Metro

Date	September 10, 2018
To	Duane Thomas, FHWA
From	Lia Yim, LA Metro Jonathen Hofert, LA Metro
Subject	Experiment 8(09)-8 (E)

Background

In September 2012, FHWA approved Metro's Request to Experiment with an Internally Illuminated Raised Pavement Markers(IIRPM) system at ten intersections along the Metro Gold Line Eastside Extension (MGLEE) in the City of Los Angeles and the County of Los Angeles. In May 2013, two more intersections on the Metro Blue Line were approved for a total of twelve experiment locations. The IIRPM system is meant to supplement existing traffic signal indications at these intersections for the left turn lanes adjacent to the light rail corridor. This non-standard traffic control system, which uses a series of LED lights embedded in the roadway and is designed to increase the awareness of the presence of street running light rail trains among motorists when trains approach the intersections and deter them from making illegal left turns. The experiment is meant to evaluate any reductions in left turn violations associated with installation of the IIRPM system.

A two-year experiment period was to begin after the installation of IIRPMs at the twelve locations in May 2015. The original evaluation plan submitted to FHWA is based on data collected by Metro's Photo Enforcement Camera program, with one intersection (1st /Indiana) utilizing manual counts of left turn violations since it is not included in the photo enforcement program. The proposed analysis used a before and after evaluation of left turn violation data to determine the effectiveness of the IIRPMs.

During the evaluation period, two issues affecting the reliability and quality of the data were noted. First, there appeared to have been an issue with the installation of some of the equipment. Equipment failures disrupted the data collection efforts. Our contractors addressed the affected equipment and continued inspections through the trial period. Second, the photo enforcement program replaced the photo enforcement cameras with higher resolution digital equipment during the evaluation period, which included the cameras used at the experiment locations. This affected the ability to compare the before data collected. All cameras were upgraded by June 2016.

Based on these data collection issues, Metro proposed a modified original evaluation plan, which was approved by FHWA (see Attachment A). Metro in partnership with California State University Fullerton Institute of Transportation Engineers assessed the effectiveness of the IIRPMs. The following summarizes the research conducted by CSUF ITE. Their full report is attached for reference (see Attachment B). Also included with this memo are Attachments C and D. Attachment C includes tables showing the actual number of average daily violations and average daily violation rates during the on and off periods. Attachment D shows images of the IIRPMs at the demonstration locations.

Evaluation

Methodology

The dataset consisted of a small sample size, so t-tests were conducted for statistical analysis. The t-distribution curves used are thick at the tails and provide a more conservative result, which compensates for smaller data availability. The analysis used two types of t-tests; paired t-test and t-tests for sample means. A paired t-test is used when assessing any differences between the means of two related observations. It also indicates how significant the differences are. Therefore, paired t-tests were used to analyze the differences in left-turn violations when the IIRPMs were on and when they were off. A t-test for sample means assuming equal variances (also known as pooled variance t-test) is used when assessing the differences between the means of two different groups. For this reason, a t-test for sample means was used to compare the differences in left-turn violations between demonstration movements and control movements. Several hypotheses were tested using the two types of t-tests based on the sample characteristics and available data.

Data Collection

A two month before and after evaluation period was presented in the modified plan from February to March 2017. Due to equipment repair and count scheduling, the two month data collection occurred during alternate dates and a slightly longer time period, see table below.

	Proposed	Actual
On Period	February 1 to February 28, 2017	February 1 to March 9, 2017
Off Period	March 1 to March 31, 2017	March 10 to April 12, 2017

Study intersections/movements were also modified due to equipment repairs and issues with count collection, see table below.

Demonstration Intersection	Movement	Actual
1. 3rd & Civic Center	EB to NB	Included
2. 3rd & La Verne	WB to SB	Included
3. 3rd & Mednik	EB to NB	Included
4. 3rd & Mednik	WB to SB	Included
5. 3rd & McDonnell	EB to NB	*Removed*
6. 3rd & McDonnell	WB to SB	*Removed*
7. 3rd & Ford	EB to NB	Included
8. 3rd & Ford	WB to SB	Included
9. 3rd & Downey	WB to SB	Included
10. 3rd & Gage	EB to NB	Included
11. 3rd & Gage	WB to SB	Included
12. 3rd & Rowan	EB to NB	Included
13. 3rd & Rowan	WB to SB	Included
14. 1st & Indiana	WB to SB	*Removed*
15. 1st & Mission	EB to NB	Included
16. 1st & Mission	WB to SB	Included
17. Washington & San Pedro	EB to NB	Included
18. Washington & San Pedro	WB to SB	Included
19. Washington & Los Angeles	EB to NB	*Removed*
20. Washington & Los Angeles	WB to SB	*Removed*

Control Intersection	Movement	Actual
1. Temple & Alameda	SB to EB	*Removed*
2. 3rd & Arizona	EB to NB	Included
3. 3rd & Arizona	WB to SB	Included
4. 3rd & Eastern	EB to NB	Included
5. 3rd & Eastern	WB to SB	Included
6. 1st & Lorena	EB to NB	Included
7. 1st & Lorena	WB to SB	Included
8. 1st & Clarence	EB to NB	*Removed*
9. 1st & Clarence	WB to SB	*Removed*
10. 1st & Utah	WB to SB	Included
11. 1st & Anderson	WB to SB	Included

Results

Several hypotheses were tested in the statistical analysis:

- The first hypothesis test was used to ensure there were no statistical differences in traffic counts during when the IIRPMs were on and when they were off. This test found no differences in traffic counts for the on and off period.
- The second hypothesis tested the effectiveness of IIRPMs in deterring left-turn violations at demonstration movements and found a statistically significant reduction in the average number of left-turn violations for when the IIRPMs were on. Additionally, it was found that IIRPMs had a statistically significant reduction in left-turn violations during weekday travel.
- The third hypothesis examined whether there was a statistically significant difference in the average number of left-turn violations at control movements during the period when the IIRPMs were on and off. It was expected there would not be any differences between both periods, since this hypothesis examined only control movements. However, the testing showed a slight but statistically significant difference between the two periods. This difference could be attributed to the sample size having too few observations, but it could not be conclusively determined what may have caused the disparities.
- The fourth and fifth hypotheses analyzed the rate of violations for demonstration and control movements. The fourth hypothesis examined the differences between demonstration and control movements during the period when the IIRPMs were on and the fifth hypothesis examined the differences during the period when the IIRPMs were off. For the fourth hypothesis, it was expected that the rate of violations would be lower for demonstration movements; however it was found that there were no statistically significant reductions when the IIRPMs were active. The fifth hypothesis also found no differences between demonstration and control movements when the IIRPMs were off, which was expected. The sample size was very small for both the fourth and fifth hypotheses, which may have affected the results.

Conclusion

The results of this research have generally indicated that IIRPMs have the potential to significantly reduce the average number of left-turn violations. The findings contribute to prior research that has shown IIRPMs and in-roadway lights encouraging road users to comply with traffic control devices. The research did encounter data limitations that prevented a more robust analysis, but the results were still able to show a statistical significance in the effectiveness of the IIRPMs.

U.S. Department
of Transportation
Federal Highway Administration

1200 New Jersey Avenue, SE
Washington, D.C. 20590

MAR 8 2017

In Reply Refer to:
HOTO-1

Ms. Basilia Yim
Transportation Planning Manager
Los Angeles County MTA
One Gateway Plaza
Los Angeles, CA 90012-2952

Dear Ms. Yim:

Thank you for your February 24 e-mail message requesting to modify the research plan for Experiment 8(09)-8 regarding the use of red internally-illuminated raised pavement markers at LRT grade crossings.

We have reviewed your request to modify your experiment. Your request to modify Experiment 8(09)-8 is approved and we look forward to receiving your semi-annual progress reports and your final evaluation report at the end of the experiment.

For recordkeeping purposes, we will continue to use the following official experimentation number and title: "8(09)-8 (E) – Red In-Roadway Lights at LRT Grade Crossings – Los Angeles, CA." Please continue to refer to this number in future correspondence.

Thank you for your interest in improving the operational capability and traffic safety for road users and LRT operators through the use of internally-illuminated raised pavement markers.

Sincerely yours,

Mark R. Kehrli

Mark R. Kehrli
Director, Office of Transportation
Operations

Metro

Date	February 24, 2017
To	Bruce Friedman, FHWA
From	Lia Yim, LA Metro
Subject	Experiment 8(09)-8 (E)

Background

In September 2012, FHWA approved Metro's Request to Experiment with an In-Roadway Warning Light (IRWL) system at 10 intersections along the Metro Gold Line Eastside Extension (MGLEE) in the City of Los Angeles and the County of Los Angeles. In May 2013, 2 more intersections on the Metro Blue Line were approved for a total of 12 experiment locations. The IRWL system is meant to supplement existing traffic signal indications at these intersections for the left turn lanes adjacent to the light rail corridor. This non-standard traffic control system, which uses a series of LED lights embedded in the roadway and is designed to increase the awareness of the presence of street running light rail trains among motorists when trains approach the intersections and deter them from making illegal left turns. The experiment is meant to evaluate any reductions in left turn violations associated with installation of the IRWL system.

The 2-year experiment period began after the installation of IRWLs at the 12 locations in May 2015. The original evaluation plan submitted to FHWA is based on data collected by Metro's Photo Enforcement Camera program. One intersection (1st /Indiana) is not included in the Photo Enforcement Camera program, so manual counts of left turn violations were to be taken and analyzed. The proposed analysis used a before and after evaluation of left turn violation data to determine the effectiveness of the IRWLs. Attached is the original MGLEE evaluation proposal and approval from FHWA for your reference. Also included is the request and approval to expand the experiment to include two locations on the Metro Blue Line.

Update

During the evaluation period, two issues affecting the reliability and quality of the data have been noted. First, there appears to have been an issue with the installation of some of the equipment. The contractors hired for the installation of the IRWLs were also tasked with inspecting the equipment for two years after the installation. Over the first year, several operational failures were experienced and the contractor has had to troubleshoot and replace equipment. Due to these operation and maintenance issues, it has been difficult to assess any level of effectiveness attributed to the IRWLs. We have been monitoring the equipment closely and have seen very few equipment issues between July 2016 and January 2017. In early February 2017, additional equipment issues arose and efforts are being taken to understand if the affected equipment was

from the initial installation. Overall, we feel many of the installation issues have been resolved and a good amount of the equipment has been operational for the past seven months.
Second, the photo enforcement program replaced the photo enforcement cameras with higher resolution digital equipment, which included the cameras used at the experiment locations. After the installation of the high resolution cameras, an increase in the number of violations was observed in the data. It is probable that due to the higher resolution the new cameras are able to capture more violations than the previous ones, so the increase appears to be linked to the installation of the new cameras and not related to the IRWLs. All cameras have now been upgraded and no further interruptions in equipment changes are anticipated.

