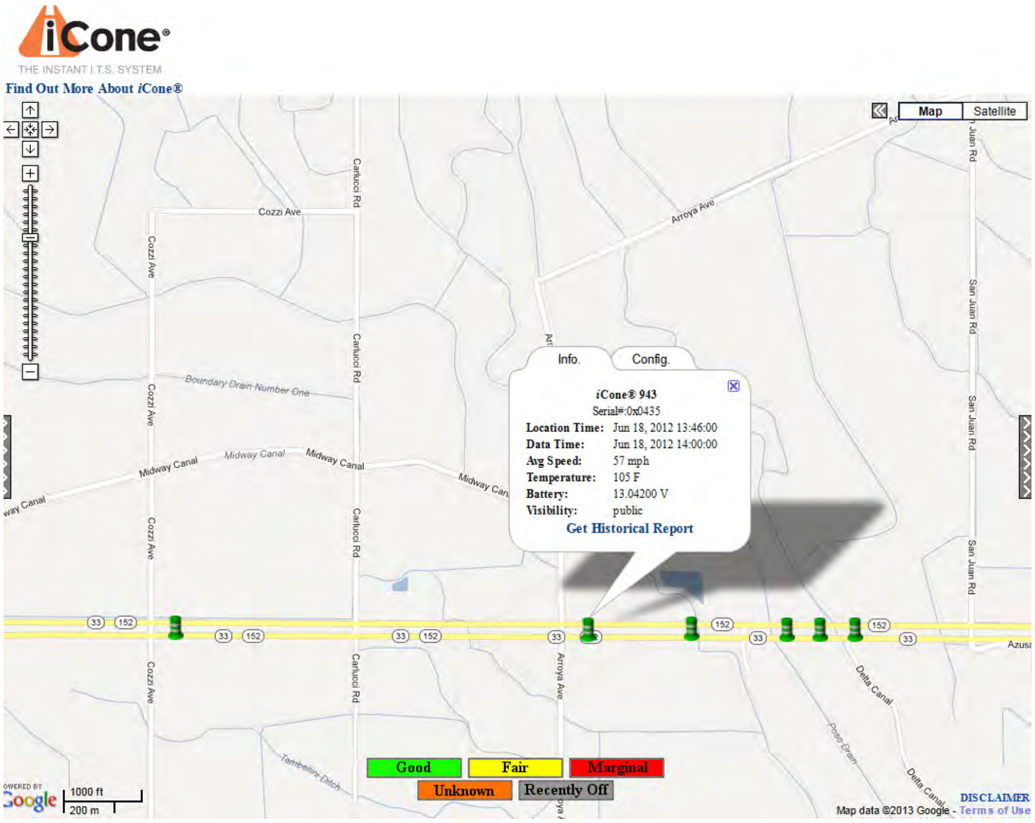


Figure 35: iCone Location Map for 6/18/12 - both

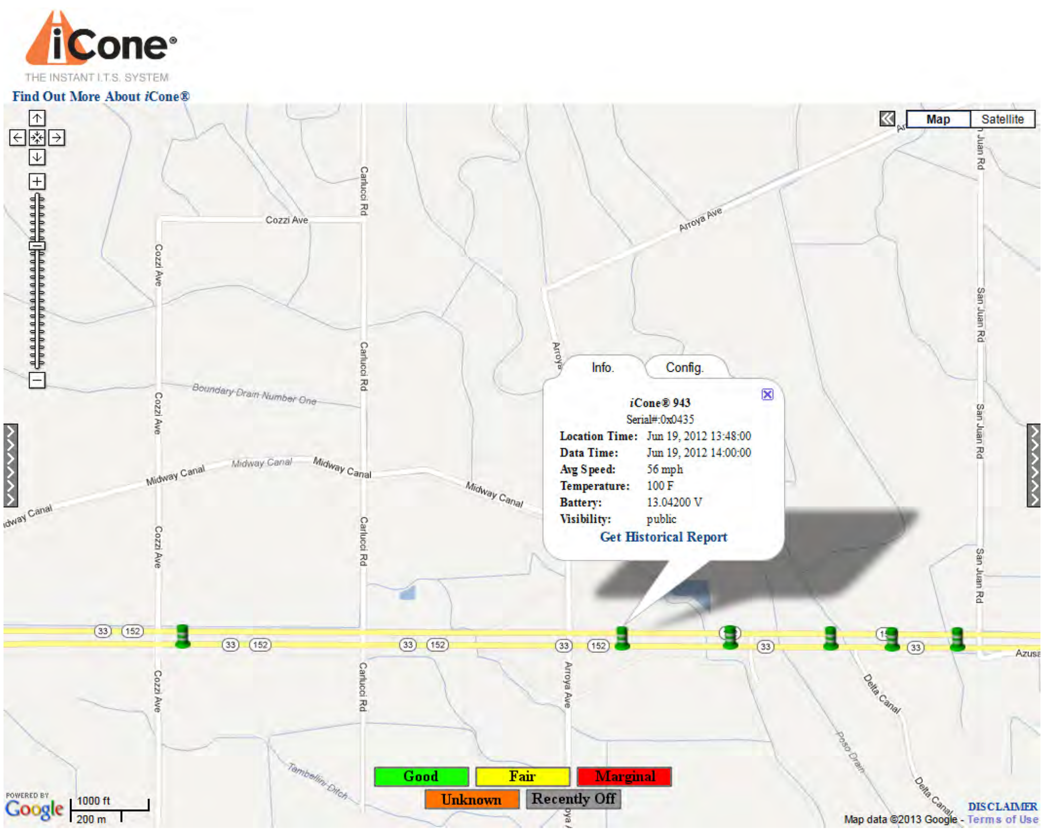


Figure 36: iCone Location Map for 6/19/12 - both

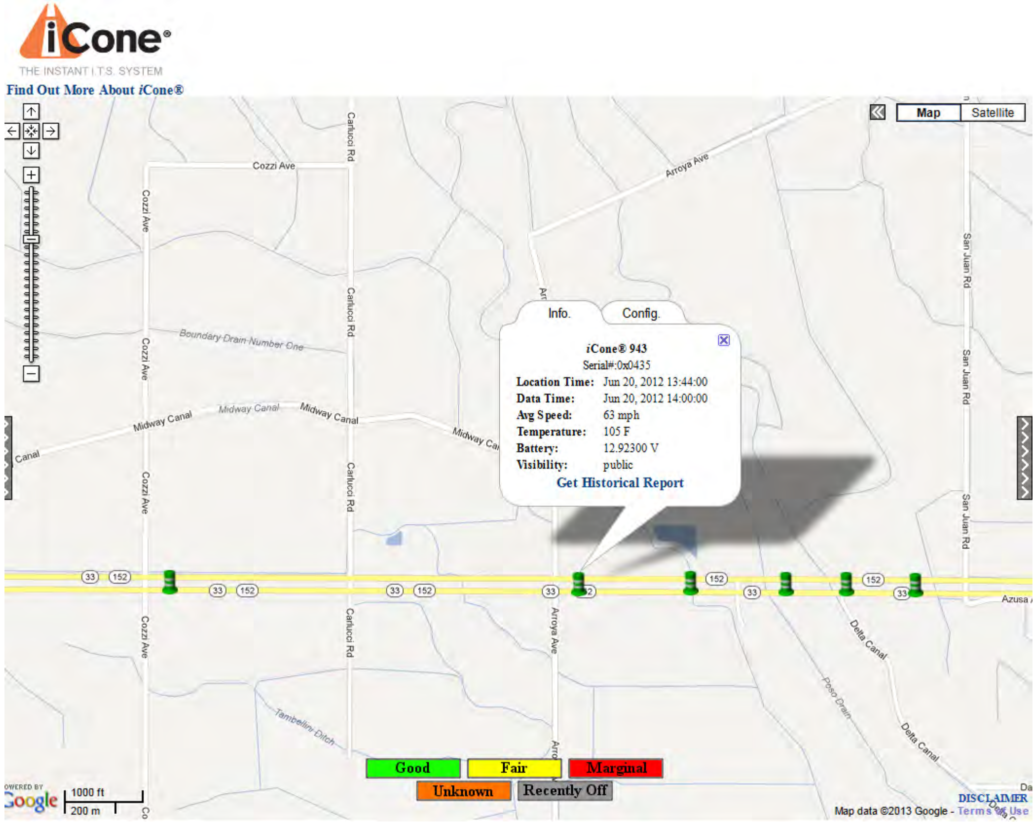


Figure 37: iCone Location Map for 6/20/12 - both

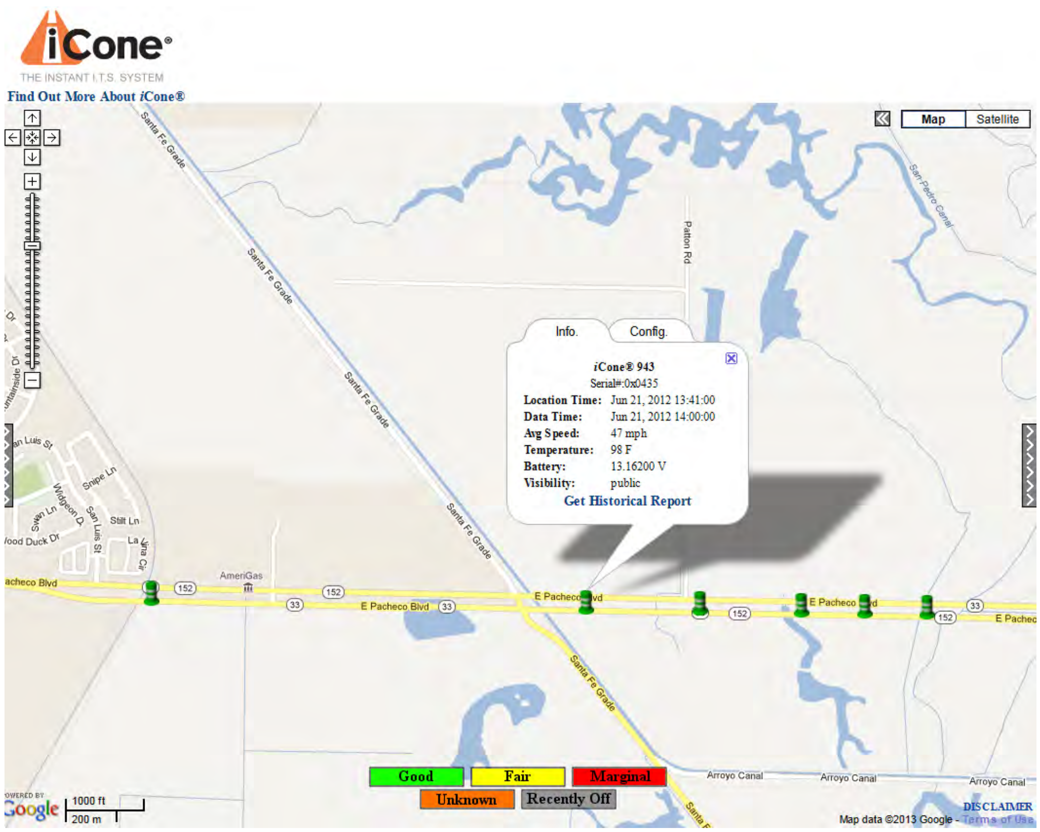


Figure 38: iCone Location Map for 6/21/12 - both

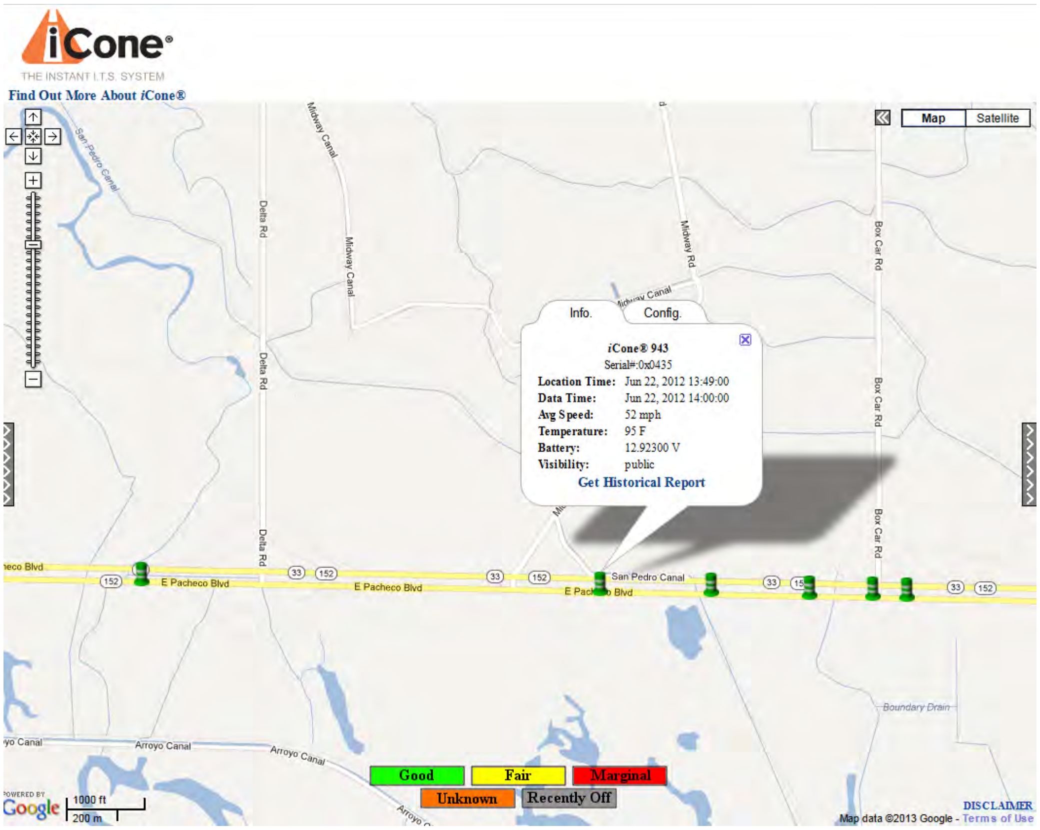


