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John Slonaker

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Division of Research Innovation, and System Information MS-83
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Sacramento CA 95816

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16. ABSTRACT

The California Department of Transportation (Caltrans) has installed wireless magnetometers for detection in vehicle count stations on freeways in recent years and would also like to have the option of using them as detectors for actuated traffic signals and ramp meters. Caltrans' Division of Research, Innovation and System Information (DRISI) worked with Sensys Networks to install their magnetometers on a conventional highway intersection approach and a metered freeway on-ramp. The traffic actuation signals output from the magnetometers to the controller were compared to those of existing inductive loop detectors. All signals from both detection systems were captured with the C1/C11 reader device. The controller was programmed to ignore the signals from the Sensys magnetometers, so the signalized traffic intersection and ramp meter continued to operate as before. Video from existing CCTV cameras at both locations was recorded concurrently and used to provide "ground truth" in order to determine if either detection system reported vehicles that weren't actually present, i.e. "false positives," failed to report vehicles, i.e. "false negatives" or dropped calls prematurely.

17. KEY WORDS

magnetometer, inductive loop detector, ramp meter, traffic signal, C1/C11 reader, VideoSync, Sensitivity, false positive, false negative, detection zone, queue, demand, passage

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Evaluation of Sensys Networks Wireless Magnetometers for Traffic Signal and Ramp Meter Actuation

Caltrans Division of Research, Innovation and System Information

John Slonaker, P.E.
Caltrans
Division of Research, Innovation and System Information
May 18, 2021

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Caltrans, Division of Research, Innovation and Systems Integration (DRISI):

Joel Retanan, Senior Electronics Engineer

Jerry Kwong, Transportation Engineer, Electrical

Jenzel Arevalo, student assistant, computer science

Aleksey Zasorin, student assistant, computer science

Minh Giang, student assistant, computer science

Caltrans, District 4:

George Young, Transportation Engineer, Electrical

Maria Hionides, Senior Transportation Electrical Engineer

Ahmad Fahimi, Transportation Engineer, Electrical

Sensys Networks:

David Sheahen, Director, Field Engineering

Abstract

The California Department of Transportation (Caltrans) has installed wireless magnetometers for detection in vehicle count stations on freeways in recent years and would also like to have the option of using them as detectors for actuated traffic signals and ramp meters. Caltrans' Division of Research, Innovation and System Information (DRISI) worked with Sensys Networks to install their magnetometers on a conventional highway intersection approach and a metered freeway on-ramp. The traffic actuation signals output from the magnetometers to the controller were compared to those of existing inductive loop detectors. All signals from both detection systems were captured with the C1/C11 reader device. The controller was programmed to ignore the signals from the Sensys magnetometers, so the signalized traffic intersection and ramp meter continued to operate as before. Video from existing CCTV cameras at both locations was recorded concurrently and used to provide "ground truth" in order to determine if either detection system reported vehicles that weren't actually present, i.e. "false positives," failed to report vehicles, i.e. "false negatives" or dropped calls prematurely.

Test Locations

Ramp Meter

Sensys wireless magnetometers were installed on the Westbound on-ramp of I-80 just North of Powell Street in Emeryville (see Figure 1).

Figure 1 - ramp meter location on I-80 just North of Powell Street in Emeryville

The magnetometers were placed in the lanes to establish six separate detection zones, including “Demand” zones (D1 & D2), “Passage” zones (P1 & P2) and “Queue” zones (Q1 & Q2) for each of the two on-ramp lanes (see Figure 2). Video was recorded from a CCTV camera mounted on a dedicated pole just North of the onramp. The camera view was positioned appropriately to capture either the queue or demand/passage zones (see Figure 3).