Modified Evaluation Proposal

Based on these data collection issues, Metro is proposing to adjust the evaluation plan submitted to FHWA. Metro has partnered with California State University Fullerton Institute of Transportation Engineers (CSUF ITE) to assist in assessing the effectiveness of the IRWL system. A preliminary study has been completed that evaluated 4 intersections along the MGLEE by using manual counts to record the number of left turn violations. The results of this preliminary study indicate that IRWLs are effective in deterring motorists from making illegal left turns. Therefore, in light of the installation issues and change in photo enforcement equipment, Metro in partnership with CSUF ITE is proposing a modification to the original evaluation plan.

A two month evaluation period is being proposed from February – March 2017. One month the IRWLs will be in operation (February), and the next month the IRWLs will be turned off to simulate a "before" scenario (March). This will allow for an "apples to apples" comparison of enforcement camera data with and without the use of IRWLs. Previously, the evaluation plan compared monthly violation rates over a two year period (24 data points at each site) with and without IRWLs in operation. This modified proposal evaluates daily violation rates for one month with the IRWLs in operation and another month with the IRWLs not in operation (28-31 data points at each site). Attached is the full Modified Evaluation Proposal for your review and consideration.

Terms

In recent conversations with the California Traffic Control Devices Committee, a recommendation was made to utilize the term "Internally Illuminated Raised Pavement Marker" in lieu of "In Roadway Warning Light" for this equipment. The §4N.01 of the MUTCD states that "In-Roadway Lights shall be flashed and shall not be steadily illuminated". FHWA has published material (FHWA-SA-09-007, attached for your reference) that describes Internally Illuminated Raised Pavement Markers. Since this experiment utilizes equipment that illuminates steadily, per CTCDC recommendations, we have used this term in the modified evaluation proposal.

August 7, 2012

Submitted to:
California Traffic Control Device Committee
Federal Highway Administration, Office of Transportation Operations

RE: Permission to Demonstrate In-Roadway Warning Lights

The Los Angeles County Metropolitan Transportation Authority ("Metro") respectively requests permission to conduct a demonstration of an In-Roadway Warning Light (IRWL) system that would supplement existing traffic signal indications at ten (10) intersections along the Metro Gold Line Eastside Extension, a Light Rail Train system located in Los Angeles, California. This non-standard traffic control system, which is composed of a series of LED lights embedded in the roadway is designed to increase the awareness of the presence of street running light rail trains among motorists approaching the intersection. The proposed application of IRWLs focuses on enhancing the warning for motorists when trains approach the intersections and deterring them from making illegal left turns. This in turn will reduce violations and accidents by increasing compliance with Red traffic signal indications.

1. Statement of Problem

Metro Gold Line Eastside Extension (MGLEE)

The MGLEE is a six-mile light rail transit (LRT) project, which extends the Metro Gold Line from Downtown Los Angeles at Union Station and proceeds easterly to the terminus near the intersection of Atlantic Avenue and Pomona Boulevard. The MGLEE opened for revenue service on November 16, 2009. For approximately four miles of the alignment, the light rail trains operate in a center median separated from adjacent vehicular traffic by a six-inch high curb. Where at-grade intersection crossings occur, the movement of trains, vehicles, and pedestrians are controlled by traffic signals, train signals, striping, and signage. The California Public Utilities Commission (CPUC) regulations limit speed on surface light rail systems to the legal speed of parallel traffic, but not to exceed 35 miles per hour. Attachment A contains a map of the MGLEE alignment and indicates the locations of the at-grade crossings.

While the MGLEE has maintained a safe standard of operations during its first 30 months of operation, the Metro Board has directed staff to increase awareness of the light rail system, enhance safety measures at at-grade crossings and further reduce left turn violations.

A review of the MGLEE incident summaries revealed that illegal turn violations are responsible for 13 of 17 (76%) incidents that occurred since service began. While a number of industry-wide best practices have already been incorporated into the design of the MGLEE to reduce the risk of left turn violations, additional refinements have been identified by Metro to further reduce this risky behavior. These include refinements to traffic signal phasing at selected intersections, improved advanced train detection, and trial demonstrations of In-Roadway Warning Lights (IRWLs). All of the improvements are designed to increase predictability of traffic signal systems and increase public awareness of train operations.

2. Proposed Solution: In-Roadway Warning Lights System

The predominant cause of train-vehicle incidents occurring on the MGLEE are left turn violations. Metro, in close coordination with the County of Los Angeles Department of Public Works (DPW) and the City of Los Angeles Department of Transportation (LADOT) has initiated improvements that specifically target left turn violations and aim to reduce the number of violations. These improvements have included adjustments to the traffic signal heads to increase the visibility of the left turn arrows at greater distances, and improvements to the advance train detection system along a portion of the alignment so that traffic signals can be programmed with maximum efficiency and predictability. Additionally, Metro is proposing to install IRWLs at ten at-grade intersection crossings to reinforce the existing traffic signals and active "Train Approaching" warning signs.

While limited data has been collected to demonstrate the effectiveness of IRWLs at reducing left turn violations, various applications of IRWLs have demonstrated the ability to change motorist behavior and reduce the tendency of motorists to violate red light signals. The proposed IRWL system would serve as a reinforcement to the standard traffic signal control devices. It would not conflict with any existing traffic control device, but would provide an additional visual warning to motorists and pedestrians that a train is approaching the intersection. A single row of lights would be embedded in the pavement parallel to the train tracks in the direct line of sight of the motorists waiting at or approaching the intersection. The lights will be embedded in the pavement at two different angles in order to be visible to all motorists approaching the intersection. In an alternating fashion, the lights will be placed at 90-degree and 45-degree angles. The series of lights that will be angled towards motorist in the eastbound and westbound left turn lanes will be adjusted to the most appropriate angle for maximum visibility. Attachment B illustrates the proposed application of warning lights.

This application would be unique, compared to other applications tested at County of Los Angeles transit crossings. The IRWLs would not be exclusively applied to stop bars as was done on a recent project on the Blue line by LACMTA. In this project, instead of a single row of lights being applied to the left turn stop bar, a row of lights would be applied parallel to the LRT tracks and run the full width of the intersection. The lights would be installed along both sides of the LRT right-of-way to create a visual barrier along the tracks. Additionally, the IRWLs would be synchronized with the active Train Approaching warning signs, so that the lights would be illuminated ONLY when a train approaches and crosses the intersection. During other red light signal phases, when no trains are detected as approaching the intersection, the warning lights would not be illuminated. Since there are many factors which can limit the effectiveness of IRWL applications, we believe it is critical that the warning lights be linked directly to the train activity rather than the red light signal phase, which may or may not indicate the presence of a train.

The maintenance and reliability of the warning light devices is another key factor that can limit the effectiveness of the warning system. Several agencies, including the City of Santa Monica, have tested multiple applications of IRWLs and documented their best practices with regards to installation and selection of a reliable manufacturer, as well as product maintenance. This proposal will incorporate these lessons learned to select the most durable equipment and to minimize maintenance issues.

3. Supporting Data

There is limited data on the use of IRWLs to increase motorist awareness at at-grade transit crossings. This application summarizes data collected from two transit agencies: Houston METRO and LACMTA. In addition, it cites a study by the City of Santa Monica which evaluated the effectiveness of IRWLS to increase motorist awareness at various pedestrian crossings. While Houston METRO and the City of Santa Monica both demonstrated positive results, LACMTA's tests were inconclusive.

<u>Houston METRO</u> – The transit agency operates a 7.5 mile stretch of light rail transit that runs through the Houston downtown. The rail system experienced several crashes due to motorists running red lights, creeping through intersections, or making prohibited right turns on Red. In 2006, the agency employed an application of IRWLs at one intersection in the downtown area. A double row of in-pavement lights were installed at the stop bar at the Jefferson Street approach to Main Street, in an attempt to reduce both through-traffic red light violations and right-turn-on-red violations. At this location there is no left turn movement available, therefore, reducing left turn violations was not a component of the study. While the trial demonstration was not finalized, preliminary results indicated that the IRWLS reduced right-turn-on-red violations by more than 50%.

<u>LACMTA</u> – LACMTA in coordination with LADOT installed IRWLs at two intersections, located on distinct transit lines, in an attempt to reduce red light violations. The first installation, which aimed to reduce left turn violations at a Metro Blue Line Light Rail Train crossing, applied a single row of in-pavement lights to the stop bars of the eastbound and westbound left turn pockets. The lights were illuminated each time the red light signal phase would occur, for the full red phase interval. Photo enforcement camera data was used to compare the before and after red light violation rates. In addition, the data collected was compared to a similar intersection where no IRWLs had been installed. The data indicated a reduction in left turn violation rates at the test location but also an equal or greater reduction in

violation rates at the non-test location. Therefore, it could not be concluded that the lights helped reduce the left turn violations.

A second installation of IRWLS was applied to a Metro Orange Line Bus Rapid Transit crossing to reinforce traffic signal indications and aimed to reduce through-traffic red light violations. The installation was located at Woodman Avenue near Oxnard Street at a place where the Metro Orange Line crosses Woodman Avenue at a slight diagonal angle. A single row of IRWLs was applied to the northbound and southbound stop bars on Woodman. Since there are no left turn or right turn movements for either the northbound or southbound traffic, reduction of left turn violations or right-turn-on-red violations was not a component of this test. The lights were illuminated each time the red light signal phase would occur, for the full red light interval. Photo enforcement camera data was used to compare the before and after red light violation rates. In addition, the data collected was compared to a similar crossing where no IRWLs had been installed. The before and after data indicated an inexplicably large increase in the northbound violation rates and a slight increase in the southbound violation rates for both the test location and the non-test location. Therefore, the test application was not able to conclude any benefit from the application of the IRWLs at the stop bars.

<u>City of Santa Monica</u> – The City has installed IRWLs at seventeen different crosswalk locations in an effort to increase driver awareness of pedestrian crossings. The City performed an evaluation of six test sites to evaluate the effectiveness of the devices in increasing driver's awareness of pedestrians, and also did a comparative analysis of the effectiveness of various manufacturers' devices. Their findings are documented in a report titled *In-Roadway Warning Lights Comparative Study,* dated July 13, 2010. The City evaluated the motorist yielding distances at the test locations when the devices were in operation and again when they were not in operation. The results showed a slight increase in yielding distances at most locations during the daytime and a very notable increase in night-time compliance when the devices were in operation (from 66% to 90%). The night time yielding distances were effectively increased to the level of daytime yielding distances, which are measurably higher. The results suggest that the devices can be particularly effective at increasing driver's awareness at dusk and during the nighttime.