Figure 39: iCone Location Map for 6/22/12 - both

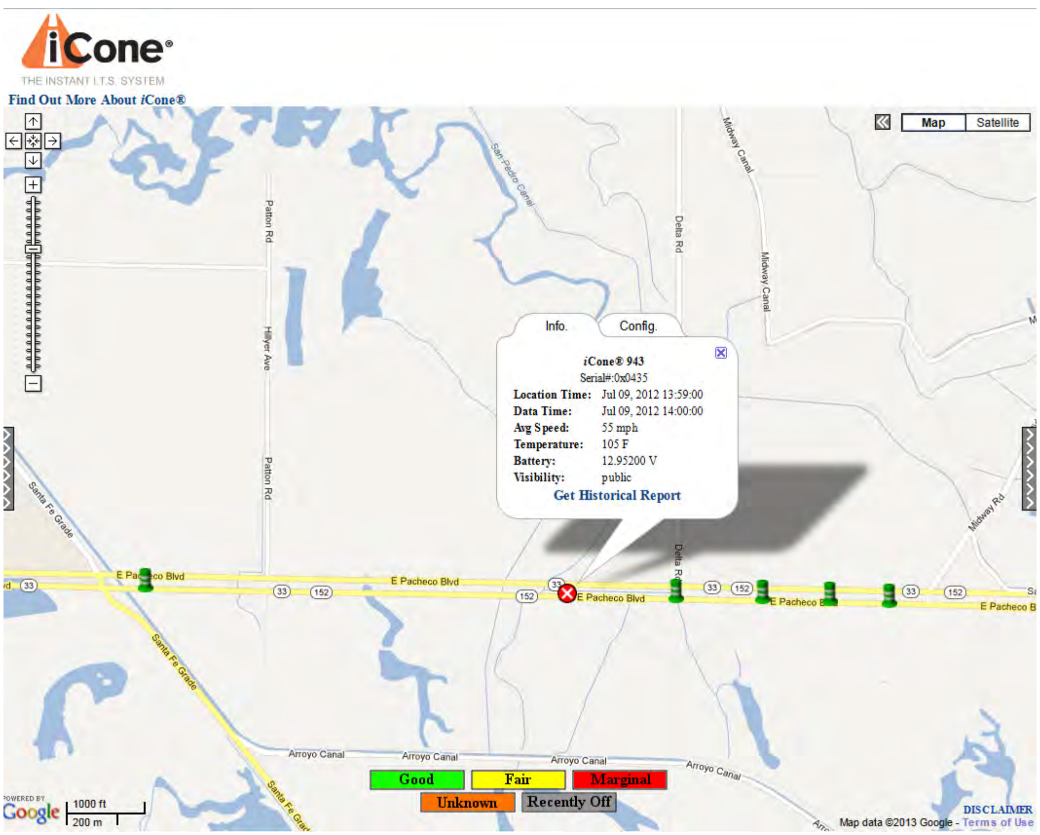


Figure 40: iCone Location Map for 7/9/12 - baseline

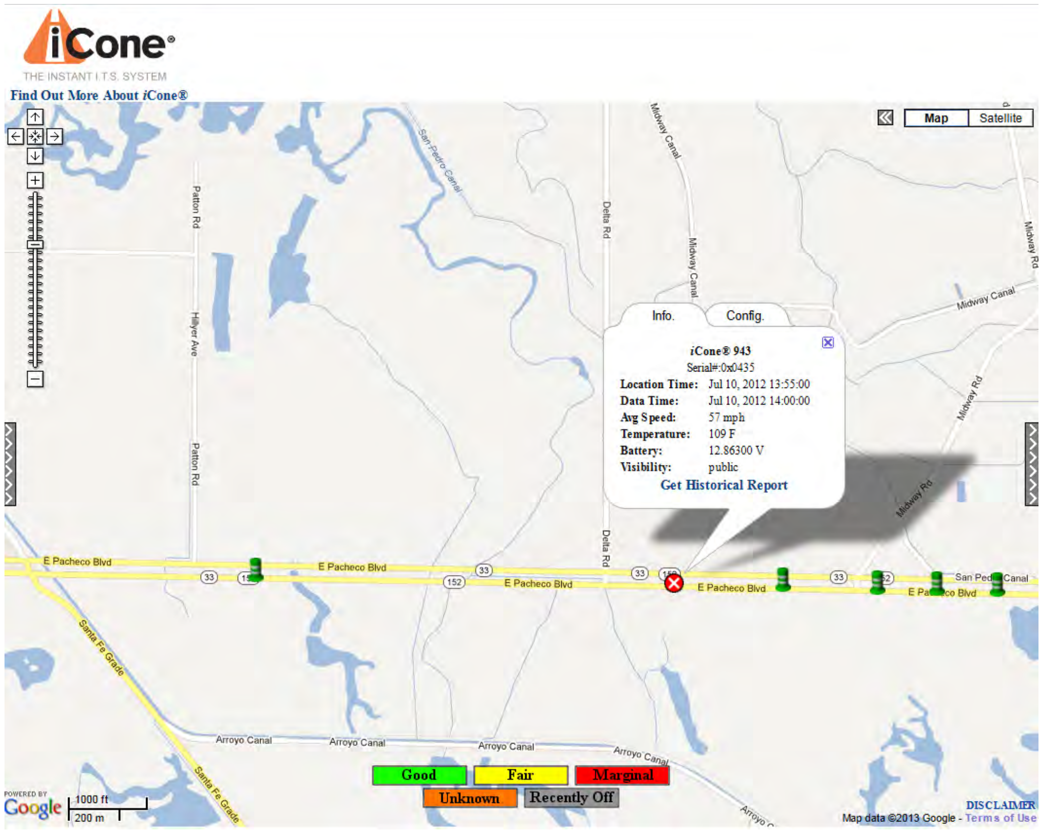


Figure 41: iCone Location Map for 7/10/12 - baseline

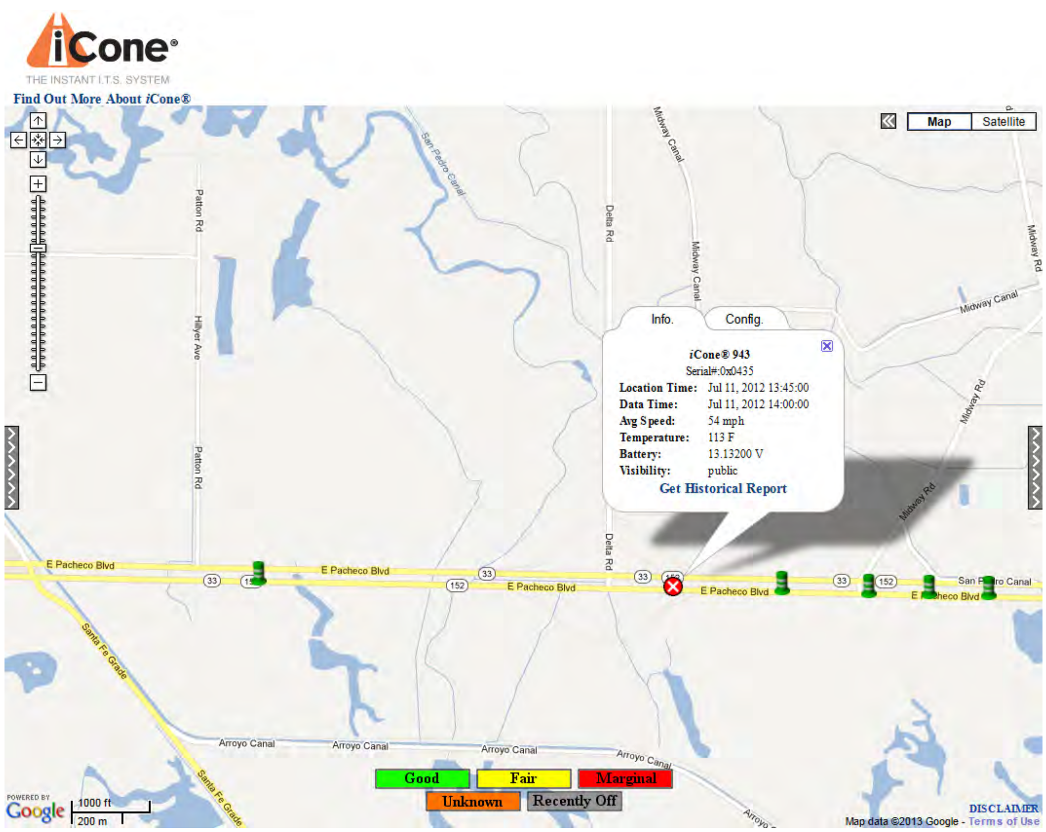


Figure 42: iCone Location Map for 7/11/12 - baseline

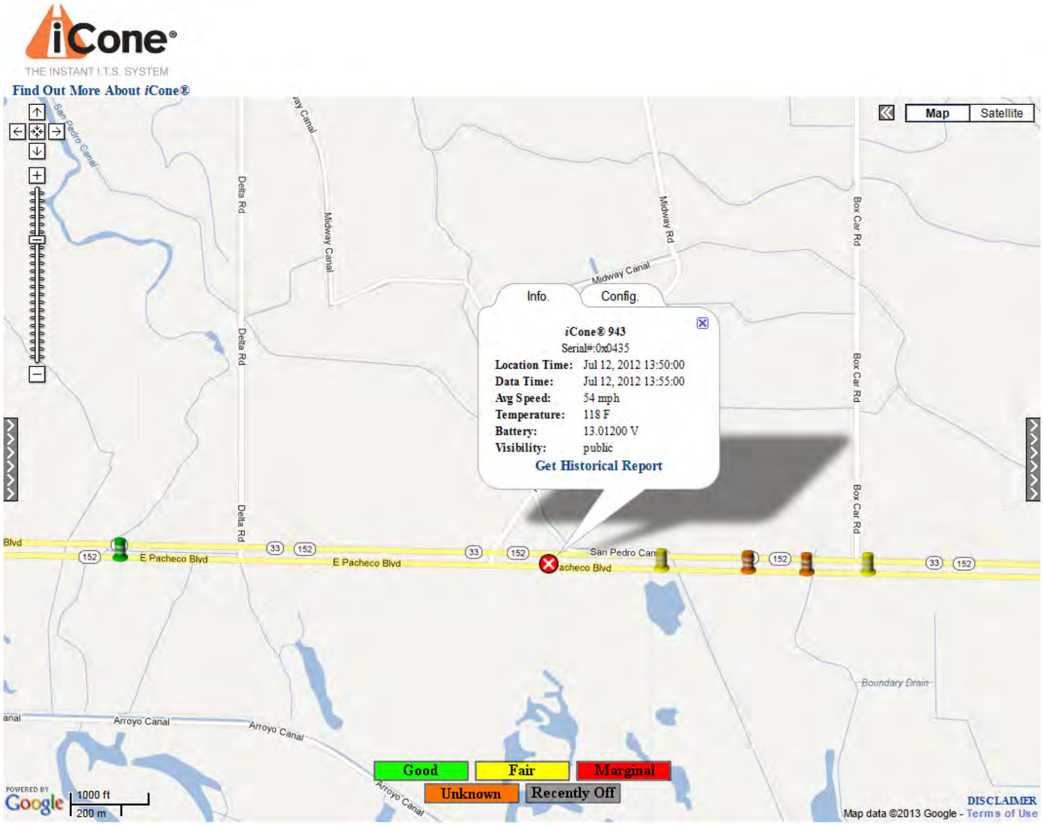