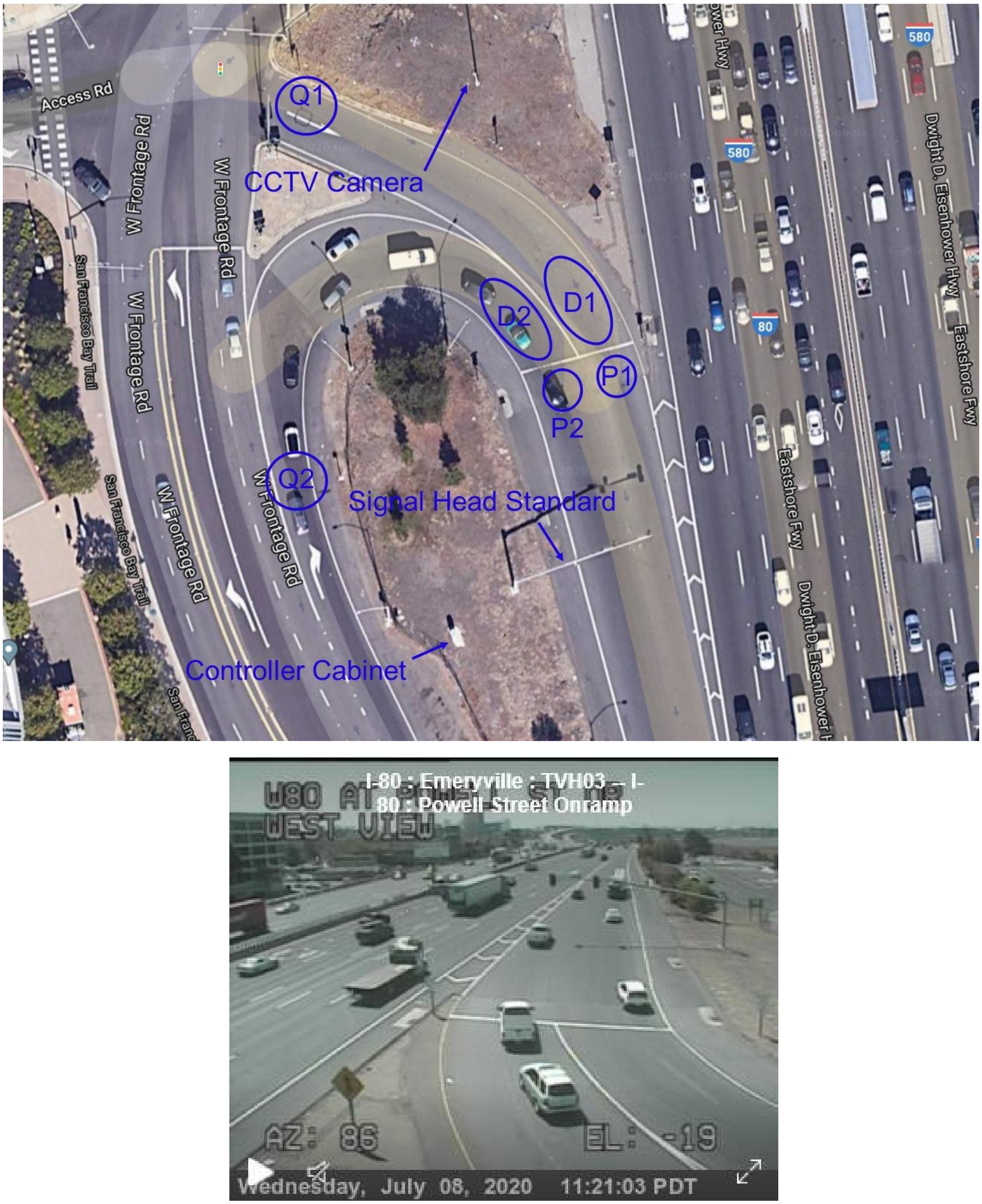
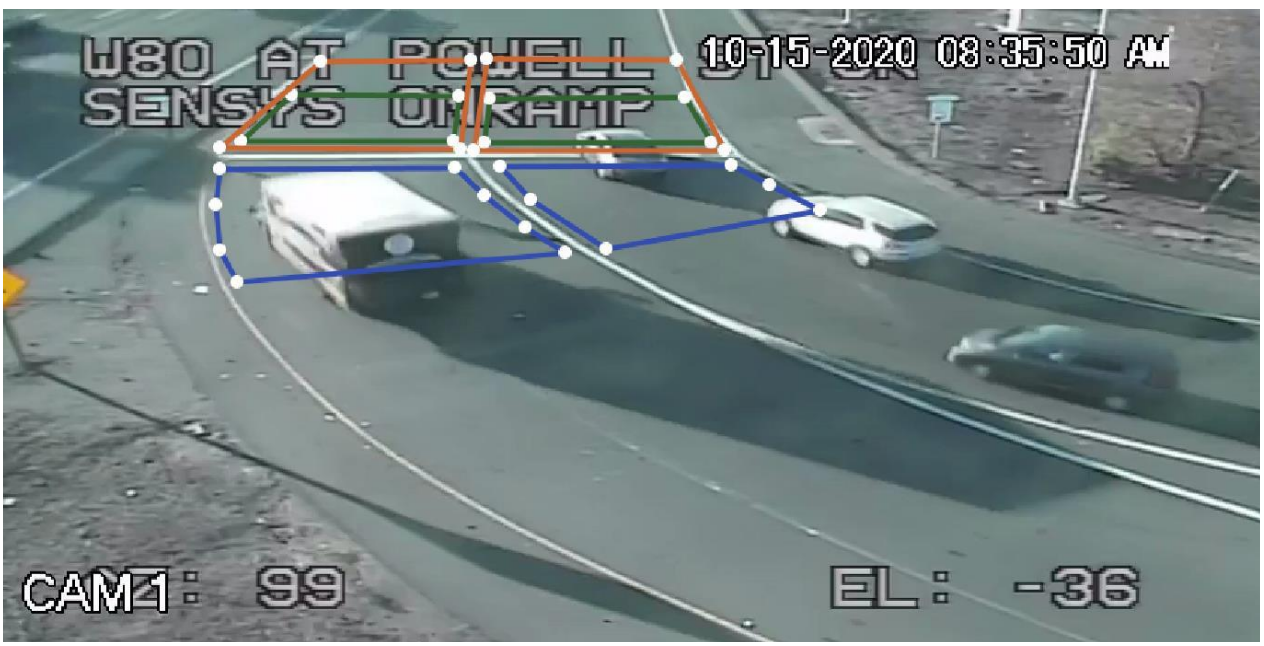


Figure 2 - Sensys detection zones at ramp meter location

(Queue detection zones – above)



(Demand and Passage detection zones – above)

Figure 3 - Caltrans' CCTV camera views of the ramp meter location

Signalized Intersection

Sensys wireless magnetometers were installed on the Northbound approach of the intersection of State Route 123, i.e. San Pablo Avenue, and Cutting Boulevard in El Cerrito (see Figure 4).