Conclusions

While trials of IRWLs to increase motorist compliance of red light signal indications have been limited, there are applications of IRWLs which have demonstrated the ability to increase motorist awareness and compliance with traffic signal indications or other traffic signs. The proposed trial would specifically target left turn violations at ten intersections on the MGLEE. The existing photo enforcement camera program provides the benefit of continuous and consistent data collection at 8 of 10 trial demonstration intersections. It also provides comparative data for seven other intersections. We believe this would allow for an excellent opportunity to test and document the effectiveness of these devices.

4. No Patent or Copyright

Metro certifies that the concept of the In-Roadway Warning Lights is not protected by patent or copyright. More than one vendor can provide similar devices.

5. Demonstration Schedule and Locations

a.	Design and Engineering	January- February 2013
b.	Installation	March 2013
c.	Experimental and Evaluation Period	May 2013 through May 2015
d.	Bi-annual Progress Reports	After each 6-month period
e.	Final Report	September 2015

The proposed demonstration would include applications of IRWLs at the ten at-grade intersection crossings listed below. All but two of the intersections in the demonstration group have photo enforced left turns.

Demonstration Locations	Photo Enforced Left Turns
1. Temple & Alameda	No
2. 1st & Indiana	No
3. 3rd & Rowan Avenue	Yes
4. 3rd & Gage Avenue	Yes
5. 3rd & Downey Road	Yes
6. 3rd & Ford Blvd.	Yes
7. 3rd & McDonnell Avenue	Yes
8. 3rd & Mednik Avenue	Yes
9. 3rd & Civic Center Way	Yes
10. 3rd & La Verne Avenue	Yes

The following is a list of the MGLEE at-grade crossings which will remain unchanged during the demonstration. This list includes seven intersections with photo enforced left turns, which will serve as the control group.

Non-Demonstration Locations	Photo Enforced Left Turns	
1. 1st & Alameda	No	
2. 1st & Hewitt	No	
3. 1st & Vignes	No	
4. 1st & Mission	Yes	(control group)
5. 1st & Anderson	Yes	(control group)
6. 1st & Utah	Yes	(control group)
7. 1st & Clarence	Yes	(control group)
8. 1st & Lorena	Yes	(control group)
9. 1st & Indiana	No	
10. 3rd & Indiana	No	
11. 3rd & SR-60 Ramps	No	
12. 3rd & Eastern	Yes	(control group)
13. 3rd & Arizona	Yes	(control group)

14. 3rd & Woods & Beverly No

6. Evaluation Plan

The evaluation plan will focus around the data collected by Metro's Photo Enforcement Camera program. The strength of the evaluation plan is the consistent and comprehensive monthly tracking reports that are produced as a part of the photo enforcement camera program. The photo enforcement cameras have been recording left turn traffic activity at 15 at-grade intersection crossings (which include 25 separate left turn movements) since the MGLEE opened for operation in November 2009. This provides us with the ability to analyze approximately 2 years of data prior to the installation of IRWLs and to compare it to data collected after the IRWLs are in operation. Additionally, the demonstration will install IRWLs at ten intersections (which include 13 photo enforced left turns and 4 non-photo enforced left turns) and use the other seven photo enforced intersections (which include 12 photo enforced left turn movements) as the control group[1]. This will allow us to analyze before and after data and also compare the performance of the IRWLS to the control group. Specifically, we will analyze average monthly left turn volumes and violations for each of 25 left turn movements and quantify whether there has been a statistically significant change in the number of monthly or annual violations. For the two intersections that are not photo enforced (Temple/Alameda and 1st/Indiana) data will be collected over a series of weekdays while the lights are in operation and again while the lights are not in operation and left turn violation counts will be analyzed. Metro will prepare and submit biannual progress reports (at 6-month intervals) which summarize the photo enforcement data collected for that period and compare it to the pre-IRWL data. Attachment C provides a sample data tracking form, illustrating the type of data that will be collected and analyzed.

At the end of the demonstration period, Metro in coordination with DPW and LADOT will produce a final report of the demonstration project. At that time, if the project shows a significant increase in pedestrian and drivers' awareness of the train at the test locations and meets other project goals, Metro, DPW and LADOT will develop recommendations on the continued use and/or expansion of the program.

7. Evaluation Procedures

Metro in coordination with DPW and LADOT will prepare the design and engineering drawings and provide construction oversight. Field observations will be conducted by Metro to help evaluate the effectiveness of the installation. Metro will be responsible for collecting and evaluating project data, preparing semiannual progress reports for the duration of the experimentation and providing a copy of the final results to the Office of Transportation Operations (HOTO) within six months of the conclusion of the experiment.

[1] The Photo Enforcement Program contract expires on June 30, 2013 and the Metro Board is expected to make a determination prior to that date on whether to continue or end the program. If the program is discontinued prior to the end of the experiment, staff will utilize data collected by the County and City of Los Angeles traffic signal systems to track left turn violations and statistically evaluate any changes.

8. Restore to Before Conditions

Metro, LADOT and DPW agree to restore the demonstration sites to a condition that complies with the provisions of the MUTCD within 3 months following the completion of the demonstration, if the experiment determines that the IRWLs were ineffective. We will also terminate the demonstration at any time if we determine that the experiment directly or indirectly causes significant safety hazards. However, if the experiment demonstrates an improvement, the devices will remain in place as a request is made to update the MUTCD and an official rulemaking action occurs.

Thank you for considering the request for experimentation. If you have any questions, comments or suggestions, please contact Mr. Eric Carlson of Metro at 213-922-3052.

Sincerely,

Frank Alejandro
Chief Operations Officer
Operations
Los Angeles County Metropolitan
Transportation Authority

Bruce Shelburne
Interim Executive Director, Rail
Operations
Los Angeles County Metropolitan
Transportation Authority

Vijay Khawani
Executive Officer, Corporate Safety
Los Angeles County Metropolitan
Transportation Authority

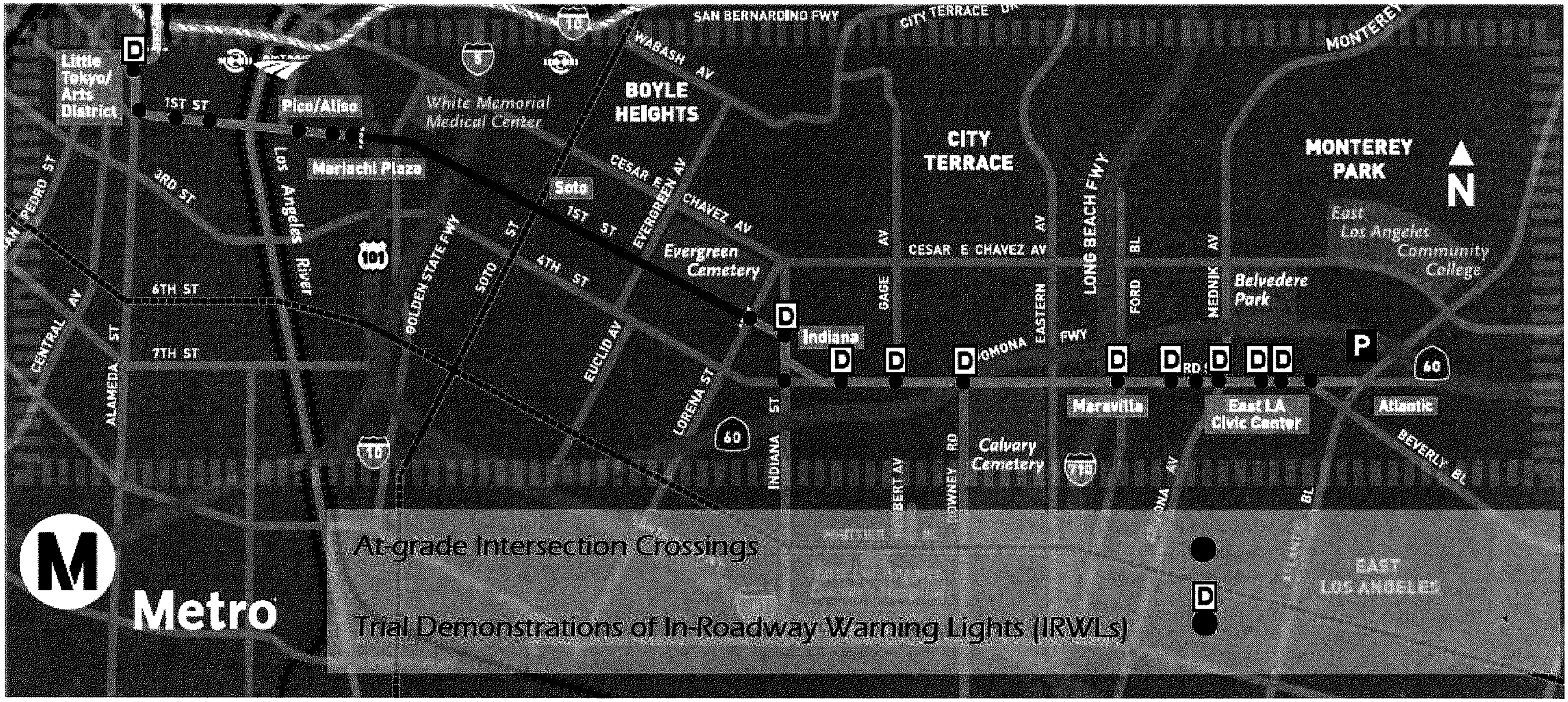
Zaki Mustafa
Executive Officer
City of Los Angeles
Department of Transportation

for John T. Walker
Assistant Deputy Director
County of Los Angeles
Department of Public Works

cc: FHWA's District Office in California
650 Capitol Mall, Suite 4-100
Sacramento, CA 95814