Figure 43: iCone Location Map for 7/12/12 - baseline

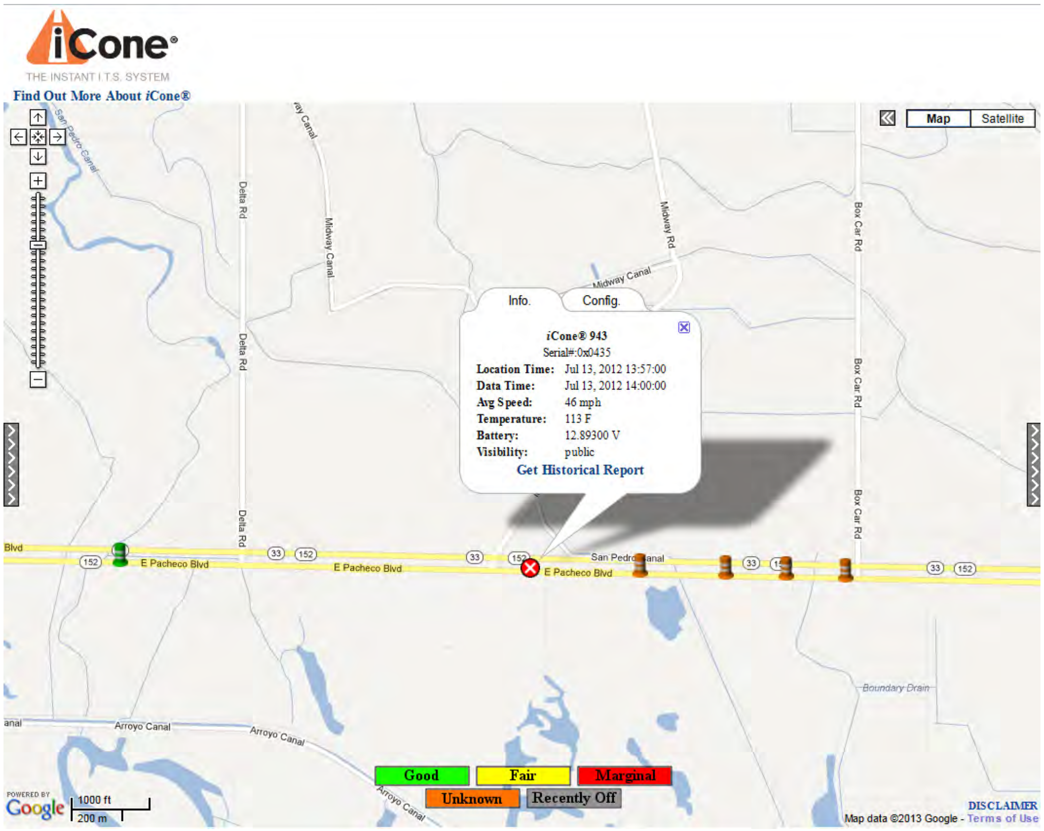


Figure 44: iCone Location Map for 7/13/12 – baseline

6.2. Daily sDrum and iCone locations

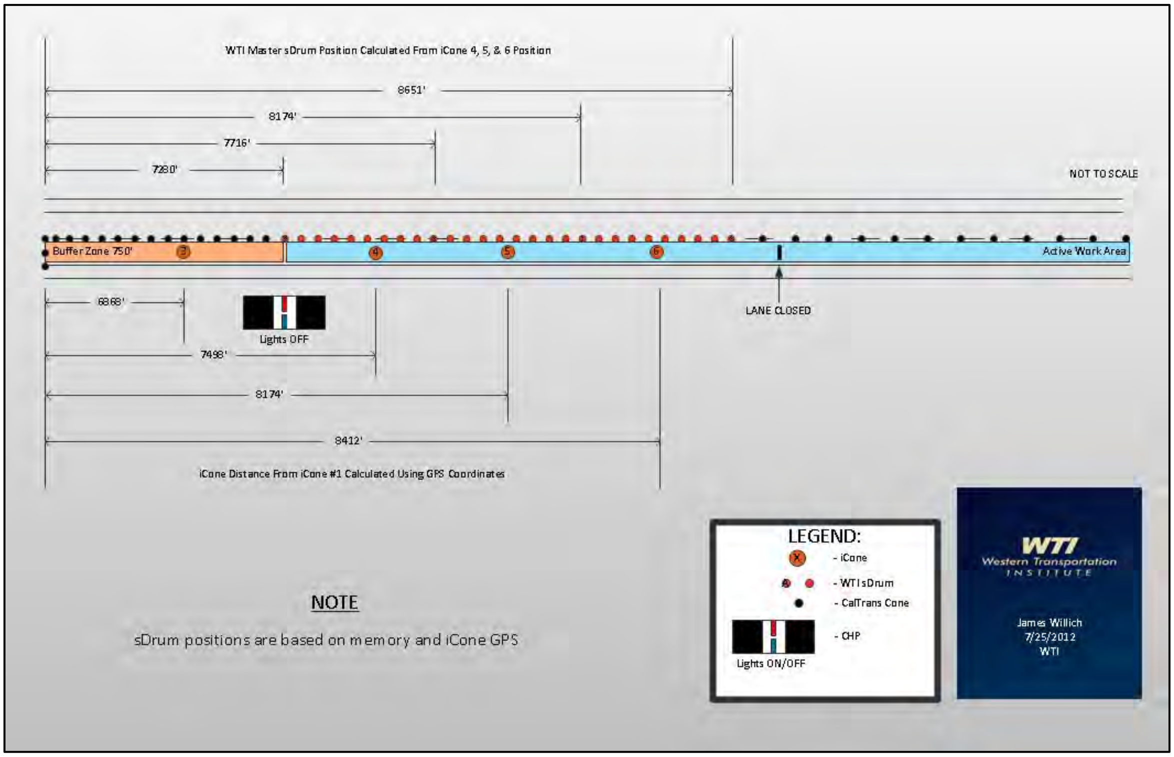


Figure 45: iCone and sDrum Locations for 5/14/12

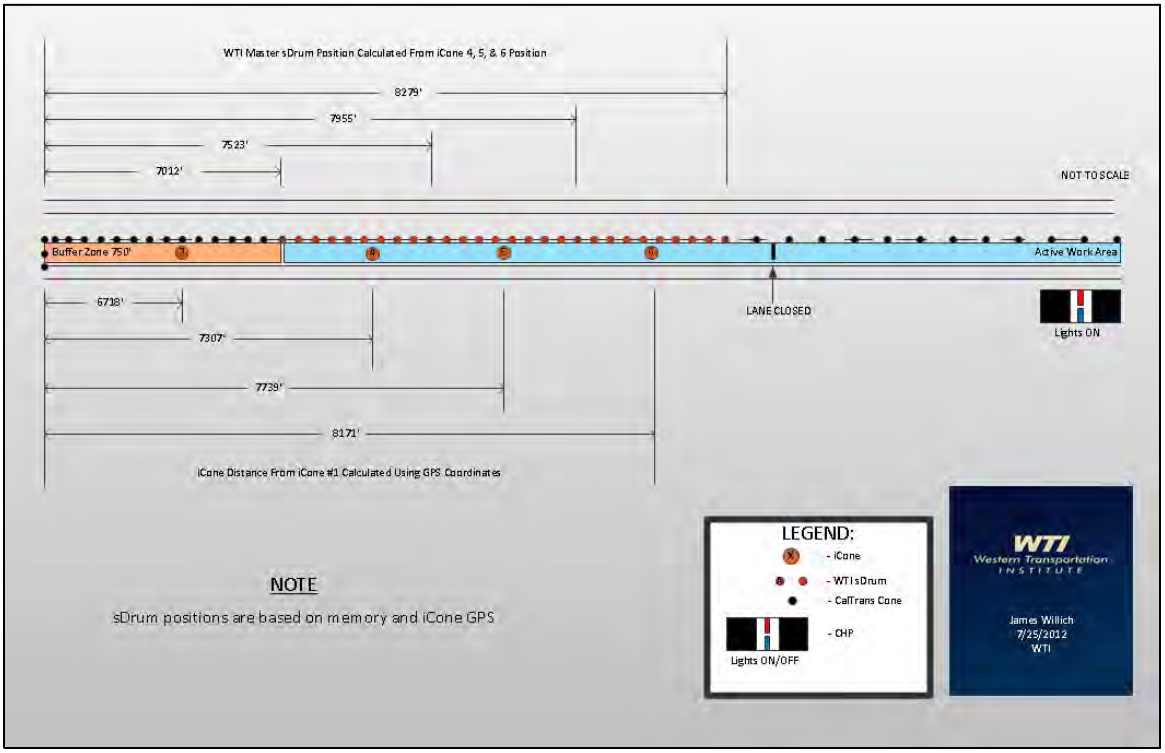


Figure 46: iCone and sDrum Locations for 5/15/12

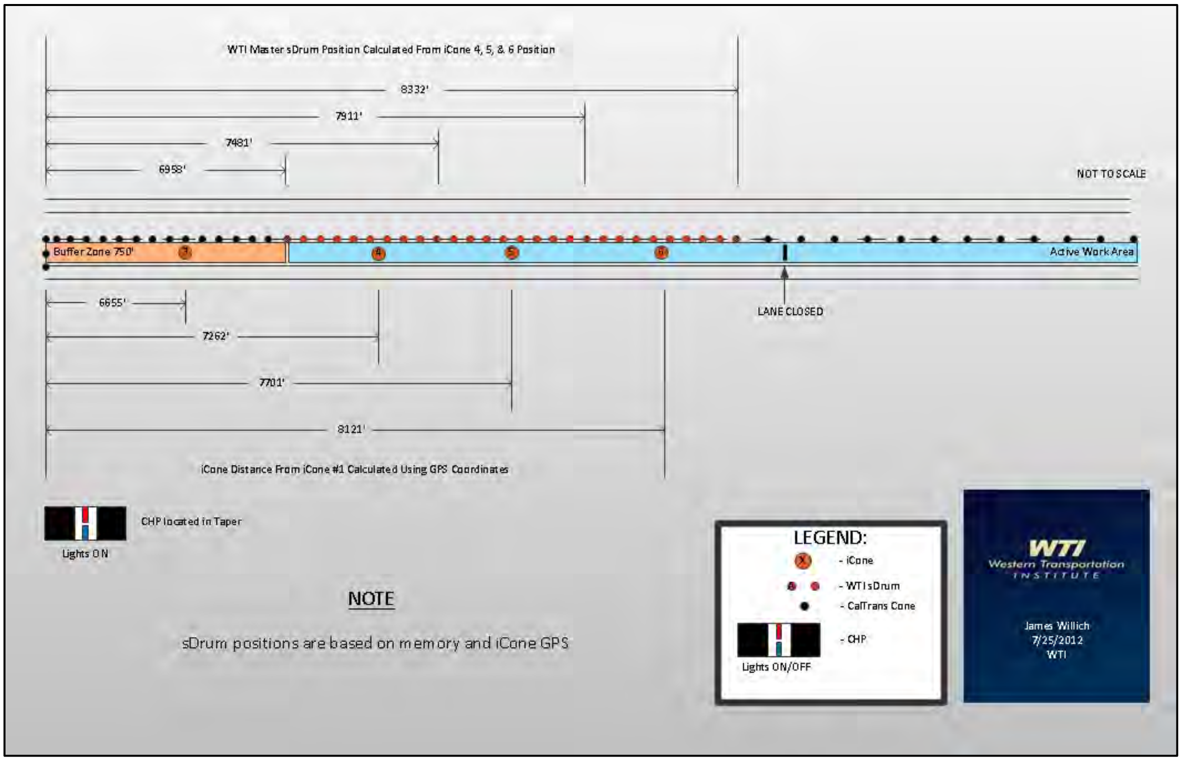