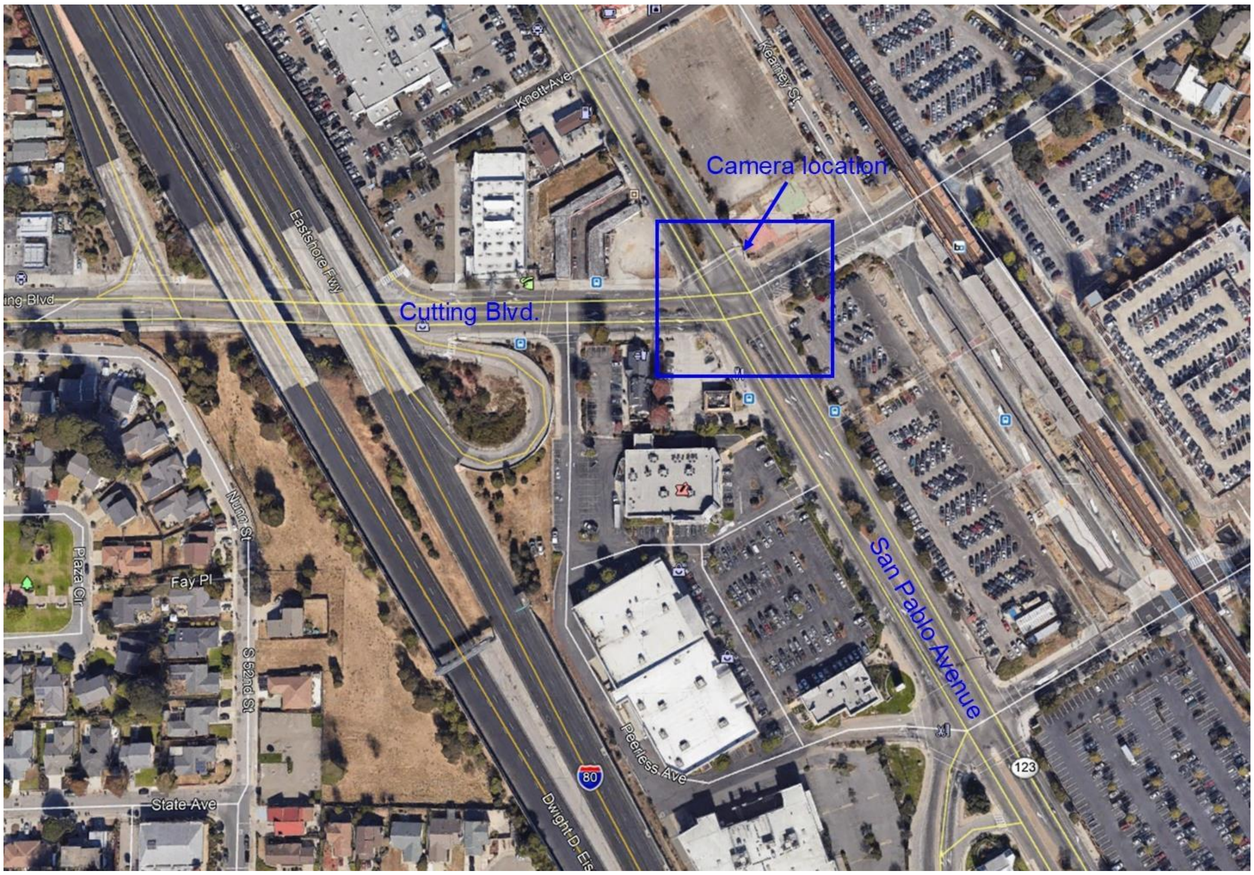


Figure 4 - Location at the signalized intersection of San Pablo Avenue, and Cutting Boulevard

The magnetometers were placed in the lanes to establish eight separate detection zones, including a "Demand" zone for each of the three through lanes (D1, D2 & D3), an "Advanced" zone for each of the three through lanes (A1, A2 & A3) and a "Left turn" zone for each of the two left turn lanes (L1 & L2). (See Figure 5). Video was recorded from a CCTV camera mounted on a signal standard at the Northeast corner of the intersection (see Figure 6).

Figure 5 - Sensys detection zones at signalized intersection location

Figure 6 - Northbound approach of intersection with detection zones

Sensys Detection System Installation

Both sites used Sensys wireless magnetometers embedded under the surface of the road. Four-inch diameter holes were drilled, vacuumed and partially filled with epoxy sealant. Magnetometers were placed in the holes, and the holes were filled to the road surface (see Figures 7 through 12). 18 magnetometers were installed at the Powell Street ramp meter location, and 23 magnetometers were installed at Cutting/San Pablo intersection location. It took a four-person crew about three hours for each installation.