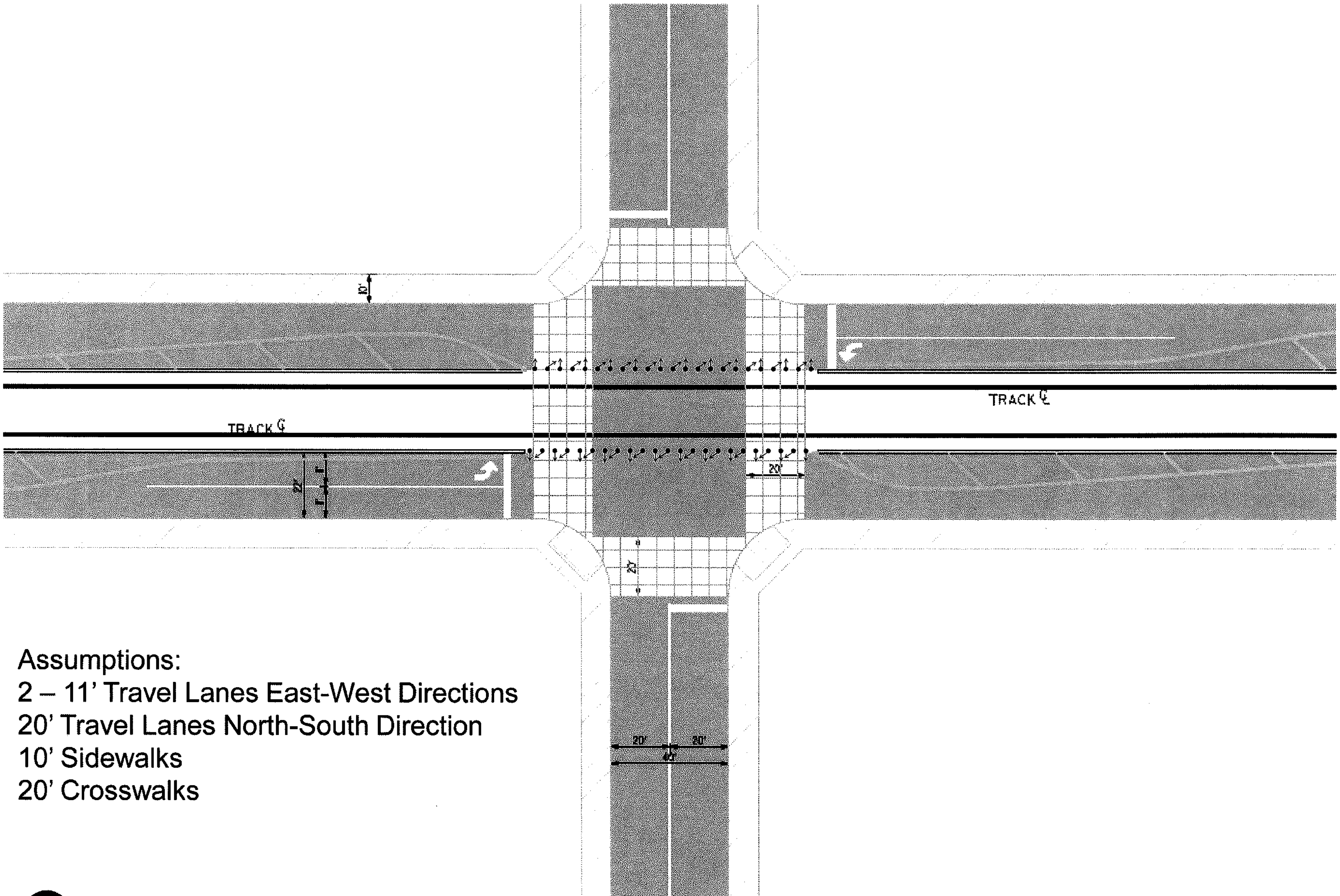
ATTACHMENT A

Proposed Demonstrations



ATTACHMENT B

Standard Ideal Intersection



Assumptions:
2 – 11' Travel Lanes East-West Directions
20' Travel Lanes North-South Direction
10' Sidewalks
20' Crosswalks

Metro

ATTACHMENT C

MGLEE Performance Tracking Form - SAMPLE

Phot Enforced Left Turns

Intersections	Turn Movements	IRWL Demonstration Location	Pre-Installation Data*: Daily Turn Volumes	Pre-Installation Data*: Avg. Monthly Violations	Pre-Installation Data*: Emergency Vehicle Violations	Post-Installation Data: Daily Turn Volumes	Post-Installation Data: Avg. Monthly Violations	Post-Installation Data: Emergency Vehicle Violations
Temple & Alameda**	NB to EB:	Yes	N/A	N/A	N/A			
Temple & Alameda**	SB to EB:	Yes	N/A	N/A	N/A			
1st & Indiana**	WB to SB:	Yes	N/A	N/A	N/A			
1st & Indiana**	NB to WB:	Yes	N/A	N/A	N/A			
1st & Mission	EB to NB:	No	1,797	86	13			
1st & Mission	WB to SB:	No	379	41	3			
1st & Anderson	WB to SB:	No	121	11	1			
1st & Utah	WB to SB:	No	80	8	1			
1st & Clarence	EB to NB:	No	173	10	2			
1st & Clarence	WB to SB:	No	577	36	3			
1st & Lorena	EB to NB:	No	920	12	1			
1st & Lorena	WB to SB:	No	565	10	1			
3rd & Rowan	EB to NB:	Yes	379	84	5			
3rd & Rowan	WB to SB:	Yes	504	62	17			
3rd & Gage	EB to NB:	Yes	574	25	2			
3rd & Gage	WB to SB:	Yes	1,237	78	13			
3rd & Downey	WB to SB:	Yes	919	64	32			
3rd & Eastern	EB to NB:	No	2,188	62	11			
3rd & Eastern	WB to SB:	No	323	9	23			
3rd & Ford	EB to NB:	Yes	602	57	7			
3rd & Ford	WB to SB:	Yes	706	22	19			
3rd & McDonnell	EB to NB:	Yes	610	48	4			
3rd & McDonnell	WB to SB:	Yes	389	26	9			
3rd & Arizona	EB to NB:	No	303	27	4			
3rd & Arizona	WB to SB:	No	220	8	6			
3rd & Mednik	EB to NB:	Yes	840	35	26			
3rd & Mednik	WB to SB:	Yes	525	14	23			
3rd & Civic Center	EB to NB:	Yes	277	45	6			
3rd & La Verne	WB to SB:	Yes	804	83	105			

* The Pre-installation Data reflects averages recorded as of 8-31-11. This data will be updated prior to commencement of the trial demonstrations

** These intersections do not have photo enforced left turns. Therefore, data will be collected for these intersections over a period of days.

U.S. Department
of Transportation
Federal Highway Administration

1200 New Jersey Avenue, SE
Washington, D.C. 20590

SEP 19 2012

In Reply Refer to:
HOTO-1

Mr. Frank Alejandro
Chief Operations Officer
Los Angeles County MTA

Mr. Bruce Shelburne
Interim Executive Director, Rail Operations
Los Angeles County MTA

Mr. Vijay Khawani
Executive Officer, Corporate Safety
Los Angeles County MTA

Mr. Zaki Mustafa
Executive Officer
City of Los Angeles DOT

Mr. John T. Walker
Assistant Deputy Director
County of Los Angeles DPW

(via e-mail transmittal)

Dear Sirs:

Thank you for your letter of August 7 transmitting your request to experiment (RTE) with an In-Roadway Lights system at ten intersections along the Metro Gold Line Eastside Extension in the City of Los Angeles and the County of Los Angeles, California. The system would use red In-Roadway Lights on each side of the LRT grade crossing that would steadily illuminate when LRT traffic is approaching or occupying the crossing. The purposes of the red In-Roadway Lights are to make road users more aware that LRT traffic is approaching and to serve as a supplement to (not a substitute for) the circular red signal indications being shown to the cross-street traffic and the red left-turn arrow signal indications being shown to the traffic in the left-turn lanes on the roadway that is parallel to and on both sides of the LRT tracks.

We have reviewed your RTE. Your request for experimentation is approved and we look forward to receiving your semi-annual progress reports and your final evaluation report at the end of the study period.

For recordkeeping purposes, we have assigned the following official experimentation number and title: "8(09)-8 (E) – Red In-Roadway Lights at LRT Grade Crossings – Los Angeles, CA." Please refer to this number in future correspondence.

Thank you for your interest in improving the operational capability and traffic safety for road users and LRT operators through the use of In-Roadway Lights.

Sincerely yours,

Mark R. Kehrli

Mark R. Kehrli
Director, Office of Transportation
Operations

CITY OF LOS ANGELES

CALIFORNIA

Jaime de la Vega
GENERAL MANAGER

DEPARTMENT OF TRANSPORTATION
100 South Main Street, 10th Floor
Los Angeles, California 90012
(213) 972-8470
FAX (213) 972-8410

ANTONIO R. VILLARAIGOSA
MAYOR

May 2, 2013
Submitted to:
Federal Highway Administration, Office of Transportation Operations

RE: Amendment to HOTO-1 Request to Demonstrate In-Roadway Warning Lights (HOTO-1 was originally approved in September 2012)

The Los Angeles County Metropolitan Transportation Authority ("Metro") respectively requests permission to conduct a demonstration of an In-Roadway Warning Light (IRWL) system that would supplement existing traffic signal indications at two (2) intersections along the Metro Blue Line, a Light Rail Train system located in Los Angeles, California. This non-standard traffic control system, which is composed of a series of LED lights embedded in the roadway is designed to increase the awareness of the presence of street running light rail trains among motorists approaching the intersection. The proposed application of IRWLs focuses on enhancing the warning for motorists when trains approach the intersections and deterring them from making illegal left turns. This in turn will reduce violations and accidents by increasing compliance with Red traffic signal indications.

1. Statement of Problem

Metro Blue Line

The Blue Line is a twenty two-mile light rail transit (LRT) project, which extends from Downtown Los Angeles to the City of Long Beach. For approximately eleven miles of the alignment, the light rail trains operate in a center median separated from adjacent vehicular traffic by a six-inch high curb. Where at-grade intersection crossings occur, the movement of trains, vehicles, and pedestrians are controlled by traffic signals, train signals, striping, and signage. The California Public Utilities Commission (CPUC) regulations limit speed on surface light rail systems to the legal speed of parallel traffic, but not to exceed 35 miles per hour.

Since illegal left turns account for approximately fifty percent of the overall accidents on the Blue Line, the Metro Board has directed staff to increase awareness of the light rail system, enhance safety measures at at-grade crossings and further reduce left turn violations.

While a number of industry-wide best practices have already been incorporated into the design of the Blue Line to reduce the risk of left turn violations, additional refinements have been identified by Metro to further reduce this risky behavior. One of these includes a trial demonstration of In-Roadway Warning Lights (IRWLs). All of the improvements are designed increase public awareness of train operations.

2. Proposed Solution: In-Roadway Warning Lights System

The proposed solution to mitigate left turn accidents is identical to what has been already approved by FHWA in application HOTO#1 for the Metro Gold Line experiment. Metro is proposing to install IRWLs at the following two at-grade crossings to reinforce the existing traffic signals and active "Train Approaching" warning signs.

Washington and Los Angeles
Washington and San Pedro

An earlier installation which aimed to reduce left turn violations at a Metro Blue Line Light Rail Train crossing, included a single row of in-pavement lights perpendicular to the tracks, at the stop bars of the eastbound and westbound left turn pockets. This proposal will differ in that, the lights will be installed parallel to the tracks to provide better visibility of the in-pavement lights. The operation and testing of the lights will be similar to that described in the application for the Metro Gold Line IRWL experimentations referenced above.