Figure 47: sDrum and iCone Locations for 5/16/12

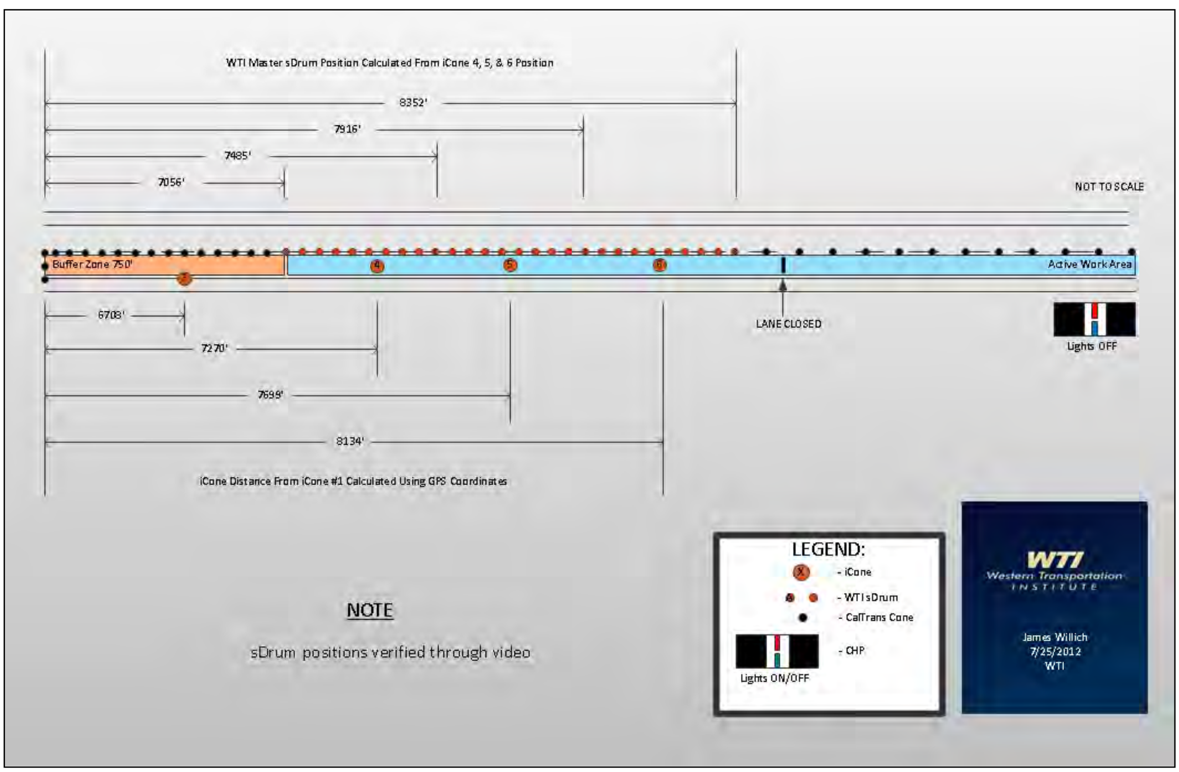


Figure 48: sDrum and iCone Locations for 5/17/12

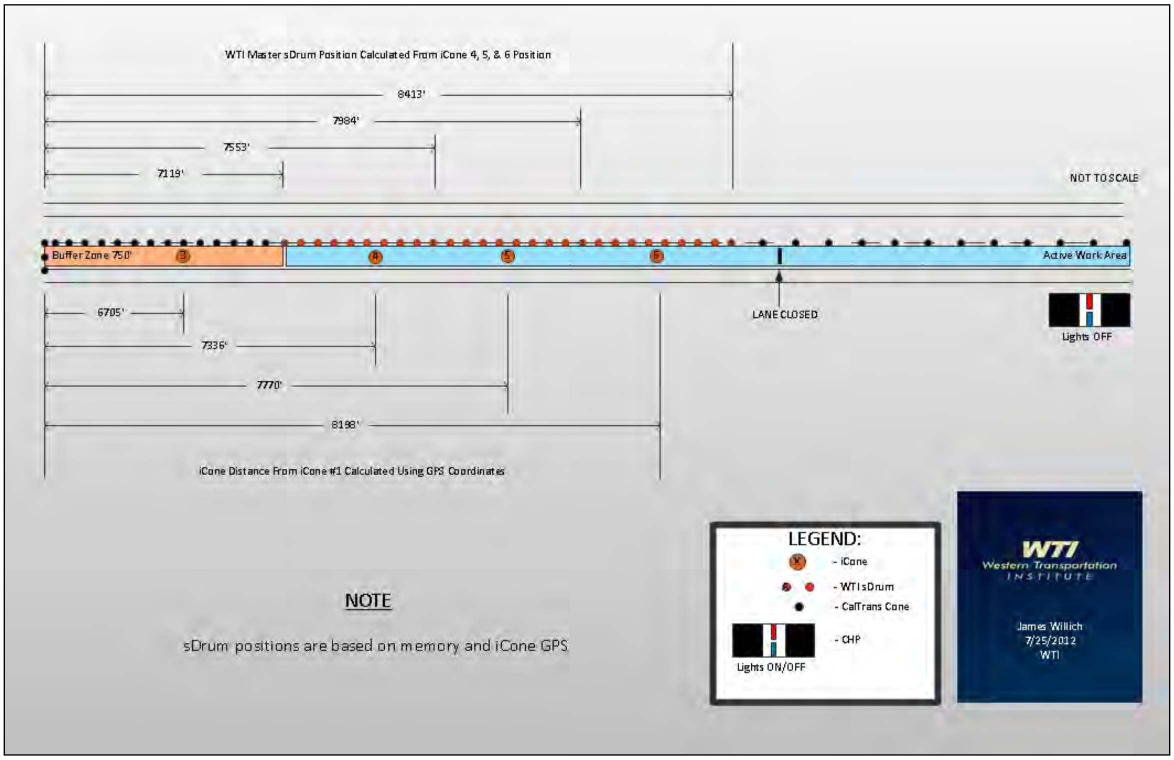


Figure 49: sDrum and iCone Locations for 5/18/12

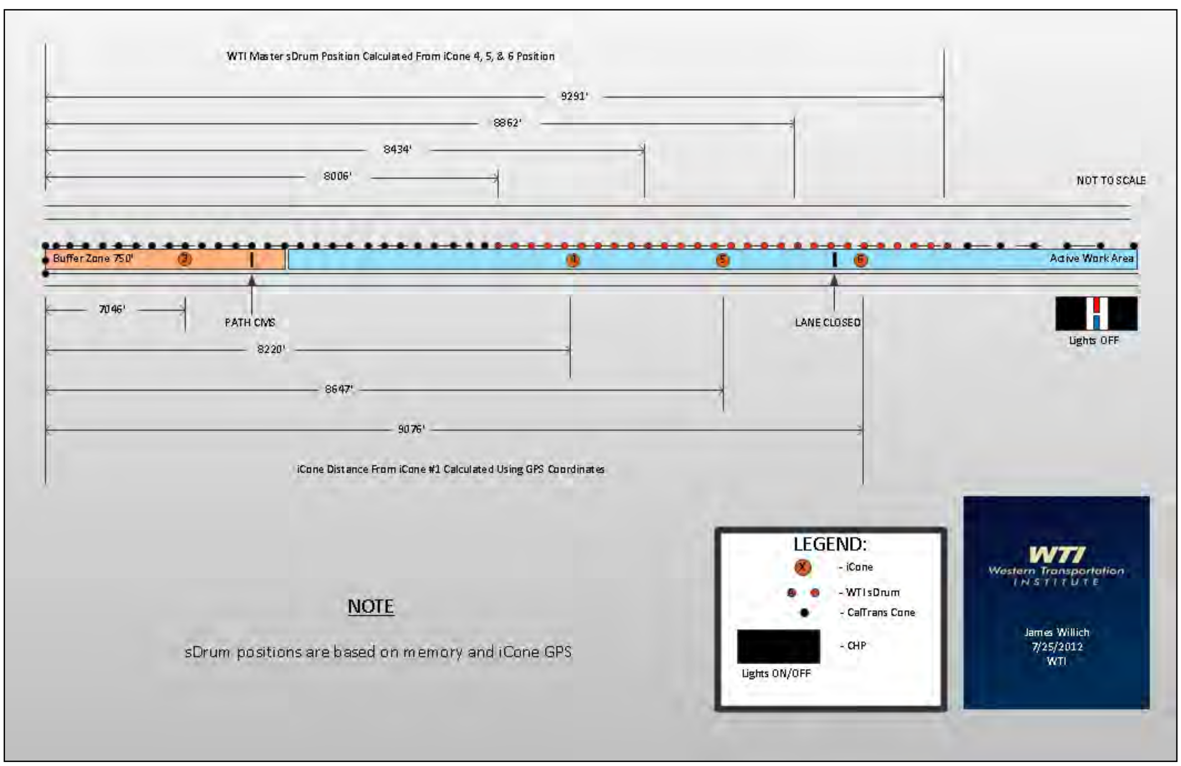


Figure 50: sDrum and iCone Locations for 5/21/12

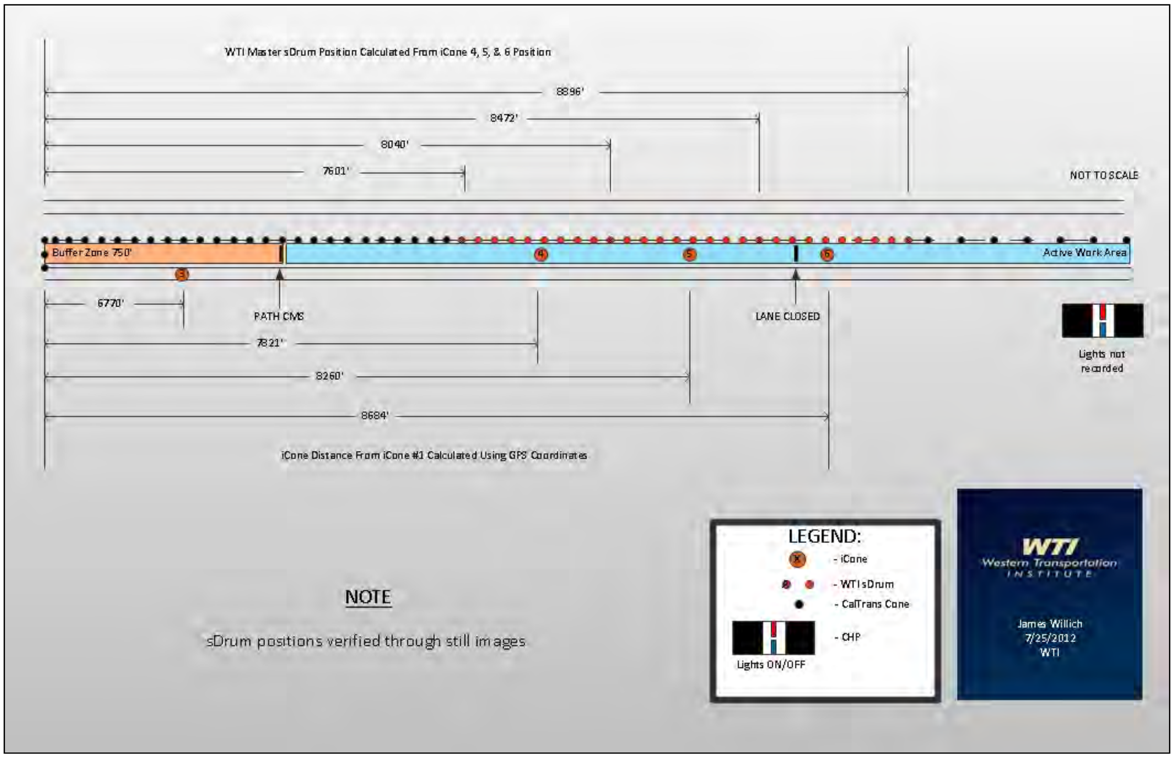