Figure 7 - Hole drill bit

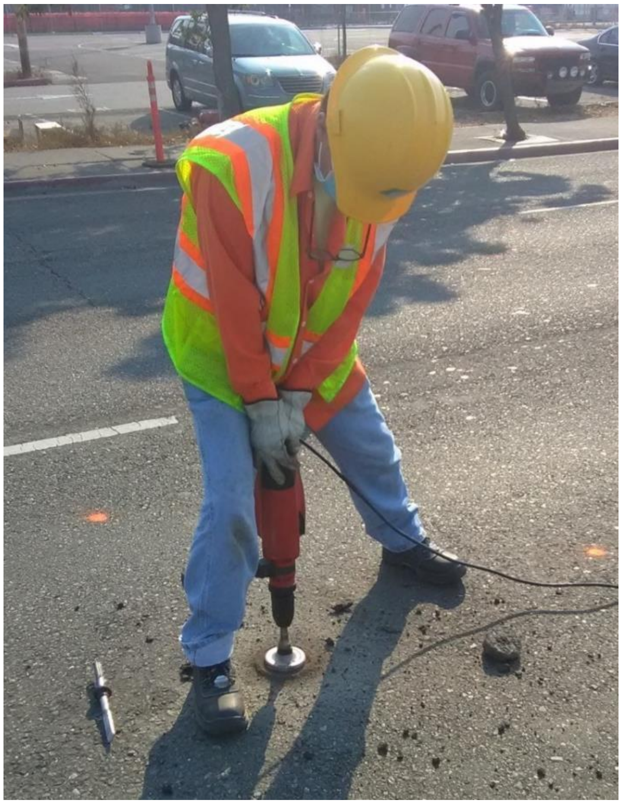


Figure 8 - Drilling hole in pavement

Figure 9 - Sensys wireless magnetometers ready for installation

Figure 10 - Filling the bottom of the hole with epoxy

Figure 11 - Placing magnetometer

Figure 12 - Filling hole to rad surface

The Sensys magnetometers communicate wirelessly with a Sensys Serial Port Protocol (SPP) Radio, either directly or through a Sensys repeater, depending on the distance. The SPP radios and repeaters were mounted on the ramp meter standard and the CCTV pole at the ramp meter location. They were mounted on the traffic signal standard and a “Trailblazer” sign pole (part of the I-80 connected corridor project) at the intersection (see Figures 13 through 18).

Figure 13 - Pulling Cat5e cable into ramp meter standard with fish tape

Figure 14 - mounting a Sensys SPP radio on the ramp meter standard

Figure 15 - mounting a Sensys repeater on the CCTV pole

Figure 16 - mounting a Sensys SPP radio on the traffic signal standard

Figure 17 - mounting Sensys repeater on Trailblazer sign pole

Figure 18 - Sensys repeater mounted on Trailblazer sign pole

The Sensys SPP Radios were connected to the ramp meter and traffic signal cabinets by pulling CAT5e cables through the conduits. In the cabinets, the CAT5e cables were connected to a Sensys Flex isolator, which provides surge protection and routes power to the radio. The Flex isolator was connected via CAT53 jumper to a Sensys Flex control unit, which receives detection data from the magnetometers and routes it, via CAT5e jumpers, to Sensys contact closure cards. The contact closure cards plug into the input file in the cabinet the same way as 222 inductive loop detector cards, so the controller doesn't know the difference. For this test, an Ethernet switch and wireless modem were also installed in the cabinet, so Sensys engineers could communicate with the detection systems (see Figures 19 through 25).

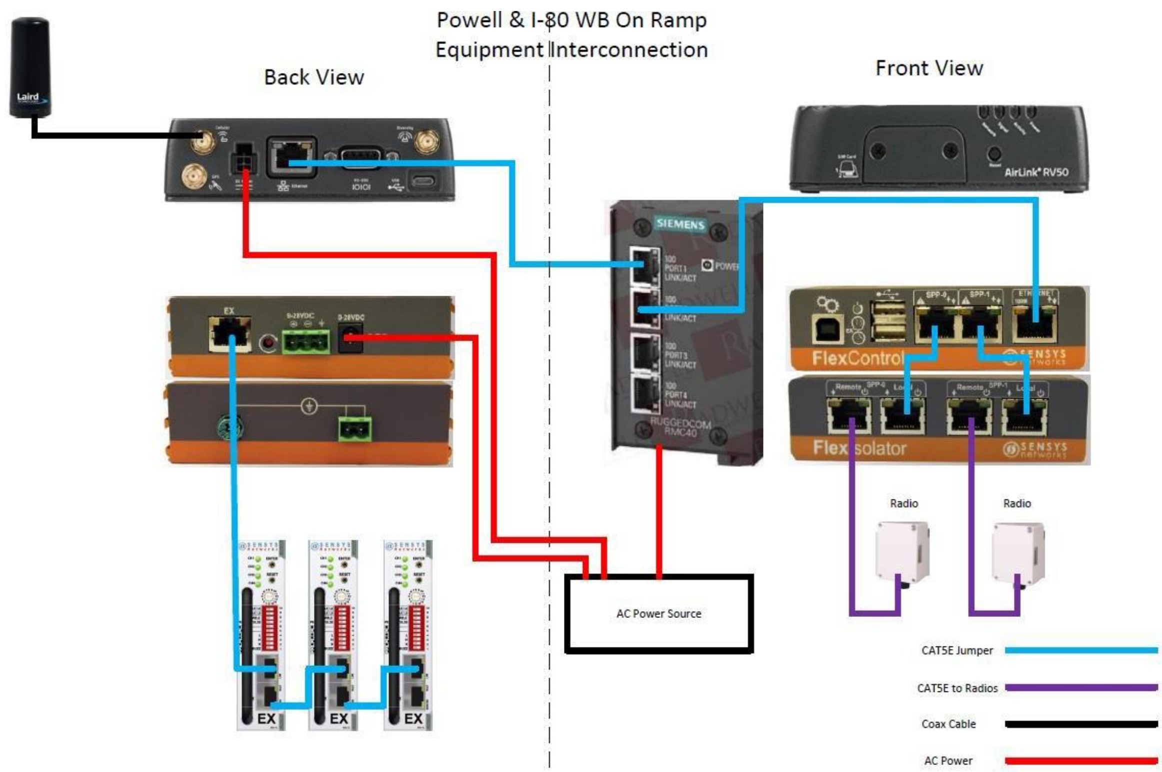


Figure 19 - Sensys equipment in the cabinet

Figure 20 - Sensys Serial Port Protocol (SPP) Radio, left and Repeater, right

Figure 21 - Sensys Flex isolator unit

Figure 22 - Sensys Flex control unit

Figure 23 - Sensys contact closure card

Figure 24 - Sensys equipment in ramp meter cabinet

Figure 25 - Sensys equipment in traffic signal cabinet

At the onramp to Southbound I-80 just North of Powell Street, there are 2 queue detection zones, one for ramp entry from Northbound Frontage Road traffic and one for ramp entry from Southbound Frontage Road traffic. There are 2 corresponding demand (stop bar) detection zones and 2 passage (downstream of stop bar) detection zones (see Figure 2). Therefore, in order to detect Northbound entry and Southbound entry traffic independently, a total of 6 detection channels (1/lane/detection zone) was needed, which required 3 2-channel contact closure cards (see Figure 26).