Conclusions

While trials of IRWLs to increase motorist compliance with red light signal indications have been limited, there are applications of IRWLs which have demonstrated the ability to increase motorist awareness and compliance with traffic signal indications or other traffic signs. The proposed trial would specifically target left turn violations at two intersections on the Blue Line in an application and configuration that here to fore has not been tested. The existing photo enforcement camera program provides the benefit of continuous and consistent data collection at booth trial demonstration intersections. We believe this would allow for an excellent opportunity to test and document the effectiveness of these devices.

Thank you for considering the request for experimentation. If you have any questions, comments or suggestions, please contact Mr. Eric Carlson of Metro at (213) 922-3052.

Sincerely,

Zaki Mustafa
Executive Officer
LADOT
City of Los Angeles

Frank Alejandro
Chief Operations Officer
Rail Operations
Los Angeles County Metropolitan
Transportation Authority

cc: FHWA's District Office in California
650 Capitol Mall, Suite 4-100
Sacramento, CA 95814

U.S. Department
of Transportation
Federal Highway Administration

1200 New Jersey Avenue, SE
Washington, D.C. 20590

MAY 20 2013

In Reply Refer to:
HOTO-1

Mr. Zaki Mustafa
Executive Officer
City of Los Angeles DOT
100 South Main Street, 10th Floor
Los Angeles, CA 90012

Dear Mr. Mustafa:

Thank you for your letter of May 2 requesting to expand Experiment 8(09)-8 to two additional intersections on the Metro Blue Line, at East Washington Boulevard and South Los Angeles Street, and at East Washington Boulevard and South San Pedro Street in the City of Los Angeles. Similar to the 10 initial intersections on the Metro Gold Line, the experiment would involve the use of red In-Roadway Lights on each side of the LRT grade crossing that would steadily illuminate when LRT traffic is approaching or occupying the crossing. The purposes of the red In-Roadway Lights are to make road users more aware that LRT traffic is approaching and to serve as a supplement to (not a substitute for) the circular red signal indications being shown to the cross-street traffic and the red left-turn arrow signal indications being shown to the traffic in the left-turn lanes on the roadway that is parallel to and on both sides of the LRT tracks.

We have reviewed your request to expand your experiment. Your request to expand Experiment 8(09)-8 is approved and we look forward to receiving your semi-annual progress reports and your final evaluation report at the end of the study period.

For recordkeeping purposes, we will continue to use the following official experimentation number and title: "8(09)-8 (E) – Red In-Roadway Lights at LRT Grade Crossings – Los Angeles, CA." Please refer to this number in future correspondence.

Thank you for your interest in improving the operational capability and traffic safety for road users and LRT operators through the use of In-Roadway Lights.

Sincerely yours,

Mark R. Kehrli

Mark R. Kehrli
Director, Office of Transportation
Operations

U.S.Department of Transportation
Federal Highway Administration

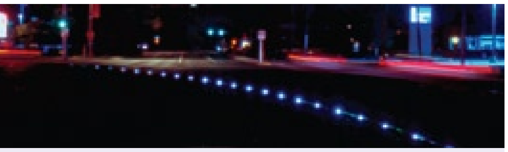
LED Raised Pavement Markers

Purpose

Light Emitting Diode (LED) pavement markers improve the safety of intersection approaches, as well as pedestrian, bicycle and other crossings. These markers enhance delineation and driver awareness, especially in low visibility conditions.

Alternative Names

Daylight-visible or solar-powered LED raised pavement markers, LED-illuminated pavement markers, solar road markers or studs.



This summary is one in a series describing Innovative Intersection Safety Treatments. The summaries identify newer technologies and techniques for intersection safety developed since NCHRP Report 500, Volumes 5 and 12, were published in 2003 and 2004, respectively. These treatments show promise for improving safety but comprehensive effectiveness evaluations are not yet available.

Operation

- Light Emitting Diode (LED) Raised Pavement Markers (RPM) function similarly to standard reflective pavement markers, but have small LEDs located inside of them instead of (or in addition to, retroreflective components).
- LED RPMs have built in sensors that can automatically turn on the LEDs when ambient light drops below a preset level or can be wired to operate as an active treatment in conjunction with vehicle detection.
- LED RPMs are currently powered either by a solar photocell charger in each marker, or by wiring to a power source such as a signal controller.
- LED RPMs should not be operated in flash-mode to comply with the Manual on Uniform Traffic Control Devices (MUTCD).

Potential Benefits

- LED RPMs increase the visibility of intersections during low-visibility conditions (e.g., darkness and inclement weather). Illumination of intersection approaches and crossings helps improve road user recognition of intersection location and features.
- At intersections with vertical or horizontal curves causing limited sight distance for traffic entering the intersection, LED RPMs activated by vehicle detectors can help provide advance notification to drivers of potential vehicle conflicts.
- LED RPMs are more visible than retroreflective RPMs under conditions that reduce the effectiveness of headlights and retroreflective material (e.g., inclement weather).
- At rural intersections, where powered lighting may not be available, the use of solar-powered LED RPMs may provide an alternative safety treatment.

Safe Roads for a Safer Future
Investment in roadway safety saves lives

May 2009
FHWA-SA-09-007

Figure 1: Example LED Raised Pavement Markers.

Figure 2: LED Raised Pavement Marker installed at intersection to guide turning movements.

Agency Experience

- LED RPMs have been used in Texas in advance of horizontal curves to notify drivers that they are approaching the curve too quickly. The Texas Department of Transportation has installed LED RPMs on roadway edgelines and centerlines, including near intersections and in conjunction with other treatments such as rumble strips or flashing beacons on the sign posts.
- LED RPMs have been employed in Florida in several locations, and Florida DOT standard drawings provide for LED RPMs at intersections along lane lines and areas of channelization.
- The Oregon DOT conducted performance testing of LED RPM from several different manufacturers. The summary report is available at *http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2007/FHWA-OR-RD-08-07.pdf* and includes results that indicate that many LED RPMs may not meet retroreflectivity and chromaticity standards.
- The known uses of LED RPMs include steady, nighttime only operation, as well as a flashing operation implemented in Texas based on speed detection, which is engaged when vehicles are travelling at excessive speeds. Note that this flashing operation does not comply with the MUTCD, as described below.

Implementation Considerations

- Hardwired LED RPMs have been found to be brighter than the solar-powered models.
- LED RPMs could potentially be implemented anywhere traditional RPMs are currently placed, including lane line delineation, gore areas, or painted channelization.
- An Institute of Traffic Engineers (ITE) study found that snow melts on LED RPMs faster than on the adjacent roadway, allowing snow plow damage to be avoided.

MUTCD Specifications

- Allow light sources, including LEDs, within raised pavement markers to accentuate their visibility, and specifies raised pavement marker design, colors, location, spacing, and usage. *MUTCD, Sections 3B.11 – 3B.13.*
- In-roadway lights (i.e. illuminated markers level with the pavement) are reserved for pedestrian crossings, even though in-roadway lights may be preferred to raised pavement markers from a maintenance standpoint. *MUTCD, Sections 4L.01 – 4L.02.*
- Internally illuminated RPMs used as positioning guides or to supplement or substitute for other markings must operate in a steady (non-flashing) mode. *MUTCD, Section 3B.14.*
- Flashing LED lights in or on the roadway are considered to be an in-roadway version of a traditional flashing beacon warning signal. Therefore, the use of flashing in-roadway lights is currently limited to use for uncontrolled marked crosswalks. At this time, any other use of flashing LED markers must receive official experimentation approval from FHWA per MUTCD Section 1A.10. MUTCD, Section 4L.02.

Costs

- A photocell powered LED RPM unit costs approximately $50 including material and installation costs.
- MUTCD, Sections 3B.11 and 3B.14 provide standards for LED RPM placement. Placement frequency will depend on the specific application.

Learn More:

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FHWA Office of Safety

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Reducing Left Turn Violations with Illuminated Raised Pavement Markers

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Draft Final Report

Submission Date: March 26th, 2018

Submitted to: LA Metro

ABSTRACT

In the absence of railroad crossing cantilever gates, at-grade light-rail transit crossings can be of concern. This problem is only exacerbated for transit lines operating within the median of a roadway, as left turning vehicles could be unaware of trains approaching from behind them. The contribution of this paper was demonstrating the potential of a novel application of internally illuminated raised pavement markings (IIRMs) to provide traffic control redundancy at these locations. IIRPMs have an internal light emitting diode (LED) that illuminates red when a train is approaching and occupying an intersection. The research presented in this paper seeks to build upon the prior knowledge and expand the scientific understanding of the impact of IIRPMs on left-hand turn violations at light-rail transit crossings. For the purpose of this study, LA Metro deactivated the IIRPMs for a period of 34 days at 14 intersections, resulting in an analysis of 23 unique left turn movements (15 Demonstration and 8 Control). The average number of left-hand turn violations and 24-hour traffic counts during this period were compared with the performance of these same intersections during a 34-day period when the IIRPMs were active. The results of the analysis suggested the IIRPMs can be an effective tool to complement existing traffic control devices at MUTCD compliant at-grade intersection crossings. The findings indicated a statistically significant reduction in the average number of left-hand turn violations when IIRPMs were operating. This may suggest that IIRPMs can be used to reduce red-light-running violations.

Keywords: Internally illuminated raised pavement markings, light-rail transit crossing, traffic control devices, at-grade rail crossing

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INTRODUCTION

The LA Metro Gold and Blue lines are light-rail public transit routes operating in Los Angeles, CA. The rails on which the Gold and Blue trains travel are located in the median of various arterial roads and are designed with at-grade intersection crossings. Because the light-rail trains on this line travel below 30 mph (48 kmh), railroad crossing cantilever gates are not required by the Manual of Uniform Traffic Control Devices (MUTCD) [1]. However, LA Metro proposed and received approval for a Request to Experiment (Official Experimentation Number 8(09)-8 (E)) with IIRPMs as an additional safety measure to prevent motor vehicles from turning left while a light-rail train is present [2]. In LA Metro's continual quest for improved safety, internally illuminated Raised Pavement Markers (IIRPMs) were installed at these crossings to reinforce the existing traffic control devices and better alert traffic to the presence of a train. The IIRPMs have an internal light emitting diode (LED) that illuminates red when a train is approaching and occupying an intersection. IIRPMs are not currently specified for use with at-grade railroad crossings in the MUTCD.