Figure 51: sDrum and iCone Locations for 5/22/12

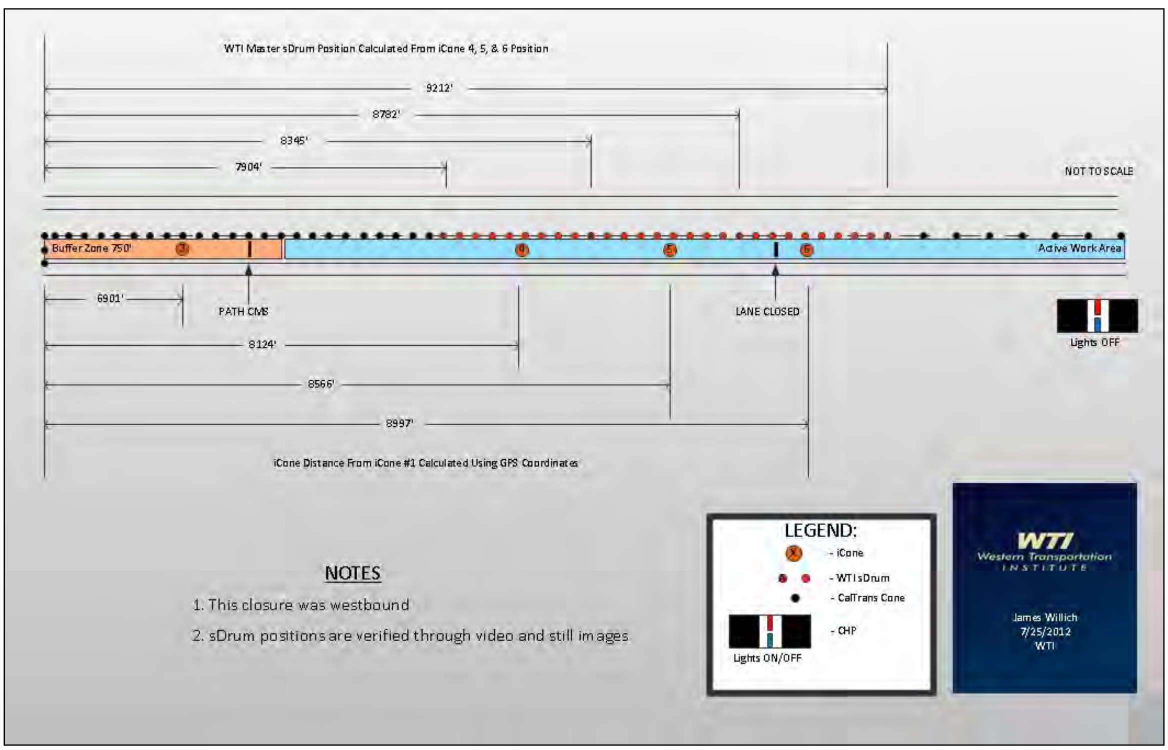


Figure 52: sDrum and iCone Locations for 5/23/12

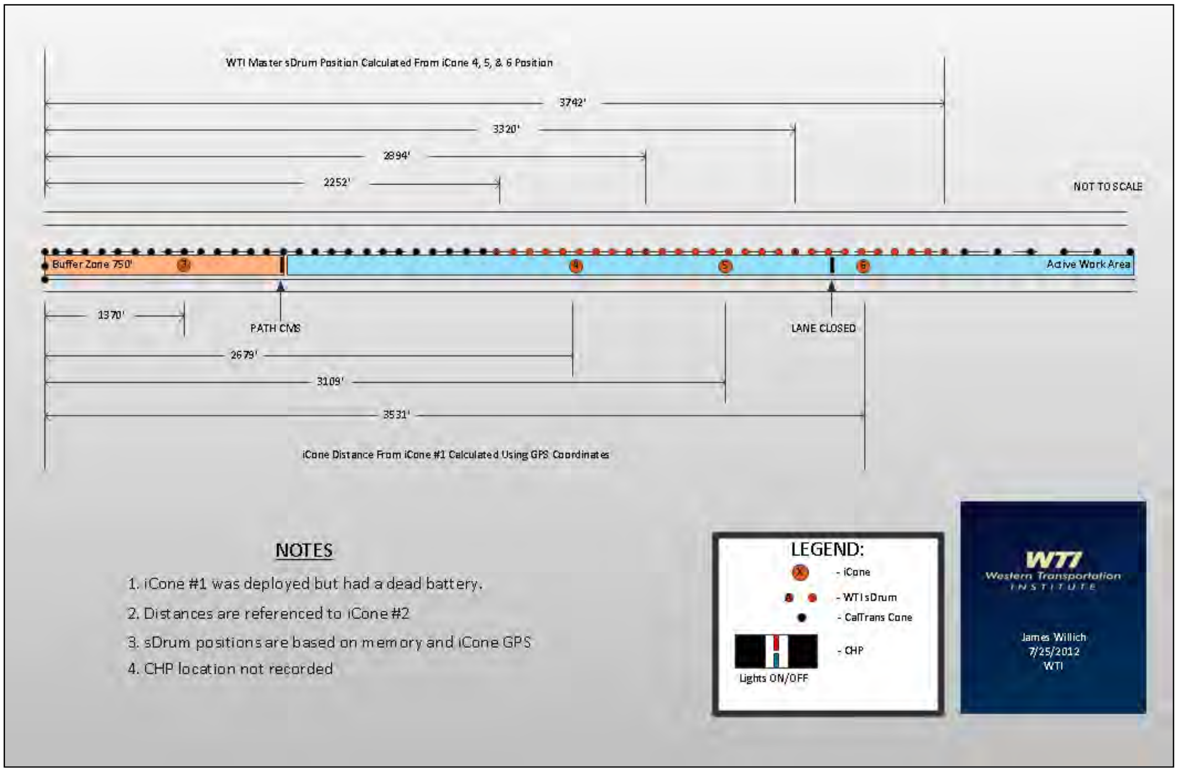
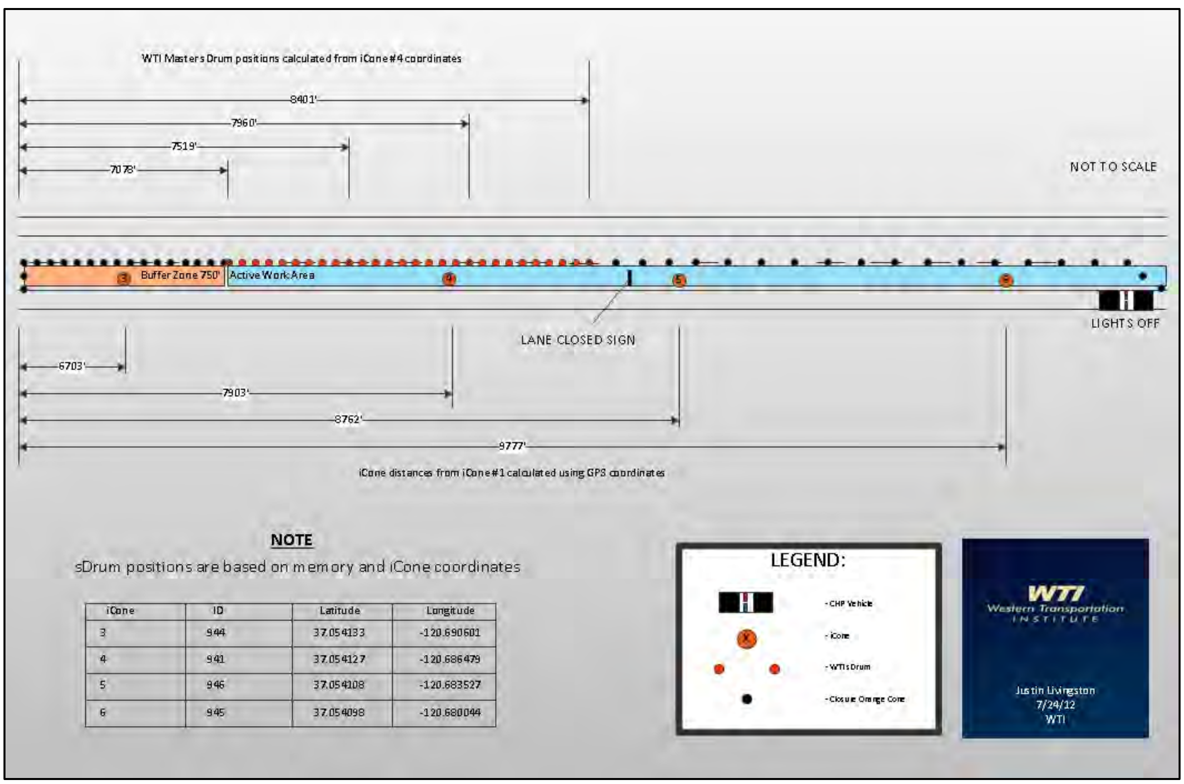


Figure 53: sDrum and iCone Locations for 5/24/12



iCone	ID	Latitude	Longitude
3	944	37.054133	-120.690601
4	941	37.054127	-120.686479
5	946	37.054108	-120.683527
6	945	37.054098	-120.680044