Figure 26 - Sensys contact closure cards in three rightmost slots

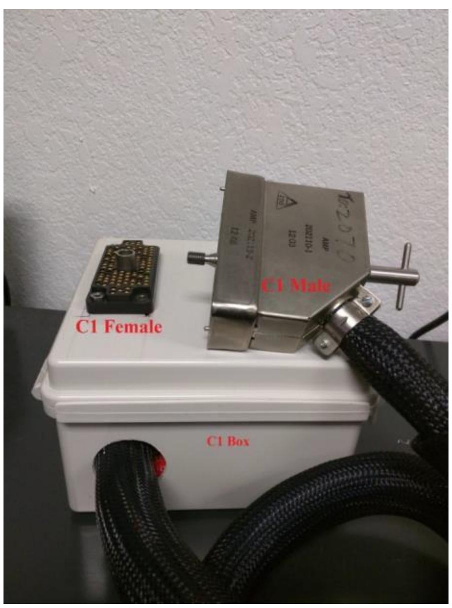
At the Northbound approach of the intersection of San Pablo & Cutting, there are 3 through lanes and two left turn pocket lanes. The through lanes have stop bar and advanced inductive loops, so 6 detection channels (1/lane/detection zone) were needed, which required 3 2-channel contact closure cards. The two left turn pocket lanes have stop bar inductive loops, so 2 additional detection channels were needed, which required another 2-channel contact closure card (see Figure 5). A total of 4 cards was needed (see Figure 27).

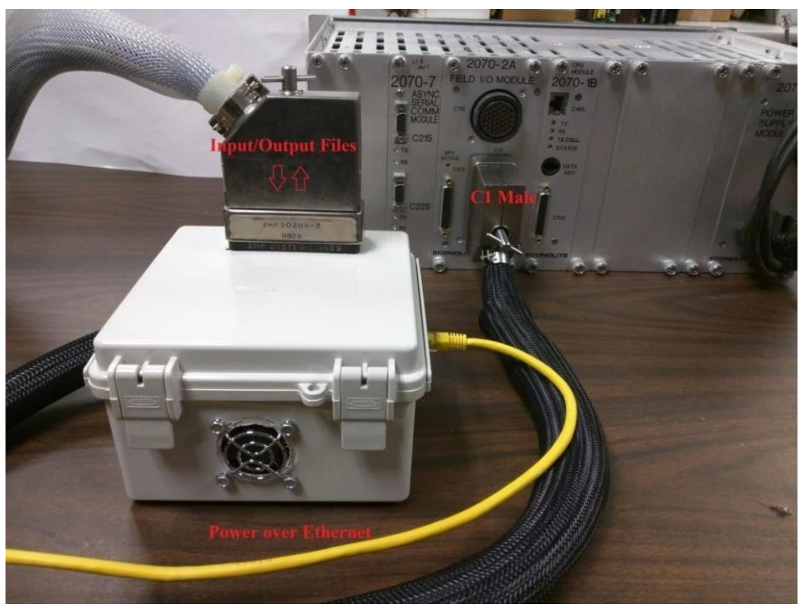
Figure 27 - Sensys contact closure cards in slots J5 - J8

Data Collection

After the Sensys detection system installations were complete, Caltrans configured the controllers to ignore the Sensys inputs and set up the data collection equipment in the two cabinets in succession. Caltrans installed a coaxial cable splitter between the analog cameras and the digital video encoders at the ramp meter and intersection cabinets. The split analog video signal was then fed to a Flir MPX digital video recorder to record video from the CCTV cameras pointed at the detection test areas. Caltrans then installed the “C1/C11 Reader” device, developed by DRISI, between the input file and the controller. This procedure required briefly putting the intersection signal on red flash while the C1 and C11 connectors were temporarily removed from the controller.

The C1/C11 reader (see Figure 28) samples all logic signals on the 104-pin C1 connector cable and the 19-pin C11 connector cable between the controller and the cabinet. This includes the detection input file, into which the inductive loop detector cards and the Sensys contact closure cards were plugged (see Figure 29). The C1 and C11 logic signals were recorded concurrently with the video at both test locations.