Figure 1 shows the intersection of E. 3rd St. and S. Arizona Ave. along the LA Metro Gold line. The illustration shows a vehicle in the left hand turn lane approaching the intersection from the eastbound direction. The figure also shows an eastbound light-rail train approaching the intersection simultaneously. From the figure, the inherent danger of this particular movement is evident. The driver, looking to make a left hand turn has their attention on westbound traffic, as this is typically where the major conflict is located for this movement. In this example, for the crash to occur, the driver must violate the traffic control devices prohibiting a left turn. However, with the absence of the railroad crossing cantilever gate, it would be possible to complete this illegal movement. While it may be impossible to prevent all crashes, LA Metro saw an opportunity to provide traffic control redundancy to improve the safety of the commuting public with the installation of the IIRPMs.

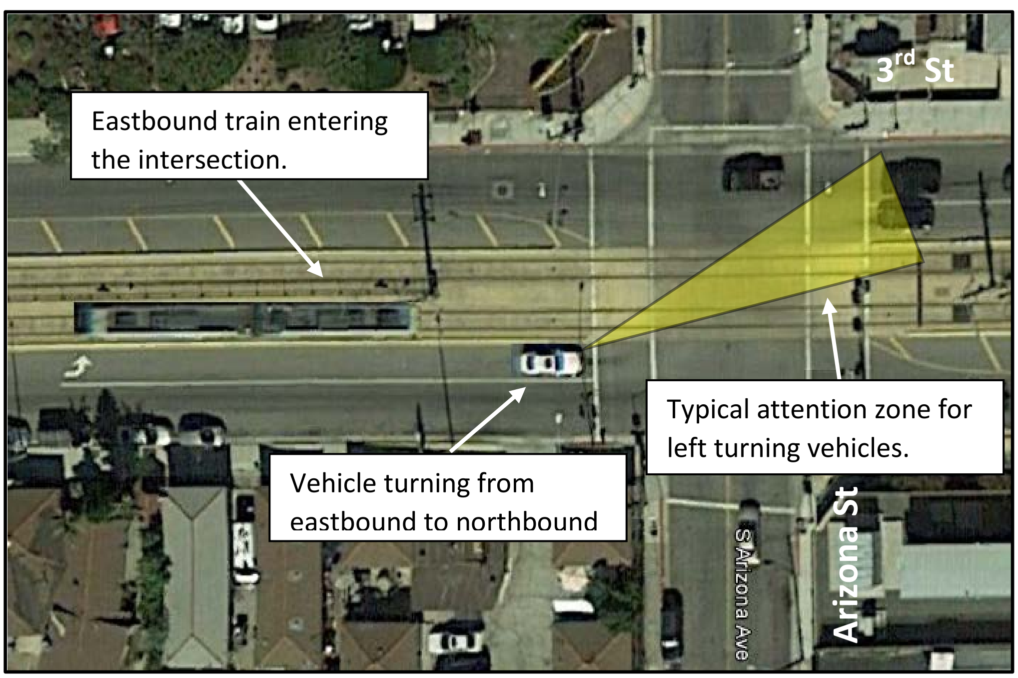

Figure 1: Intersection E 3rd St. and S. Arizona Ave.

The goal of this study was to investigate the impact of IIRPMs on motorist compliance with traffic signal indicators and by extension, intersection safety. The selected intersections consisted of 15 "Demonstration" movements and 8 "Control" movements (total of 23 movements). The Demonstration intersections were located along the Gold and Blue lines and had both an at-grade railroad crossing and IIRPMs. The Control intersections had at-grade railroad crossings with the Gold line and were sufficiently similar to the Demonstration intersections but did not have IIRPMs installed. The research used red-light-running cameras to quantify the number of left-hand turn violations for the 15 Demonstration movements, over two, 34-day periods. During the first period, the IIRPMs operated in their regular fashion, illuminating red when a train approached the intersection. In the second period, the IIRPMs were turned off. It is important to note that IIRPMs were not required by the MUTCD and therefore turning the IIRPMs off did not create any additional risk when compared to similar, MUTCD compliant intersections. Additionally, traffic counts were collected over selected weekdays during each of the 34-day periods..

The results of the analysis suggested the IIRPMs can be an effective tool to complement existing traffic control devices at MUTCD compliant at-grade intersection crossings. The findings of a series of paired t-test indicated a statistically significant reduction in the average number of left-hand turn violations. While prior research has found that IIRPMs can be used to improve driver compliance with traffic laws, this research investigated a novel application to reduce turning violations at signalized intersections with at-grade rail crossings. The result of this work may also suggest that IIRPMs could potentially be used at other signalized intersections to reinforce the traffic signal indicator.

LITERATURE REVIEW

The Manual of Uniform Traffic Control Devices (MUTCD) discuss the application and guidelines for the implementation of IIRPMs (section 3B) and in-roadway lights (section 4B), respectively [1]. IIRPMs provide steady illumination i.e. the lights do not flash (3B.11 section 06). The MUTCD considers flashing, raised pavement markers as a form of in-roadway lights (4N.01 standard 04). In general, the MUTCD states that IIRPMs and in-roadway lights may be used to complement and in some instances, supplement existing traffic control measures within strict guidelines. IIRPMs may be used in addition to or instead of, reflective raised pavement markers but, must conform to the color and spacing guidelines of reflective raised pavement markings. In-roadway lights are typically used to notify road users they are approaching an area which may require drivers to slow down or stop. The current application of in-roadway lights, as specified by the MUTCD is primarily limited to pedestrian crosswalks and "shall not be used for any application that is not described in this chapter" (section 4N.01 Standard 02). However, the U.S. Federal Highway Administration (FHWA) can and does provide special exemptions from this standard on a limited basis for experimentation [2]. In general, IIRPMs and in-roadway lights have been used for three primary purposes: 1) pedestrian crosswalks, 2) inclement weather, and 3) freeway ramp entry and/or exit.

Whitlock & Weinberger Transportation, Inc. conducted an observation based study on the impact of in-roadway lighting to complement existing pedestrian crosswalk traffic control devices at uncontrolled intersections. This research found that in-roadway lights "clearly (have) merit in modifying driving habits to be more favorable to pedestrians" and that amber lighting appeared to be the most appropriate color because of its consistency with traffic laws. The research also recommended the use of an automatic pedestrian activation system, instead of a push-button actuation [3]. Another study on in-roadway lighting was conducted on a six-lane arterial pedestrian crossing. This paper found that average speeds decrease by as much as 27.2 percent, with the maximum speed observed on this road decreasing by 17.8 percent when the in-roadway lights were activated. The average time spent by the pedestrians at the curb was reduced from 26.7 seconds to 13.2 seconds and the curb-to-curb travel time reduced by 6.5 seconds. Further observations showed a decrease in the number of pedestrians running across the intersection as well as more pedestrians remaining within the delineated crosswalk area [4]. Further studies on in-roadway lights for pedestrian crossing focused on the design and implementation of the devise, such as beam spread, light color, aiming, system optics, and pulsing schemes [5]. Later research analyzed the proportion of drivers yielding to pedestrians with a before and after study. Video cameras were used to collect data on pedestrian/vehicle interactions at seven crosswalks in Amherst, MA. The results found significantly higher yield ratios for drivers and significantly higher crosswalk usage by pedestrians [6]. Another study, following up on the recommendations of Whitlock & Weinberger [1], investigated a video detection system for activating in-roadway lights at crosswalks [7]. Additional research has sought to develop Highway Safety Manual, crash modification factors for various uncontrolled pedestrian crossing treatments, in-roadway lights being one of them [8]. One study investigated the application of in-roadway lights for at-grade railroad crossings. Off-the-self in-roadway lights were modified and a variety of illumination patterns were evaluated. Laboratory experiments found that incorporating alternating groups of spatially-separated flashing lights led to improved visual response and stimulated the perception of movement [9].

The Afton Mountain fog guidance system consist of 841 IIRPMs spaced at 200 ft on tangent sections and 100 ft on curves. Installed in 1976 at a cost of nearly $2,000,000 the illuminated section covers a distance of nearly six miles. The system was designed to alert and guide drivers in dense fog through this particularly hazardous section of highway. Six fog detectors control the activation and intensity of the illumination [10]. A study from Australia investigated self-activating IIRPMs for use during wet weather, fading light, and ice formation. The experiment conducted laboratory testing of the on/off activation threshold, installation at several trial sites, and a before and after observational study. The results found were consistent with research conducted in the United States and showed a significant reduction in driver's speeds and promoted driving in the center of the lane [11, 12].

The Florida Department of Transportation (FDOT) District 4 received permission from FHWA to experiment with in-roadway lights to address safety concerns at a particularly hazardous freeway off-ramp. Based on crash reports and the ramp geometry, FDOT believed that a speed reduction on the off-ramp could lead to a decrease in the number and severity of crashes. Therefore, FDOT installed speed activated in-roadway lights along the ramp, longitudinally. Vehicles traveling at speeds higher than 50 mph would activate the in-roadway lights which were timed to produce a "strobing" effect, directed toward the driver. The results of a before and after analysis found a significant decrease in average speed but, no significant effect on the number of crashes [13, 14]. In another research study conducted by FDOT the experimental application of IIRPMs was used to prevent wrong-way entries on freeway ramps. The results concluded that IIRPMs should be considered to complement existing countermeasures for mitigating wrong-way entries [15].

In general, this literature review found in-roadway lights and IIRPMs can significantly impact driver's speed and tended to encourage yielding of the right-of-way to pedestrians. This review also found that pedestrians showed a tendency to remain within the illuminated crosswalks when compared to non-illuminated crosswalks. From a practitioner point-of-view, it was found that self-activating systems were preferable to push-button activation. In-roadway lights and IIRPMs were also shown to be useful in delineating paths in adverse weather conditions and have been used to influence driving speeds at hazardous times or conditions. Prior research has investigated illumination patterns to improve safety for at-grade railroad crossing within a laboratory setting. The research presented in this paper seeks to build upon the prior knowledge and expand the scientific understanding of the impact of IIRPMs on left-hand turn violations at light-rail transit crossings.

METHODOLOGY

The research methodology was designed to provide an "apples to apples" comparison to quantify the impact of IIRPMs on motorist compliance with signal indicators. Broadly, the methodology consisted of three primary tasks.

> Task 1: Collect the number of left-hand turn violations for 23 unique movements at intersections with at-grade railroad crossings, during a period when the IIRPMs were operating
> Task 2: Collect the same data at these intersections during a period when the IIRPMs were not operating
> Task 3: Perform statistical analysis to compare these two periods.

LA Metro provided all of the traffic counts and the number of left-hand turn violations.