Figure 54: sDrum and iCone Locations for 6/11/12

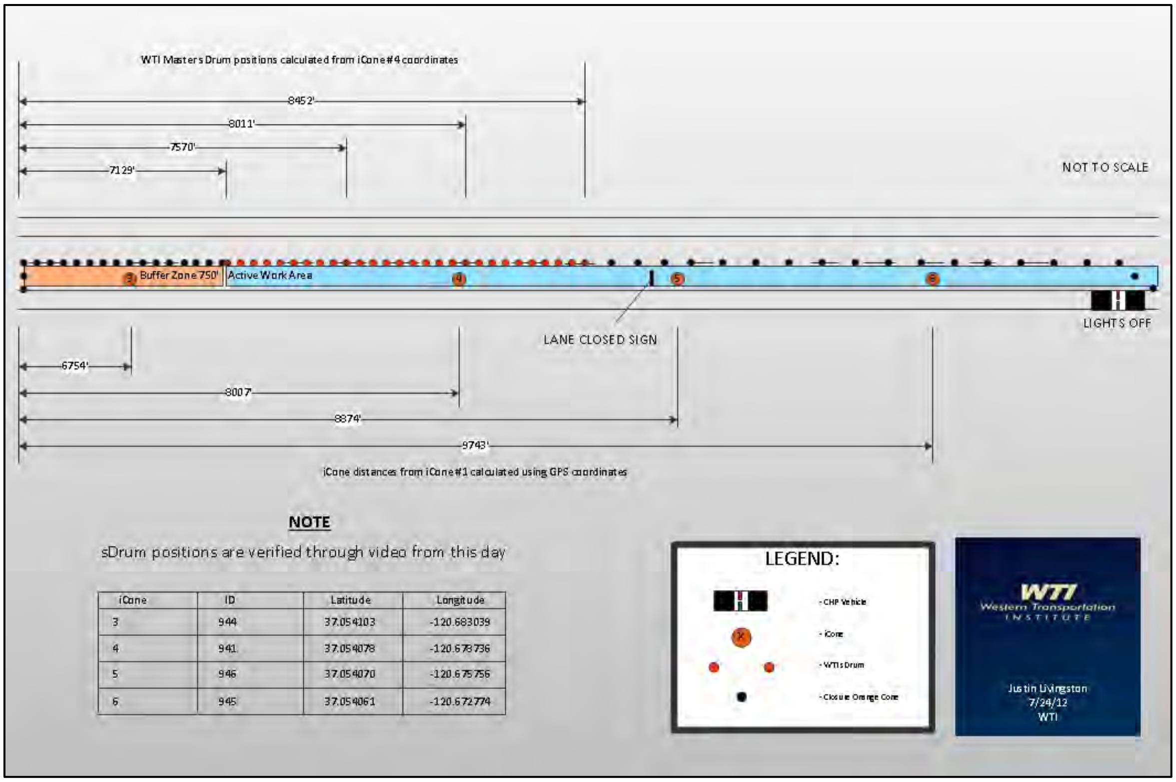


Figure 55: sDrum and iCone Locations for 6/12/12

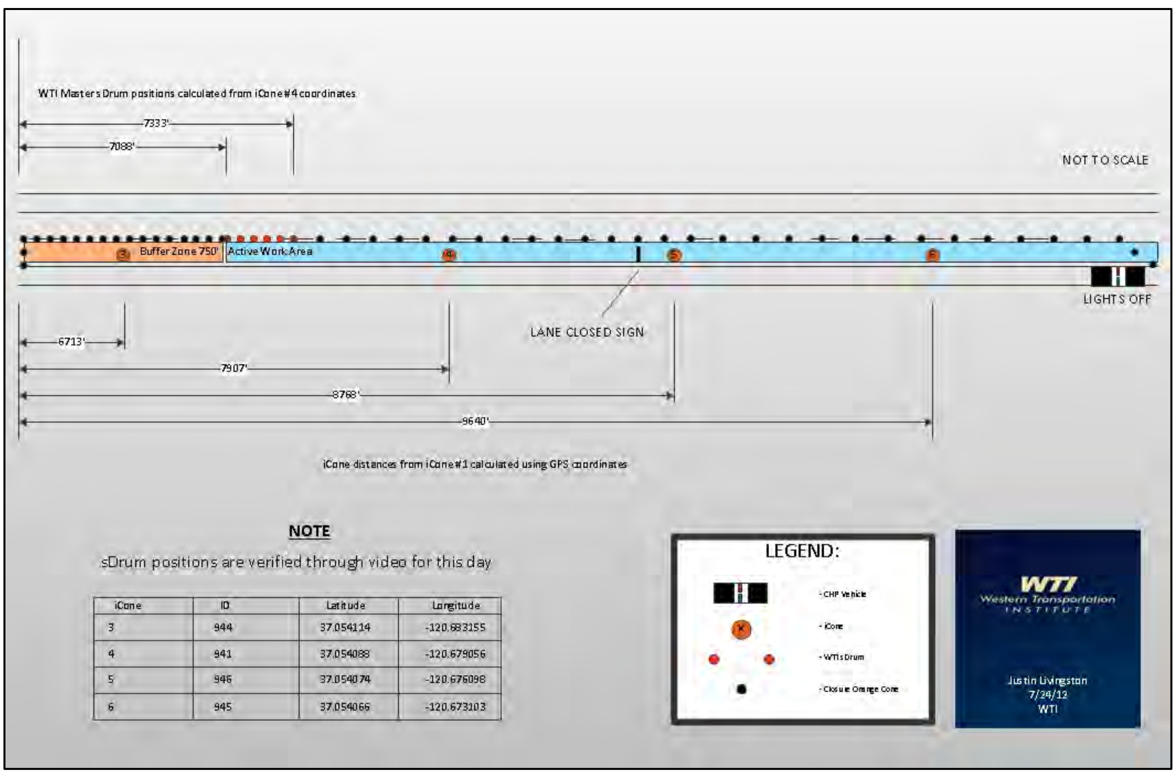


Figure 56: sDrum and iCone Locations for 6/13/12

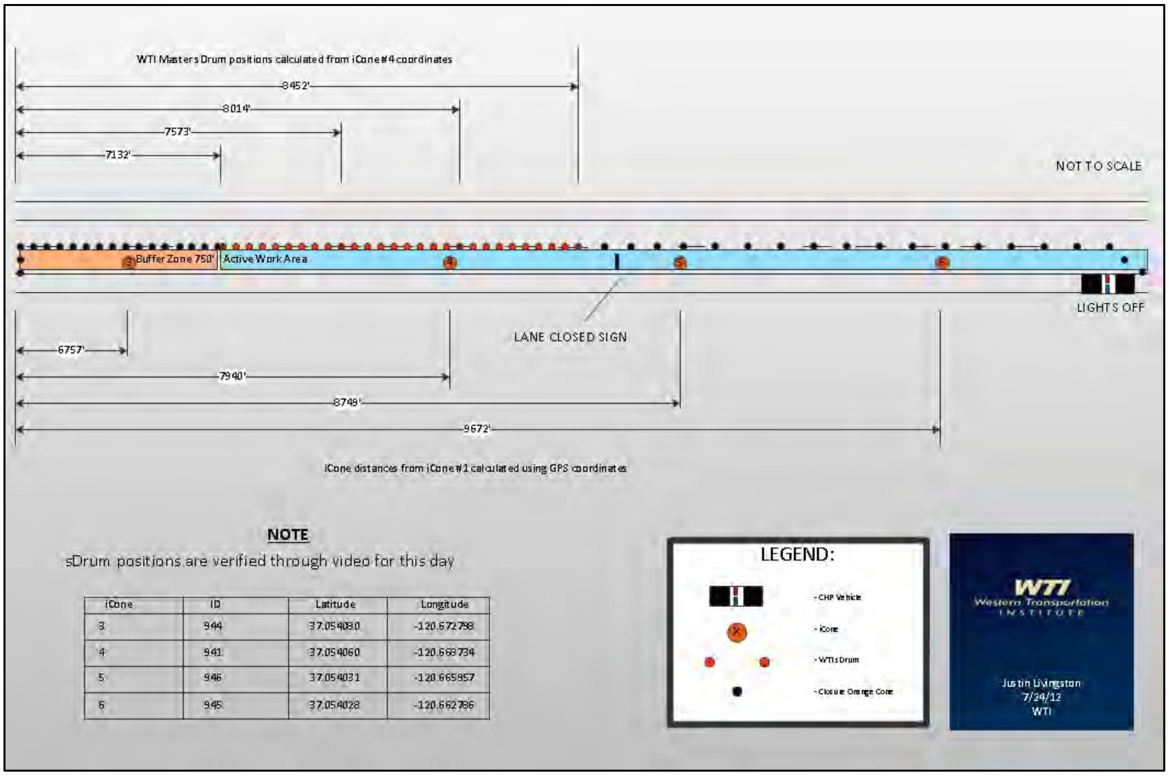


Figure 57: sDrum and iCone Locations for 6/14/12

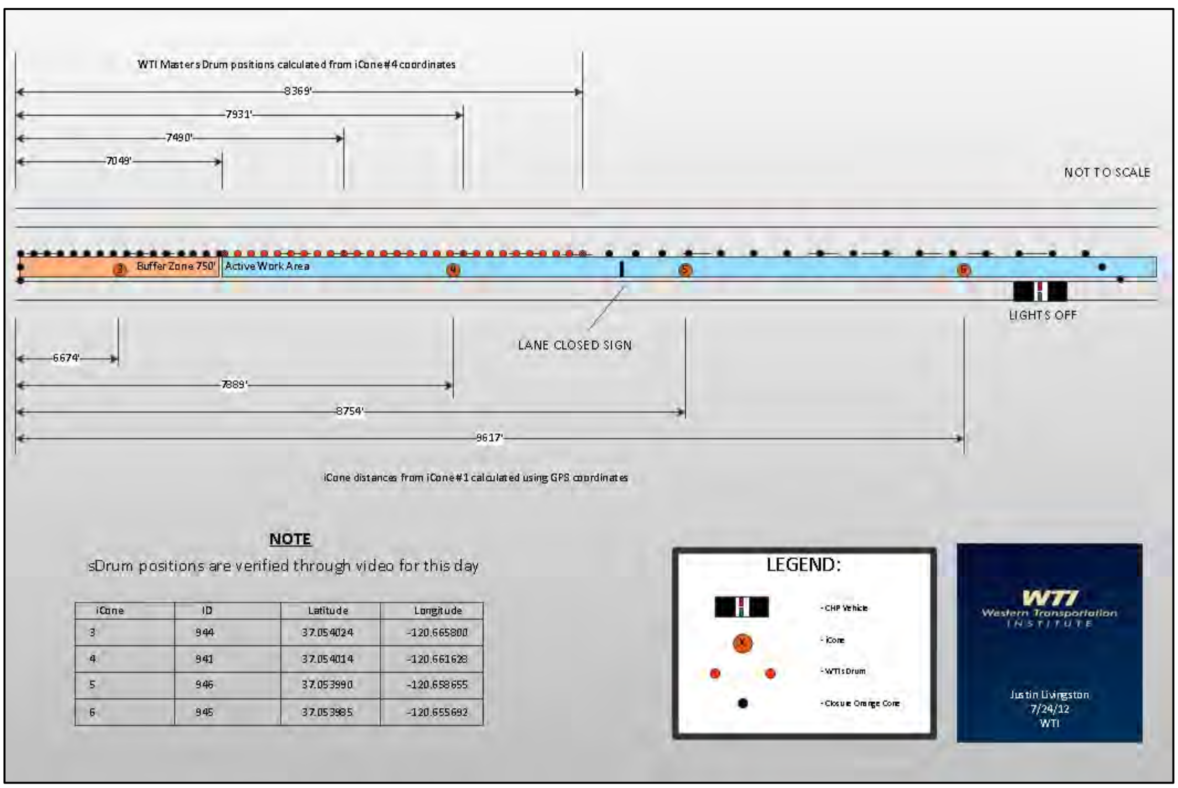