C1 Reader data collector **C1 Reader connected between the controller and the cabinet**

Figure 28 - C1 reader

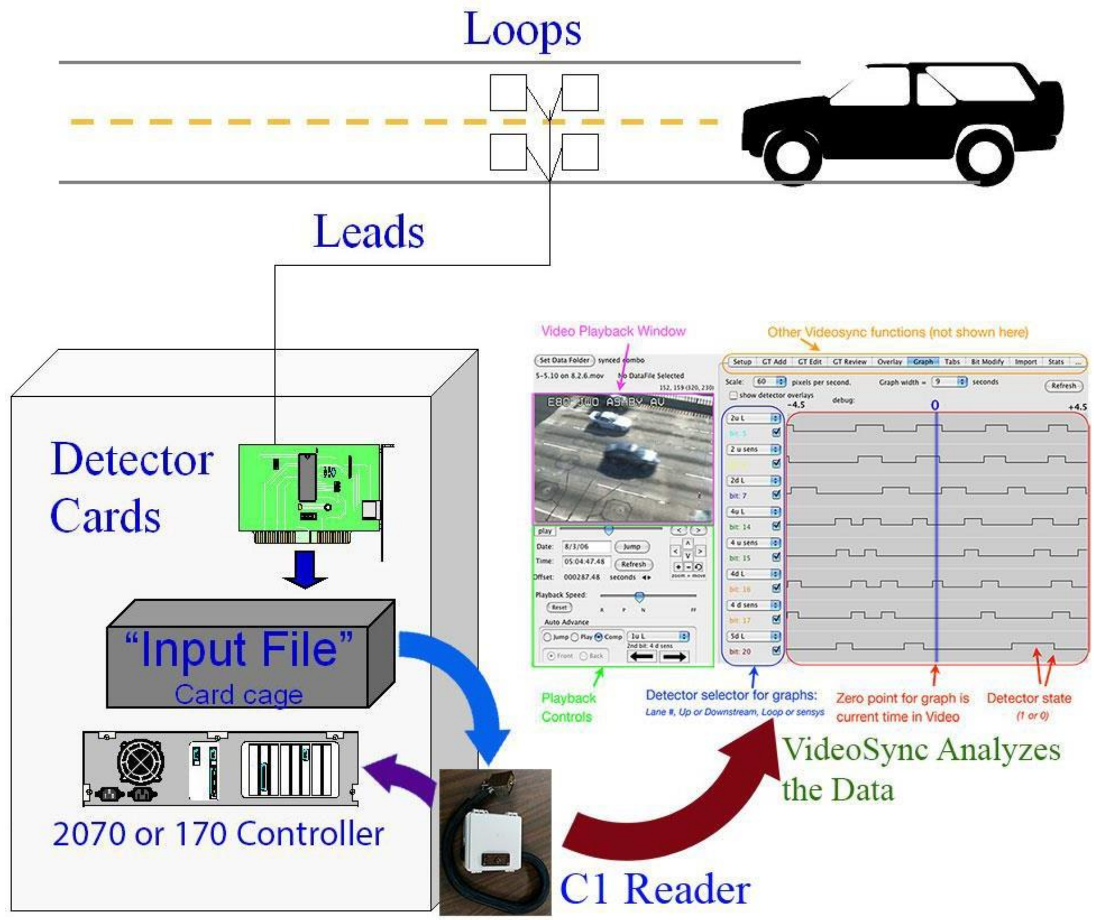


Figure 29 - C1 Reader connected into a field traffic detection system

Approximately one week of C1/C11 data and video were concurrently collected at the ramp meter from October 15th, 2020 to October 22nd, 2020. Approximately one week of C1/C11 data and video were concurrently collected at the intersection from November 17th, 2020 to November 24th, 2020.

Data Analysis

After all the C1/C11 data and video had been captured, Caltrans processed it for analysis. The data and video were divided into corresponding half hour segments for manual analysis in the DRISI developed VideoSync software. It would have been labor-prohibitive to look at all the data and video, so a few half hour segments were chosen from the entire data set to include various time periods, e.g. AM peak, midday, PM peak and nighttime, corresponding to traffic conditions of interest, e.g. congestion, max out, gap out and single vehicle actuations. The analysis of the ramp meter included 7 half-hour segments and a total of 2,675 vehicle passages through the Sensys detection zones. The loop detector in the Q1 detection zone wasn't working during the data collection, so the total vehicle passages through the loop detection zones, without considering those in the Q1 zone, was 1,798. The analysis of the intersection included 5 half-hour segments and a total of 3,522 vehicle passages through the Sensys and loop detection zones, which were all working during the data collection.

VideoSync can display "ground-truth" video alongside a graphical representation of the detection logic signals on user selected C1 or C11 connector pins (see Figures 30 and 31). VideoSync includes a pattern recognition algorithm that looks at the spacing of vehicle platoons and matches the vehicles to corresponding detection signals with like spacing. In some cases, this can be used to automatically apply a time offset to synchronize the video with the detection logic signals. In other cases, depending on offset length and video quality, synchronization needs to be done manually. Once the detection logic signals and video are synchronized, false detections (i.e. false positives), missed detections (i.e. false negatives), dropped calls, detector contact bounce and other erroneous data reported by detectors are readily visible. The operator then looks at each event where there is disagreement among the detection logic signals from the detection systems (loops and Sensys in this case) and the video and classifies the events as false positives or false negatives for one or more detectors. VideoSync includes tools that use these data sets, once compiled and analyzed, to generate statistics on the accuracy of any vehicle detector under test.