Data collection and processing

For the purpose of this study, this research investigated a 34-day period from 2/1/2017 through 3/9/2017 while the IIRPMs were operating under their normal conditions, hereto after referenced as the ON period. LA Metro deactivated the IIRPMs for a period of 34 days beginning 3/10/2017 through 4/12/2017, hereto after referenced as the OFF period. LA Metro collected 24-hour traffic counts for Demonstration and Control intersections during both the ON and OFF periods. Traffic counts were collected according to generally accepted practices during weekdays between Tuesday and Thursday. The number of left-hand turn violations during the months of February, March, and April were collected by LA Metro via red-light-running cameras and provided for analysis.

The raw data obtained from LA Metro was initially analyzed for missing data, discrepancies, and unexpectedly high data variations. For example, one of the study intersections reported a traffic count of zero; other such outliers were identified and removed for any further analysis. Additionally, during the study period there were some issues with the traffic count equipment, which resulted in unavailable data for some intersections; this data limitation affected portions, but not all of the data analysis (only those elements that utilized violation rates). Of the 15 Demonstration movements, 8 movements had at least one, 24-hour traffic count available in both the ON and OFF period. Only three Control movements had traffic counts available from both periods. Overall, a total of 23 movements were analyzed (both number of violations and violation rates). Table 1 summarizes the collected data. The 15 Demonstration movements consisted of left-hand turns from either eastbound to northbound (EB to NB) or westbound to southbound (WB to SB) at nine intersections along the Gold and Blue lines. The Control movements were also from EB to NB or WB to SB along the Gold line.

Table 1: Data Collection

Study Movements		
Intersection	**Direction**	**24-Hr Counts**
1. E. 3rd St. & Civic Center Way	EB to NB	2 days available
2. E. 3rd St. & S. La Verne Ave.	WB to SB	3 days available
3. E. 3rd St. & S. Mednik Ave.	EB to NB	Data unavailable
4. E. 3rd St. & S. Mednik Ave.	WB to SB	Data unavailable
5. E. 3rd St. & S. Ford Blvd.	EB to NB	3 days available
6. E. 3rd St. & S. Ford Blvd.	WB to SB	3 days available
7. E. 3rd St. & S. Downey Rd.	WB to SB	3 days available
8. E. 3rd St. & S. Gage Ave.	EB to NB	3 days available
9. E. 3rd St. & S. Gage Ave.	WB to SB	Data unavailable
10. E. 3rd St. & S. Rowan Ave.	EB to NB	3 days available
11. E. 3rd St. & S. Rowan Ave.	WB to SB	1 day available
12. E. 1st St. & S. Mission Rd.	EB to NB	Data unavailable
13. E. 1st St. & S. Mission Rd.	WB to SB	Data unavailable
14. E. Washington Blvd. & San Pedro St.	EB to NB	Data unavailable
15. E. Washington Blvd. & San Pedro St.	WB to SB	Data unavailable
Control Movements		
Intersection	**Direction**	**24-Hr Counts**
1. E. 3rd St. & S. Arizona Ave.	EB to NB	Data unavailable
2. E. 3rd St.& S. Arizona Ave.	WB to SB	Data unavailable
3. E. 3rd St. & S. Eastern Ave.	EB to NB	3 days available
4. E. 3rd St. & S. Eastern Ave.	WB to SB	Data unavailable
5. E. 1st St. & S. Lorena Ave.	EB to NB	Data unavailable
6. E. 1st St. & S. Lorena Ave.	WB to SB	Data unavailable
7. E. 1st St. & S. Utah St.	WB to SB	3 days available
8. E. 1st St. & S. Anderson St.	WB to SB	3 days available

Figure 2 is a map of the Demonstration and Control intersection locations in the East Los Angeles area. The Blue line is located in the Southwest area of the map and the Gold line is centrally located. The Demonstration locations are marked with solid stars and the Control intersections are mark with a hollow stars.

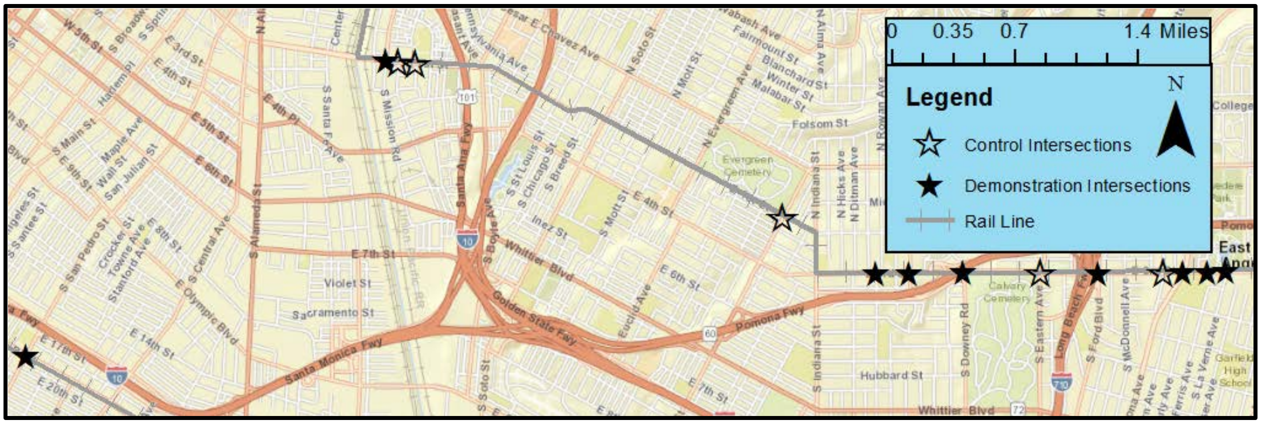

Figure 2: Study and Control Intersection Locations

Statistical Analysis:

The data was categorized and organized for analysis in two ways. First, the data was organized on the basis of time period wherein the IIRPMs were turned ON vs the time period when they were turned OFF. This analysis was used to test whether the use of IIRPMs made a significant impact in the average number of left-hand turn violations between the two periods. The second categorization considered the type of movement and the data was organized on the basis of Demonstration movement vs Control movement. This was designed to test if the Demonstration movements were significantly different than the Control movements. Because the volume of traffic at the Demonstration and Control intersections were likely to be different, the average rate of violations was used in the second category of analysis.

Since the dataset had limited sample size only t-tests were considered for analyses. The t-tests are recommended when limited data is available. T-tests provide a conservative result compared to those obtained from historical data tests, the z-test. The t-distribution curves used are thicker at the tails as compared to the z-distribution curves and thus provide a more conservative result, compensating for the smaller data availability [16].

Two types of t-test were used for analyses, paired t-test and t-tests for sample means. Paired t-tests were used to analyze the ON vs OFF data. These tests are used to investigate statistical difference before vs. after a change has been implemented. This research assumed that turning the IIRPMs ON and OFF created a change in driver behavior. Hence, using a paired t-test enabled investigating the effectiveness of IIRPMs. On the other hand, t-test for sample means (assuming equal variance) was used to compare data between Demonstration movements and Control movements. The t-test for sample means compares the means of two samples and enables identifying statistical difference between two population means. Using the two t-tests several hypotheses were tested based on the sample characteristics and available data. The hypotheses testing was done using MS Excel's inbuilt Data Analysis tool.

The p-value (probability of obtaining results equal to or more extreme than) was used to quantify the strength of evidence for the statistical hypothesis testing. P-values closer to zero are indicative of higher strength test and a rejection of the null hypothesis. Low p-values also suggest the result of the analysis are not likely to change if more observations were available. Traditionally a value less than 0.01 is considered as highly significant (less than 1 in 100), 0.05 is considered as significant, and 0.1 indicates sufficient evidence for rejecting a null hypothesis [17]. These values are shown in Table 2.

Table 2: P-Value Significance

Sr No	P Value (for one tail tests)	Interpretation
1	0.01	Highly Significant
2	0.05	Significant
3	0.1	Have evidence

First Hypothesis

The combined ON-OFF period consisted of 68 days and it was reasonable to assume the daily traffic patterned and subsequent 24-hour traffic counts over this relatively short duration did not change in any significant manner. However, the alternate hypothesis to this assumption was the traffic pattern did change during the combined period. Therefore before any further analysis could be done, a pair t-test was conducted on the following hypothesis:

H_0: Traffic count during ON Period = Traffic count during OFF period
H_1: Traffic count during ON Period ≠ Traffic count during OFF period

Second Hypothesis

The second hypothesis test represents the core of this research work. It is aimed at determining the effectiveness of IIRPMs and was used only for Demonstration movements. In this test the focus was to demonstrate that the use of IIRPMs significantly reduces left-hand turn violations. This was done by setting the alternate hypothesis to indicate that the ON period violations were fewer than the OFF period violations. The null hypothesis becomes representative of the condition that the average violations during ON period are equal to or greater than the OFF period. Obtaining a low p-value on this hypothesis would allow rejecting the null hypothesis, indicating that IIRPMs could significantly reduce the average number of left-hand turn violations. Paired t-tests were conducted to test this hypothesis on several variations of the data. A total of 3 one-tailed paired t-tests were conducted for this hypothesis.

Test 1: Looked at Demonstration movements for the entire ON and OFF analysis period
Test 2: Looked at Demonstration movements but only for weekdays during the analysis period
Test 3: Examined weekend violations only for Demonstration movements during the analysis period

H_0: Average violations during ON Period ≥ Average violations during OFF Period
H_1: Average violations during ON Period < Average violations during OFF Period

Third Hypothesis

The third hypothesis was tested to determine if there was any difference in average violations for Control movements during the ON and OFF periods. A two-tailed paired t-test was conducted only for control intersections between ON and OFF periods. The hypothesis for this analysis is stated below:

H_0: Average violations during ON Period = Average violations during OFF Period
H_1: Average violations during ON Period ≠ Average violations during OFF Period

Fourth and Fifth Hypotheses

The fourth and the fifth hypotheses were set to investigate if the Demonstration movements were fundamentally different than the Control movements. Because this analysis compared one group of movements to a different group of movements, a paired analysis was not appropriate. Therefore, a t-test for population means assuming equal variances (a.k.a. pooled variance t-test) was conducted. Furthermore, the number of violations was assumed to be a function of traffic volume and thus, a comparison of the average number of violations was not appropriate. It was necessary to normalize the average number of violations by the average 24-hour traffic count. This would allow for an "apples to apples" comparison of the Demonstration and Control movements, despite having different traffic volumes. The average rate of violations was defined as the average number of violations during a period divided by the average 24-hour traffic count during that same period. The fourth hypothesis investigated if the rate of violations for Demonstration and Control movements were similar during the ON period and provided below:

H_0: Study intersection's $\frac{Average\_Violations}{Average\_Count} \geq$ Control intersection's $\frac{Average\_Violations}{Average\_Count}$

H_1: Study intersection's $\frac{Average\_Violations}{Average\_Count} <$ Control intersection's $\frac{Average\_Violations}{Average\_Count}$

While the fourth hypothesis was focused on the ON period, the fifth hypothesis was focused on the OFF period. The fifth hypothesis examined if the rate of violations for the Demonstration and Control movements were similar during the OFF period. The fifth hypothesis was:

H_0: Study intersection's $\frac{Average\_Violations}{Average\_Count} =$ Control intersection's $\frac{Average\_Violations}{Average\_Count}$

H_1: Study intersection's $\frac{Average\_Violations}{Average\_Count} \neq$ Control intersection's $\frac{Average\_Violations}{Average\_Count}$

EMPIRICAL RESULTS

Overall, the results of the statistical analysis suggested IIRPMs significantly reduced the average number of left-hand turn violations for the Demonstration movements. This finding was consistent between a number of different statistical test and observations. Table 3 shows the results of the hypotheses testing. The following sections provide context and a discussion of the results.