Figure 58: sDrum and iCone Locations for 6/15/12

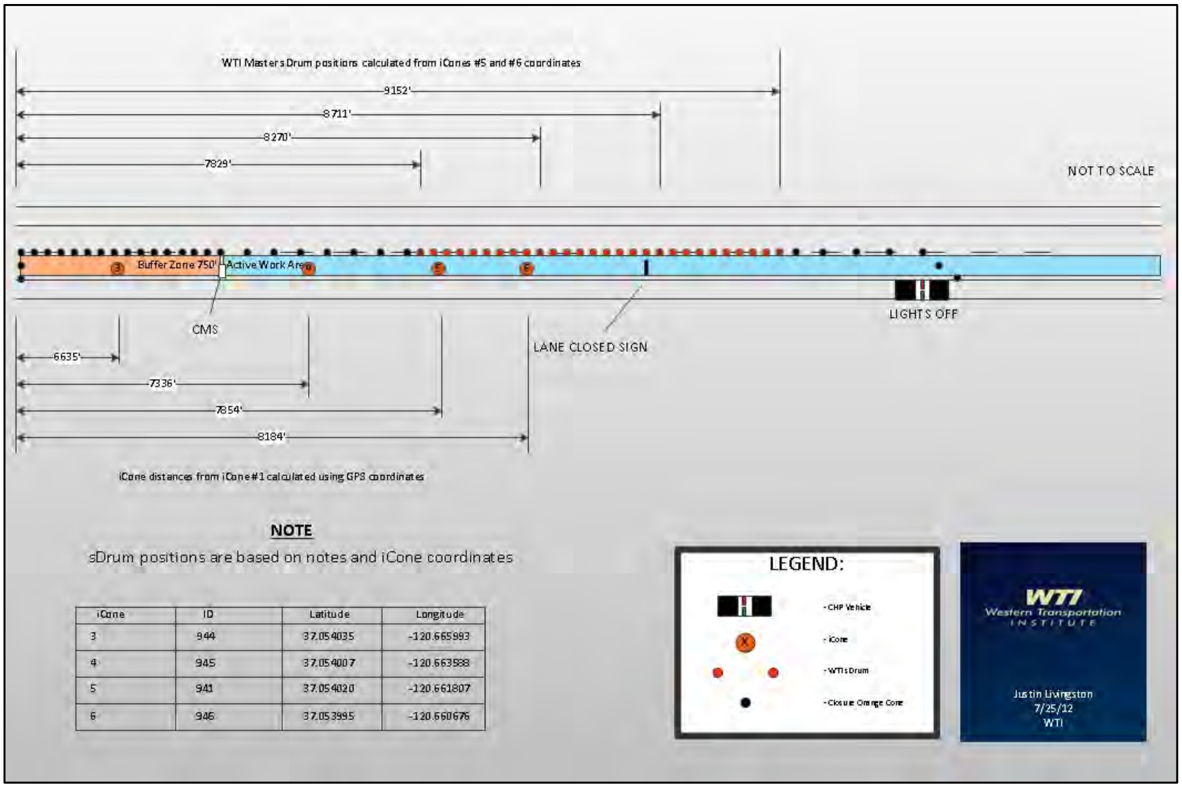


Figure 59: sDrum and iCone Locations for 6/18/12

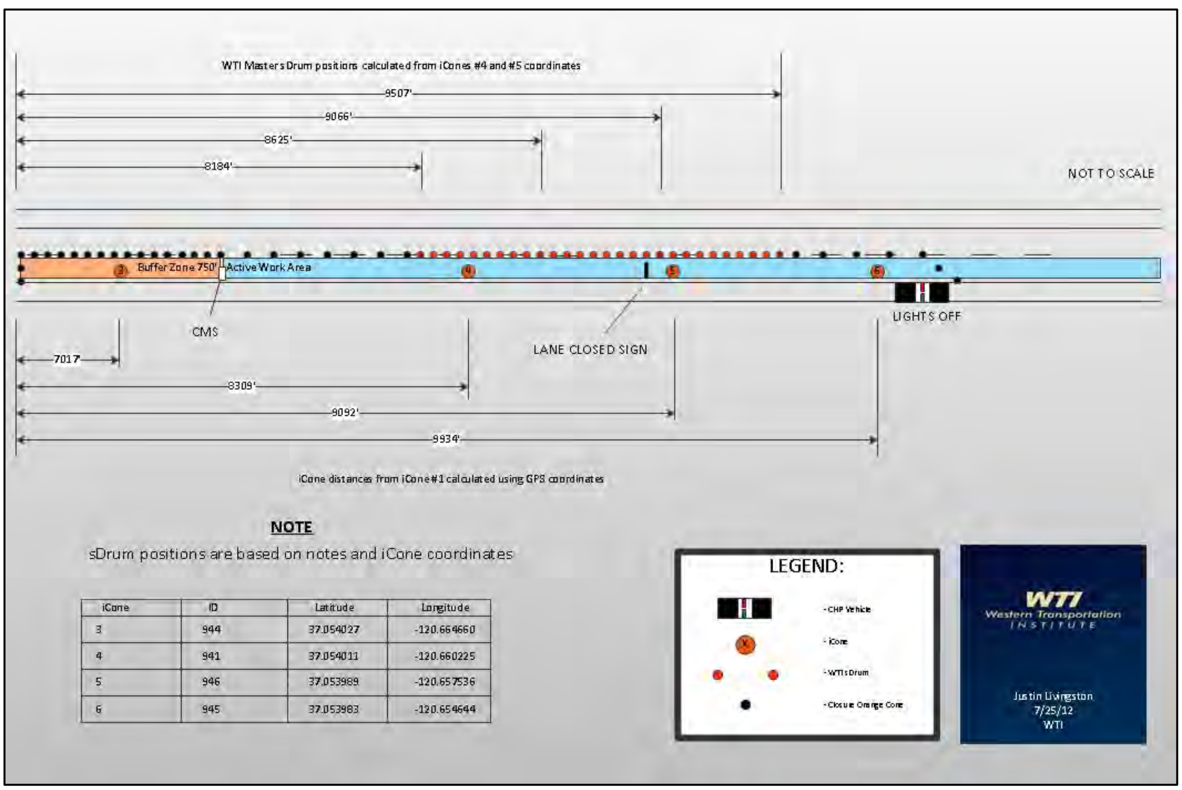


Figure 60: sDrum and iCone Locations for 6/19/12

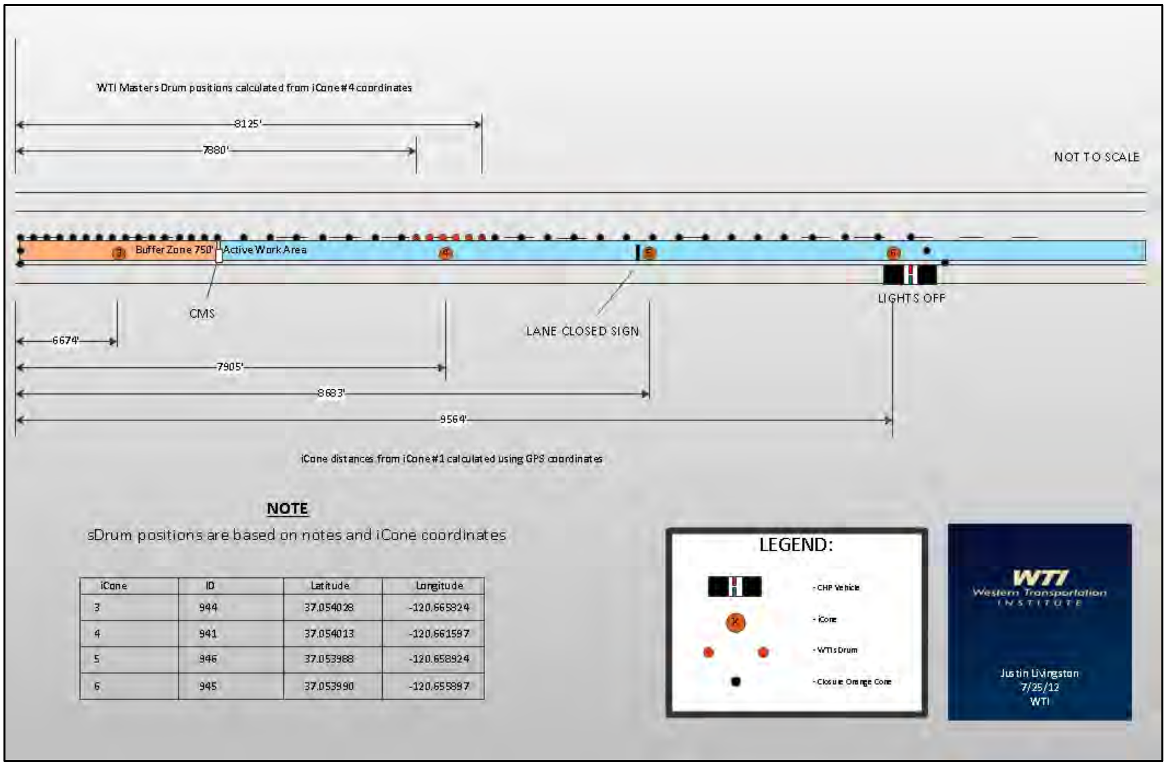


Figure 61: sDrum and iCone Locations for 6/20/12