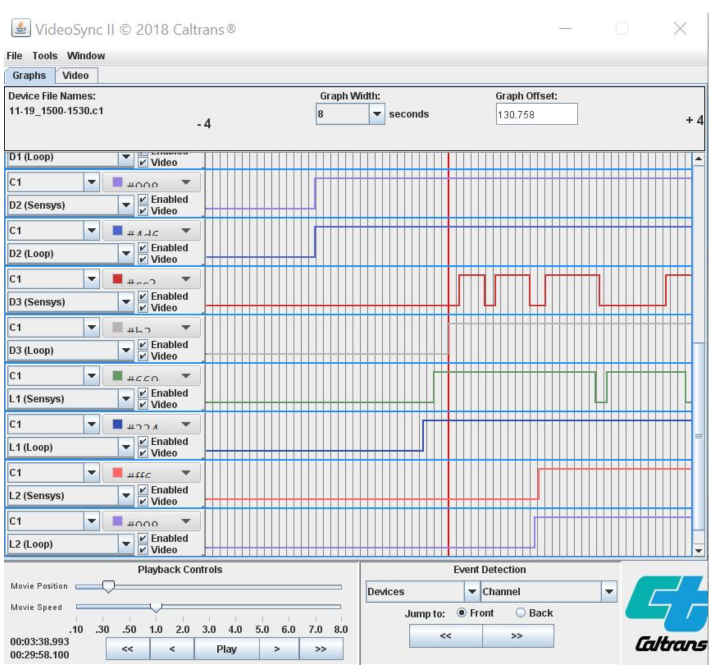


Figure 30 - graphical display of detection signals from signalized intersection in VideoSync

Figure 31 - Traffic video of the signalized intersection with detection zones in VideoSync

For this test, the degree of accuracy of a vehicle detector is defined as its “Sensitivity,” where

$$\text{Sensitivity} = \frac{\text{True Positive}}{\text{False Positive} + \text{False Negative} + \text{True Positive}} \times 100.0$$

According to this definition, the detector is penalized equally and cumulatively for each false positive and false negative. The more of either, the lower the Sensitivity. If there are none of either, the Sensitivity equals 100%.

Another quantified result was dropped calls, which are cases when the detector correctly identifies a vehicle but reports that it has left the detection zone when it is still actually present. Dropped calls don’t necessarily affect vehicle counts, e.g. for vehicle count stations on freeways, but they could affect traffic signal or ramp meter operation if they occur during a red phase, and there are no other calls from other detectors to actuate that phase.

The same 7 half-hour segments for the ramp meter and 5 half-hour segments for the intersection were analyzed by both Caltrans and Sensys staff. Caltrans provided Sensys with the VideoSync software and the processed detection data files. The initial results from Caltrans and Sensys were quite similar, but a few detection events were initially characterized differently, e.g. “false negative” instead of “correctly detected.” These events were then reviewed, compared and resolved by Caltrans, sometimes choosing the Sensys characterization and other times using the initial Caltrans characterization.

Results

At the ramp meter, the Sensitivity of the Sensys detectors was a little lower than that of the loops. The two lanes of this ramp meter are unusually wide. They are almost 24 feet, or twice the standard width, in some places. This contributed to the relatively low Sensitivity values in general, and for the Q detection zones in particular (see Table 1). In the case of the Sensys detectors, this is probably because only one magnetometer was installed for each Q detection zone. On the other hand, Sensys installed two adjacent magnetometers for each Demand and Passage detection zone (see Figure 32), which resulted in higher Sensitivity values (see Table 1). The unusual width of the lanes also seems to have accommodated queue skipping by several vehicles, as observed in the videos, particularly during periods of heavy congestion. These queue skipping vehicles tended to bypass both the Sensys and loop detectors and probably contributed to the generally lower Sensitivity values for the ramp meter compared to those of the intersection.

Table 1 - Detector Sensitivity at Ramp Meter

Detection Zone	Loops	Sensys	Difference
All	98.05%	94.17%	3.88%
Q1	100.00%	84.91%	15.09%
Q2	No data	93.04%	NA
D1	95.43%	97.56%	-2.13%
D2	99.36%	98.93%	0.43%
P1	95.77%	97.29%	-1.52%
P2	99.35%	91.13%	8.22%

Figure 32 - two Sensys magnetometers installed abreast in unusually wide lane

At the intersection, the lanes are all 12 feet wide and relatively straight compared to those at the ramp meter. No vehicles were observed to pass another in the same lane. These factors probably contributed to the significantly higher Sensitivity values for both sets of detectors at the intersection compared to the ramp meter (see Table 2).

Table 2 - Detector Sensitivity at Signalized Intersection

Detection Zone	Loops	Sensys	Difference
All	99.69%	99.55%	0.14%
A1	100.00%	98.86%	1.14%
A2	99.02%	99.01%	0.01%
A3	100.00%	98.89%	1.11%
D1	100.00%	100.00%	0.0%
D2	99.34%	99.83%	-0.49%
D3	98.88%	100.00%	-1.12%
L1	100.00%	100.00%	0.0%
L2	100.00%	100.00%	0.0%

The data showed a few more dropped calls from the Sensys magnetometers than from the inductive loops at both the ramp meter and signalized intersection locations (see Tables 3 and 4).

Table 3 - Dropped Calls at Ramp Meter

Detection Zone	Loops by Number	Sensys by Number	Difference by Number	Loops by Percentage of Total	Sensys by Percentage of Total	Difference by Percentage
All	0	8	8	0.0%	0.30%	0.30%
Q1	0	0	0	0.0%	0.0%	0.0%
Q2	No Data	0	NA	0.0%	0.0%	NA
D1	0	1	1	0.0%	0.30%	0.30%
D2	0	7	7	0.0%	1.50%	1.50%
P1	0	0	0	0.0%	0.0%	0.0%
P2	0	0	0	0.0%	0.0%	0.0%

Table 4 - Dropped Calls at Signalized Intersection

Detection Zone	Loops by Number	Sensys by Number	Difference by Number	Loops by Percentage of Total	Sensys by Percentage of Total	Difference by Percentage
All	5	19	14	0.14%	0.54%	0.40%
A1	0	0	0	0.0%	0.0%	0.0%
A2	0	0	0	0.0%	0.0%	0.0%
A3	0	0	0	0.0%	0.0%	0.0%
D1	0	2	2	0.0%	0.29%	0.29%
D2	5	1	-4	0.83%	0.17%	0.66%
D3	0	1	1	0.0%	1.14%	1.14%
L1	0	9	9	0.0%	3.44%	3.44%
L2	0	6	6	0.0%	1.27%	1.27%