Table 3: Hypothesis Testing Results

Hypothesis	**Test**	**Description**	**Expectation**	**Result**	**Interpretation**
Hypothesis 1: Traffic counts (ON v. OFF)	1.1	Study movement	High p-value	0.9316	No significant differences between traffic counts at Demonstration movements between ON and OFF periods
	1.2	Control movement	High p-value	0.8926	No significant differences between traffic count at Control movements between ON and OFF periods
Hypothesis 2: Avg. num. of violations for Demonstration movements (ON v. OFF)	2.1	Demonstration movement	Low p-value	0.004***	Significant reduction in the avg. num. of violations
	2.2	Demonstration movement weekdays	Low p-value	0.011**	Significant reduction in the avg. num. of violations
	2.3	Demonstration movement weekends	Low p-value	0.1208	No significant reduction in the avg. num. of violations
Hypothesis 3: Avg. num. of violations for Control movements (ON v. OFF)	3.1	Control movement	High p-value	0.0508*	Slight differences in the avg. num. of violations
Hypothesis 4 & 5: Rate of violations (Demonstration v. Control)	4.1	ON period	Low p-value	0.373	No Significant differences between the rate of violations at Demonstration and Control movements
	5.2	OFF period	High p-value	0.3475	No Significant differences between the rate of violations at Demonstration and Control movements

Notes: * represents 10% significance, ** represents 5% significance and *** represents 1% significance

First Hypothesis

The first hypothesis investigated if the traffic counts were sufficiently similar during the ON and OFF periods. Because it is generally accepted that overall traffic patterns tend to be consistent over short periods of time, the expectation was this test would result in a high p-value. The results of the statistical testing did show high p-values (0.9316 and 0.8926) and a failure to reject the null hypothesis. This finding supports the assumption that traffic counts were more-or-less consistent between the ON and OFF periods. This finding was important because the overall number of violations was assumed to be dependent on the traffic volume. Large disparities between traffic volumes during the analysis period could significantly bias the t-test results. By showing the traffic counts remained stable during the test period it was possible to conduct hypothesis testing on the average number of violations (the second hypothesis) without necessarily having to account for fluctuations in traffic volume.

Second Hypothesis

The second hypothesis tested if Study movements showed fewer average violations during the ON period when compared to the OFF period. This was tested in a number of ways and each test had the expectation of low p-values. A low p-value would lead to a rejection of the null hypothesis and in this experimental design, suggest IIRPMs significantly reduced the average number of left-hand turn violations. The results found that overall, looking at all Demonstration movements and incorporating all days of the week, IIRPMs showed a strong relationship with reducing left-hand turn violations (p-value = 0.004) and was significant at one percent. Furthermore, this relationship was also observed between the use of IIRPMs and left-hand turn violations when removing weekend travel from the sample (p-value = 0.011). However, the results found no significant impact from IIRPMs on weekend violations (p-value = 0.1208). The difference between the significance level seen between weekday and weekend travel may suggest that travel behavior was slightly different on weekends or simply be the result of having fewer weekend observations in the sample.

Third Hypothesis

The third hypothesis tested if there was a significant difference in the average number of left-hand turn violations at the Control intersections during the ON and OFF periods. Because the Control intersections did not have IIRPMs, nothing was changed for the Control movements between the ON and OFF period. It was therefore assumed this hypothesis would result in a high p-value. The results of the test however, found a relatively low p-value (0.0508). P-values between the ranges of 0.05 and 0.010 are typically seen as slight but significant differences. Given the experiment design of this research the reason for the disparity between ON and OFF periods for the Control movements cannot be conclusively determined. However, the sample contained only eight Control movements and may have been too few observations to get an accurate understanding of the traffic dynamic at these intersections.

Fourth and Fifth Hypotheses

The fourth and fifth hypotheses tested the rate of violations which occurred for Demonstration and Control movements, first for the ON period (fourth hypothesis) and then for the OFF period (fifth hypothesis). During the ON period it was assumed that the rate of violations would be significantly fewer for the Demonstration movements and thus a low p-value was expected. Conversely, during the OFF period, it was assumed the Demonstration and Control movements would be similar and result in a high p-value. The test found high p-values for both analyses. The ON period comparison resulted in a p-value of 0.373 and supports a failure to reject the null hypothesis. This indicated that when IIRPMs were active, the rate of violations was not significantly lower for Demonstration movements. Again, the experimental design prohibited a more robust understanding of why this may have occurred. However, the sample size for the analysis of this hypothesis was very low, as few traffic counts were available for the Control movements. The fifth hypothesis found a high p-value when analyzing the OFF period (p-value = 0.3475). While this is consistent with the expectations of the test it too should be scrutinized for a having a small sample size.

CONCLUSION

In general, the results of the research showed that IIRPMs may significantly reduce the average number of left-hand turn violations. These findings were expected and consistent with prior research on the impact of IIRPMs and in-roadway lights which showed a clear pattern of encouraging drivers to comply with traffic control devices. However, data limitations prevented a more robust analysis of the hypothesis testing. Although the ON and OFF periods consisted of 34 days, outlier data and issues with the vehicle count equipment resulted in a limited data set. It is recommended that additional research be undertaken.

It is the authors' hope the findings presented here and the collection of work within the area of IIRPM and in-roadway lights, could be used to support changes in the Manual of Uniform Traffic Control Devices (MUTCD) allowing the general use of IIRPMs for at-grade light-rail crossings where cantilever gates are not required. Currently, special permission to experiment is required for installation. Future research will be able to build upon this work by expanding the application of IIRPMs at other atypical intersections. One area of significance may be rural, two-stop controlled intersections particularly at night or otherwise poorly lighted conditions.

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Attachment C

Table 1 below shows the number of average daily violations for the on and off period. Six out of the sixteen demonstration intersection movements experienced decreases in violations, while ten had no change. Most of the intersection movements decreased from a daily average of either 1 to 0 or 2 to 1. First & Mission EB to NB and Washington & San Pedro EB to NB had the highest average daily violations. These intersection movements experienced a 12% and 16% decrease respectively. While these decreases may appear small, the statistical analysis performed for this study determined there is a high probability (i.e. statistically significant) that the decreases were attributed to the IIRPMs effectively deterring left-turn violations and did not simply happen by chance.

Table 1: Number of Average Daily Violations

Demonstration Intersection	Movement	OFF Period	ON Period	Change in # of Violations
1. 3rd & Civic Center	EB to NB	1	0	Decrease
2. 3rd & La Verne	WB to SB	2	2	No Change
3. 3rd & Mednik	EB to NB	1	0	Decrease
4. 3rd & Mednik	WB to SB	0	0	No Change
5. 3rd & Ford	EB to NB	1	1	No Change
6. 3rd & Ford	WB to SB	0	0	No Change
7. 3rd & Downey	WB to SB	0	0	No Change
8. 3rd & Gage	EB to NB	1	1	No Change
9. 3rd & Gage	WB to SB	1	1	No Change
10. 3rd & Rowan	EB to NB	2	1	Decrease
11. 3rd & Rowan	WB to SB	2	1	Decrease
12. 1st & Indiana	WB to SB	0	0	No Change
13. 1st & Mission	EB to NB	6	5	Decrease
14. 1st & Mission	WB to SB	0	0	No Change
15. Washington & San Pedro	EB to NB	8	7	Decrease
16. Washington & San Pedro	WB to SB	2	2	No Change

Control Intersection	Movement	OFF Period	ON Period	Change in # Violations
1. 3rd & Arizona	EB to NB	0	0	No Change
2. 3rd & Arizona	WB to SB	1	0	Decrease
3. 3rd & Eastern	EB to NB	2	1	Decrease
4. 3rd & Eastern	WB to SB	0	0	No Change
5. 1st & Lorena	EB to NB	1	1	No Change
6. 1st & Lorena	WB to SB	1	1	No Change
7. 1st & Utah	WB to SB	0	0	No Change
8. 1st & Anderson	WB to SB	0	0	No Change

Attachment C

Table 2 below shows the rate of average daily violations for the intersection movements for the off and on period. Four out of the eight intersection movements that had available traffic count data showed decreases in violation rates and one control intersection movement out of the three that had available traffic count data showed a decrease. The statistical analysis tested whether there was a statistical difference between control and intersection movements during the off period and on period. The results showed no statistical differences among either; however this could have been attributed to very small sample sizes for this data group.

Table 2: Average Daily Violation Rates

Demonstration Intersection	Movement	OFF Period	ON Period	Change in Rate of Violation
1. 3rd & Civic Center	EB to NB	0.41%	0.00%	Decrease
2. 3rd & La Verne	WB to SB	0.16%	0.19%	Decrease
3. 3rd & Ford	EB to NB	0.12%	0.12%	No Change
4. 3rd & Ford	WB to SB	0.00%	0.00%	No Change
5. 3rd & Downey	WB to SB	0.00%	0.00%	No Change
6. 3rd & Gage	EB to NB	0.13%	0.09%	Decrease
7. 3rd & Rowan	EB to NB	0.24%	0.11%	Decrease
8. 3rd & Rowan	WB to SB	0.11%	0.07%	No Change

Control Intersection	Movement	OFF Period	ON Period	Change in Rate of Violation
1. 3rd & Eastern	EB to NB	0.14%	0.07%	Decrease
2. 1st & Utah	WB to SB	0.00%	0.00%	No Change
3. 1st & Anderson	WB to SB	0.00%	0.00%	No Change

Attachment D

Image 1: IIRPMs illuminated during daylight at the intersection of 3rd & Gage facing west.

Image 2: IIRPMs illuminated at night at the intersection of 3rd & Ford facing east.

Image 3: A close up of the IIRPMs illuminated during daylight at the intersection of 3rd & Gage.

Image 4: Installation photos of the IIRPMs.