This article presents an evaluation of two supplemental traffic control devices, a Lighted Stop Bar System (LSBS) and light emitting diode (LED) outlined traffic signal backplates. The LSBS consists of lighted pavement markers placed in the pavement parallel to the painted intersection stop line. The pavement markers contain LEDs which emit a red light during the red signal indication of the traffic signal. The LED outlined backplate emits a red light around the perimeter of the traffic signal backplate when the traffic signal indication is red. The intended impact of the devices was to reduce red light running (RLR) violations and crashes on intersection approaches to an arterial with an at-grade light rail line within the median of the street. These two types of devices were installed separately at separate intersections, and before and after studies were conducted to determine changes in crashes, RLR violations, and right turn on red (RTOR) movements, which are prohibited at the study sites. From the analysis results, it was determined that the intersection with the LED outlined backplates exhibited significant reductions in RLR violations, and minor reductions in RTOR violations. Multiple sites with the LSBS were evaluated, and significant reductions were noted for both RLR and RTOR violations after the LSBSs were installed.

**Introduction**

In 2004, the first 7.5 miles of METRO-Rail (the Red Line) was constructed by the Metropolitan Transit Authority of Harris County (METRO) to fulfill part of Houston’s long-range transportation plan. The light rail system provides for high-capacity transit service in the travel corridor linking the Central Business District with Midtown, the Museum District, the Texas Medical Center, and the Reliant Park area. The light rail line travels at grade along surface streets, to the left or right of the vehicle travel lanes in some areas and in the street median in others.

After the Red Line opened, there were several crashes involving both a passenger motor vehicle and a light rail vehicle, and one of these crashes resulted in a fatality. RLR violations were listed as factors in several of these crashes. It is unclear what the primary causes of these types of crashes were, but driver inattention or issues with visual clutter have been surmised as primary causative factors. In order to reduce RLR violations, RTOR violations, and crashes at these intersections, METRO outfitted the stop bar at the Jefferson Street approach to Main Street with a LSBS to enhance visibility of the red signal indications at the intersection. This LSBS consisted of internally illuminated raised pavement marker lights, which were activated during the red interval of each traffic signal cycle for the Jefferson approach at Main Street.

Additionally, Light Emitting Diode (LED) outlined backplates have been theorized to enhance visibility of the traffic signal head assembly. In response to the red light running issues, METRO installed LED outlined traffic signal backplates at the intersection of Main Street and Gray Street, in downtown Houston, on the Gray Street approach. These devices were operated in a steady burn mode with an LED light source producing a continuous line of red light around the outer border of the traffic signal backplate for each of the two traffic signal heads on that approach. The red backplate outline is activated at the onset of the red signal indication and remains active for the duration of the red interval, producing a red box outline around the traffic signal head. During the green interval and yellow change interval, the red outline of the backplate is off and inconspicuous. Both the LSBS and the LED backplates were installed with the approval of the Federal Highway Administration (FHWA) through a request for experimentation.

**Project Implementation**

The LED outlined backplates were installed on each of the two signal faces for the westbound Gray Street approach to Main Street as a pilot installation. These backplates were activated in October 2006, and they were operated in a steady burn mode with the red LED outlined backplates active during the steady red indication of the traffic signal. Figure 1 shows the LED outlined backplates for westbound Gray Street at Main Street.
The first LSBS was installed in the pavement along the stop bar for the eastbound Jefferson Street approach to Main Street. The LSBS was activated in March 2006, and it was operated in a steady burn mode with red lighted pavement markers active during the steady red indication of the traffic signal. Figure 2 shows the lighted stop bar application for eastbound Jefferson Street at Main Street.

The LSBS at this location was configured in a linear layout with two offset rows of red LED markers installed in front of the painted stop line. The spacing of individual markers in each row was approximately one foot, but the offset of the markers between the two rows effectively presented a six inch spacing. This LSBS was operated in a steady burn mode with the red lighted pavement markers active when the eastbound traffic signal indication for the Jefferson Street approach displayed the red indication. During the green interval and yellow change interval, these pavement markers were off and inconspicuous. Further, the LSBS was deactivated when the traffic signal operated in an all-red flashing mode. While the pavement markers ran at maximum intensity during daylight hours, they were dimmed during the nighttime hours.

Over time, heavy traffic volumes and environmental factors led to the failure of some of the individual markers. Initially, a majority of them remained active such that the system still operated at an acceptable level; however, eventually enough of them failed, forcing METRO to replace the system with a next generation system of markers from another vendor in late 2008.

After the early positive results (including red light running documentation and crash statistics) from the pilot installations with the LSBS and the LED outlined backplates, management at METRO decided that they wanted to continue to improve safety along the light rail line. METRO sought and received FHWA approval to expand the experimentation and outfitted 21 additional intersections with LSBSs and/or LED outlined backplates between late 2006 and early 2009.