Not all dropped call behavior was necessarily equally indicative of a detector's lack of functionality. For example, in two events at the intersection, the detector only dropped the call for a few seconds but then regained it with the same vehicle still stationary over its detection zone. In other events, the detector dropped the call with the vehicle at the stop bar and only regained it once the vehicle started moving after receiving a green indication. In still other events, the detector dropped the call and only regained it after another vehicle entered the detection zone. The first case, in which the detector regained the call by itself, would only result in the phase at a traffic signal it actuates being skipped if the dropped call happened to occur just as the previous phase were about to terminate. This would only happen if there were no other functional calls for the phase in question waiting to be served. However, the other cases, in which the detector needed outside influence to regain the call, would be more likely to result in the phase being skipped if there were no other functional calls for that phase waiting to be served. With that in mind, Tables 5 and 6 categorize the dropped call events at the intersection and ramp meter respectively.

Table 5 - Categorized Dropped Calls at Signalized Intersection

Detection Zone	Loops	Sensys			Difference
		Regained call by itself	Regained call only after vehicle started moving after receiving green indication	Regained call only after another vehicle entered the detection zone	
All	5	2	6	11	14
A1					0
A2					0
A3					0
D1			2		2
D2	5			1	-4
D3				1	1
L1		1	2	6	9
L2		1	2	3	6

Table 6 - Categorized Dropped Calls at Ramp Meter

Detection Zone	Loops	Sensys		Difference
		Vacated detection zone without ever regaining call	Regained call only after another vehicle entered the detection zone	
All	0	7	1	8
Q1				0
Q2	No Data			NA
D1		1		1
D2		6	1	7
P1				0
P2				0

Conclusion

Based on the sensitivity measurements in this test, the Sensys wireless magnetometers were very close in accuracy to the inductive loops. However, the loops were still a little more accurate in general. For example, the sensitivity of the loops at the ramp meter was 98.05% while the sensitivity of the Sensys magnetometers was 94.17%. At the signalized intersection, the difference was essentially negligible, with sensitivities of 99.69% for the loops and 99.55% for Sensys. The slightly lower sensitivity values of the magnetometers would probably not affect traffic signal or ramp meter operation in most cases, since there would most likely be more than one call to actuate each phase, especially for high traffic conditions. However, in very low traffic conditions, e.g. late at night with only one vehicle present to actuate a phase, a false negative or dropped call could conceivably result in delayed phase service. Sensys says that the issue of dropped calls can be mitigated by independently adjusting the threshold for deactivating a call sent by their magnetometers to the controller, since they have separate thresholds for activating and deactivating call signals. Ultimately, it will be up to the district traffic engineers to decide whether the benefit of the relative ease of installation of the Sensys detection system is worth the slightly increased probability, as shown in this particular test, of delayed phase service.

This test shows that consideration should be given to installing two magnetometers abreast in lanes that are wider than the standard 12 feet or where the roadway geometry is unconventional. This could be seen at the ramp meter, where the single magnetometers in the queue detection zones missed significantly more vehicles than the dual abreast magnetometers in the demand and passage detection zones. This test also indicates that extra care should be taken when configuring the call deactivation threshold of the magnetometers in any new Sensys installation, because this should minimize the risk of dropped calls.

Appendix

Table A1 - Detector Data from Ramp Meter Location

Detector	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
Loop	98.05%	1798	1763	35	0	0
Sensys	94.17%	2675	2521	154	2	8
Loop						
Channel Name	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
Q1	100.00%	212	212	0	0	0
Q2	No data	No data	No data	No data	No data	No data
D1	95.43%	328	313	15	0	0
D2	99.36%	466	463	3	0	0
P1	95.77%	331	317	14	0	0
P2	99.35%	461	458	3	0	0
Sensys						
Channel Name	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
Q1	84.91%	212	180	32	0	0
Q2	93.04%	877	816	61	0	0
D1	97.56%	328	320	8	0	1
D2	98.93%	466	461	5	0	7
P1	97.29%	331	323	8	1	0
P2	91.13%	461	421	40	1	0

Table A2 - Detector Data from Signalized Intersection Location

Detector	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
Loop	99.69%	3522	3518	4	7	5
Sensys	99.55%	3522	3508	14	2	19
Loop						
Channel Name	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
A1	100.00%	702	702	0	0	0
A2	99.02%	607	607	0	6	0
A3	100.00%	90	90	0	0	0
D1	100.00%	697	697	0	0	0
D2	99.34%	604	600	4	0	5
D3	98.88%	88	88	0	1	0
L1	100.00%	262	262	0	0	0
L2	100.00%	472	472	0	0	0
Sensys						
Channel Name	Sensitivity	Cumulative Car Count Total	Cumulative True Positive Total	Cumulative False Negative Total	Cumulative False Positive Total	Cumulative Dropped Call Total
A1	98.86%	702	695	7	1	0
A2	99.01%	607	601	6	0	0
A3	98.89%	90	89	1	0	0
D1	100.00%	697	697	0	0	2
D2	99.83%	604	604	0	1	1
D3	100.00%	88	88	0	0	1
L1	100.00%	262	262	0	0	9
L2	100.00%	472	472	0	0	6