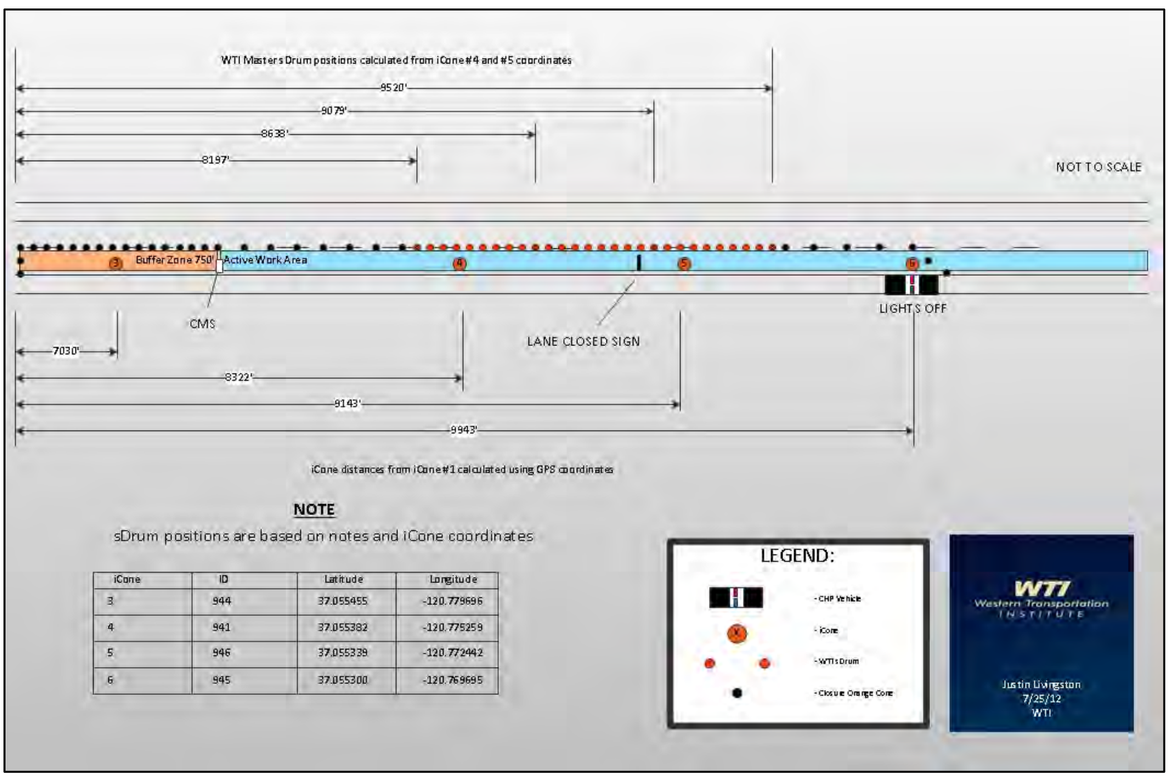


Figure 62: sDrum and iCone Locations for 6/21/12

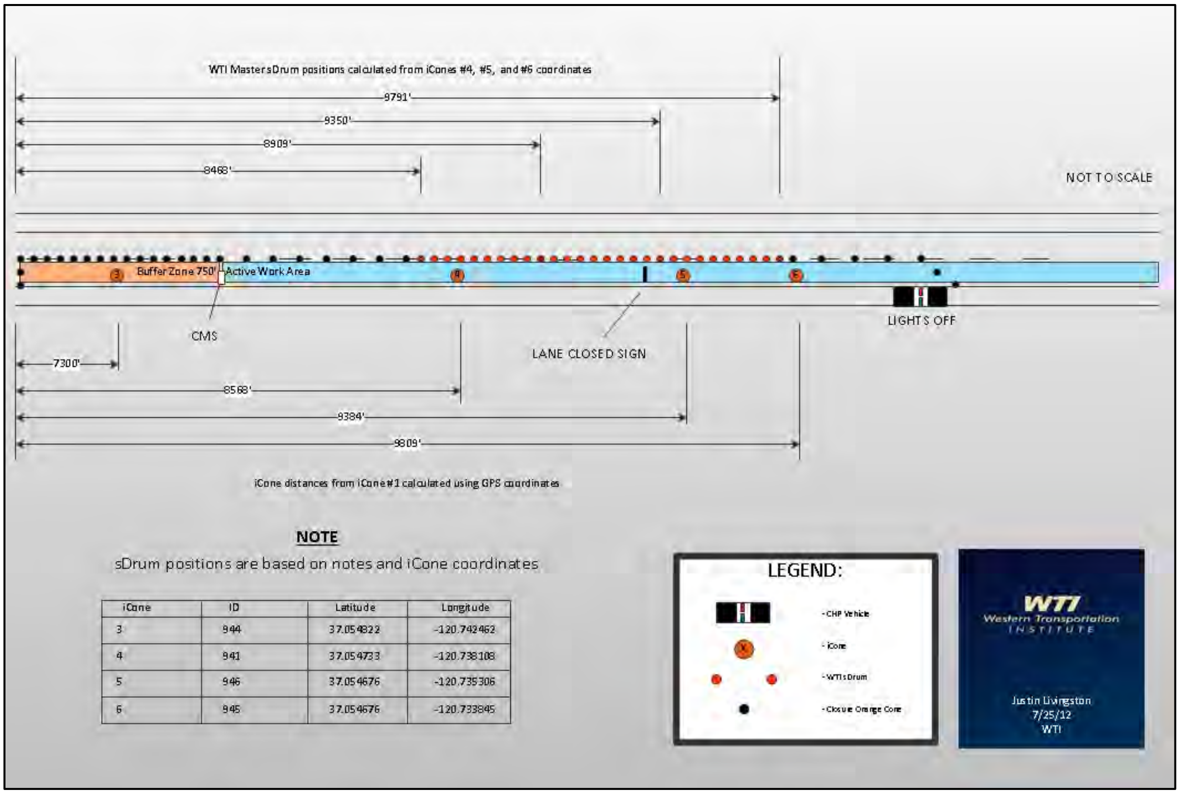


Figure 63: sDrum and iCone Locations for 6/22/12

7. REFERENCES

[1] Professor Chris J. Baker, ECE 5194.01: Lecture Notes, 13. Doppler Radar and MTI_2013.pdf, -- Page 14, http://esl.eng.ohio-state.edu/~cbaker/notes.html (as of April 26, 2013).