The backplates operated exactly as they did at the pilot installation, but all of the additional sites with LSBSs had the newer next generation system, which consisted of a linear layout with a single row of red LED pavement markers installed approximately one to two feet downstream of the painted stop line. The spacing of individual markers in each row was approximately 18 inches. The LSBSs for these intersections operated with red lighted pavement markers active when the traffic signal indication for the cross street approach displayed the red indication. As with the pilot intersection, these pavement markers were off and inconspicuous during the green interval and yellow change interval. The LSBSs at all of these intersections were deactivated when...
These next generation LSBS markers operated in almost the same way as those installed at the pilot intersection with one notable exception. The markers at these additional sites operated in an alternating wig-wag pattern. This type of LSBS operation involves the LEDs inside each individual pavement marker being activated by alternating between the LEDs on the left side of the marker and the LEDs on the right side of the marker. Therefore, each individual pavement marker operated in a wig-wag operation, and all markers in the system operated exactly the same.

**Effectiveness of LED Outlined Backplates**

METRO installed the LED outlined traffic signal backplates with the hope that they would help increase the visibility of the traffic signal face assembly and reduce RLR violations and crashes. Using recorded video from the intersection, a before and after study was completed, and the results showed reductions in both RLR and RTOR violations after the backplates were installed and activated. The after video was recorded approximately five months after the LED outlined backplates were installed and activated, and during the study period, no major changes to roadway geometry, traffic signal hardware, traffic signal phasing, or traffic volumes were noted. The only noticeable change was the addition of the LED outlined backplates. Table 1 includes the results from the before and after study for the LED backplates. Again note that right turns on red are prohibited on all cross street approaches to the Red Line in downtown Houston.

**Table 1. Results for LED Outlined Traffic Signal Backplates – Gray at Main, Houston, Texas**

The reduction in RLR violations per day was statistically significant (at the 90% confidence level), and only a minor reduction in RTOR violations was noted. Based on the results produced, it appears that the LED outlined traffic signal backplates at the Gray approach to Main Street significantly reduced RLR violations.

<table>
<thead>
<tr>
<th>Type of Violation</th>
<th>Average Violations per Day per 10,000 Vehicles - BEFORE</th>
<th>Average Violations per Day per 10,000 Vehicles - AFTER</th>
<th>Statistically Different Reduction?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Light Running (RLR)</td>
<td>21.8</td>
<td>11.2</td>
<td>YES, at 90% Confidence Level</td>
</tr>
<tr>
<td>Right Turn On Red (RTOR)</td>
<td>76.3</td>
<td>71.0</td>
<td>NO</td>
</tr>
</tbody>
</table>
Evaluation of Lighted Pavement Marker Stop Bars and LED Outlined Traffic Signal Backplates

Continued from page 46

Technical Details and Durability of LED Outlined Backplates
The LED outlined backplates were custom built using a standard traffic signal backplate and attaching readily available lines of red LEDs along the border. The backplates are powered directly from the signal cabinet and are connected through a standard load switch. They do not run through the flash relay, which is used in the event of a signal cabinet malfunction. This is done to keep from damaging the transformer that powers the LEDs. Therefore, the backplates are active during the steady red signal indication, but they are off if the signal operates in a red flash mode.

The LEDs operate at the same luminous intensity during both daytime and nighttime. They do have the ability to run with a lower luminous intensity, but METRO does not dim these at night. In over three years, there have not been any failures or malfunctions with any of the LED outlined backplates.

Effectiveness of Lighted Stop Bar Systems
Video was recorded at the original pilot intersection before and after the original LSBS was activated. The after video was recorded approximately 12 months after the LSBS was installed and activated, and during the study period, no major changes to roadway geometry, traffic signal hardware, traffic signal phasing, or traffic volumes were noted. The only noticeable change was the addition of the LSBS. Table 2 includes the results from the initial before and after study of the LSBS. Again note that right turns on red are prohibited on all cross street approaches to the Red Line in downtown Houston.

Table 2. Results for LSBS – Jefferson Street at Main Street, Houston, Texas

<table>
<thead>
<tr>
<th>Type of Violation</th>
<th>Average Violations per Day per 10,000 Vehicles - BEFORE</th>
<th>Average Violations per Day per 10,000 Vehicles - AFTER</th>
<th>Statistically Significant Reduction?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Light Running (RLR)</td>
<td>12.9</td>
<td>11.3</td>
<td>NO</td>
</tr>
<tr>
<td>Right Turn On Red (RTOR)</td>
<td>64.7</td>
<td>25.4</td>
<td>YES, at 95% Confidence Level</td>
</tr>
</tbody>
</table>

The results of this initial before and after study revealed reductions in both RLR and RTOR; however, only the reduction in RTOR was found to be statistically significant. Based on the results from this study of the original LSBS installation, it appeared as though the LSBS was more effective at producing reductions in RTOR violations rather than RLR violations. However, once the next generation pavement markers were installed at this and other sites, an opportunity for additional testing became available.

A second, more robust study was devised to evaluate the effectiveness of the next generation LSBS pavement markers. In this study, three intersections were selected as treatment sites. The LSBS installations at these three sites consisted of the same layout and operational characteristics as the other sites added between 2006 and 2009 (i.e., a single row of markers operated in an alternating wig-wag pattern). In addition, a comparison intersection was selected to provide a reference as a non-treatment site. No LSBS was installed at this comparison intersection. Each of the four intersections consisted of a five-lane, one-way, cross street approach to Main Street in downtown Houston.

Once again, a before and after study approach utilized recorded video to determine if the number of RLR or RTOR violations were affected by the addition of an LSBS at each of the three treatment sites and to determine any change in the number of violations at the non-treatment site. The after video was recorded approximately 4 months after the LSBSs were installed and activated, and between the before and after study periods, no major changes to roadway geometry, traffic signal hardware, or traffic signal phasing were noted. Other than minor changes in approach traffic volumes, the only noticeable change was the addition of the LSBSs at the three treatment sites. There were no noted changes of any kind at the comparison site. Table 3 includes the
The results revealed statistically significant reductions in RTOR violations for all three treatment sites after the LSBSs were installed. Noted reductions in RLR violations were also observed at all three treatment sites, and those reductions were statistically significant at two of the three treatment sites. Additionally, the statistical test for the non-treatment site (Pease Street at Main Street) showed that there was no statistically significant change (reduction or increase) in either type of violation between the before and after periods.

Based on the results from this study of the new next generation LSBS installations, it appears as though these LSBSs are effective at producing reductions in both RLR and RTOR violations. While the violations were also divided into two daylight conditions categories, the results appeared to be similar for violations occurring during daylight and violations occurring during no daylight. Therefore, the effect of the LSBS does not appear to be significantly different between daylight and non-daylight conditions.

All violations were further categorized into two groups based on the amount of time after onset of the red signal indication that the violation occurred. These two categories were greater than two seconds (>2), and less than or equal to two seconds (<=2). The researchers chose two seconds because the typical all-red signal interval for traffic signals in the area is approximately that value. Vehicles making a violation after 2 seconds are more likely to conflict with cross street traffic, which would have received a green signal indication by that time.

### Table 5. Results for Additional LSBS Sites

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Type of Violation</th>
<th>Average Violations per Day per 10,000 Vehicles - BEFORE</th>
<th>Average Violations per Day per 10,000 Vehicles - AFTER</th>
<th>Statistically Significant Reduction?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capitol at Main TREATMENT SITE</td>
<td>Red Light Running (RLR)</td>
<td>5.7</td>
<td>1.0</td>
<td>YES, at 95% Confidence Level</td>
</tr>
<tr>
<td>Clay at Main TREATMENT SITE</td>
<td>Right Turn On Red (RTOR)</td>
<td>47.6</td>
<td>21.3</td>
<td>YES, at 95% Confidence Level</td>
</tr>
<tr>
<td>Leeland at Main TREATMENT SITE</td>
<td>Red Light Running (RLR)</td>
<td>4.3</td>
<td>0.0</td>
<td>YES, at 95% Confidence Level</td>
</tr>
<tr>
<td>Leeland at Main TREATMENT SITE</td>
<td>Right Turn On Red (RTOR)</td>
<td>106.6</td>
<td>55.4</td>
<td>YES, at 90% Confidence Level</td>
</tr>
<tr>
<td>Pease at Main NON-TREATMENT SITE</td>
<td>Red Light Running (RLR)</td>
<td>4.5</td>
<td>5.2</td>
<td>NO</td>
</tr>
<tr>
<td>Pease at Main NON-TREATMENT SITE</td>
<td>Right Turn On Red (RTOR)</td>
<td>24.3</td>
<td>23.8</td>
<td>NO</td>
</tr>
</tbody>
</table>

The average number of RLR and RTOR violations per day for all three treatment intersections was reduced from before to after for the >2 and <=2 data sets. The number of RLR violations reduced 81% for the >2 data, while the reduction was 74% for the <=2 data. Additionally, the number of RTOR violations reduced by 55% for the >2 data, while the reduction was only 41% for the <=2 data. For both RLR and RTOR, the percent reduction was higher for the violations occurring greater than 2 seconds into the red interval, so it seems plausible that these markers may perform a little better at reducing the violations that occur later in the red interval.

### Technical Details and Durability of Lighted Stop Bar Systems

The original system at the pilot location had noted performance issues. One issue was that the manufacturer would not warranty any markers in the wheel path. This system used inductive power, meaning that the markers did not have to be individually wired. Circular bored holes were made over the imbedded inductive power cable, and the markers were secured to the holes in the pavement with epoxy. Initially, only a few individual markers needed replacing due to epoxy failure resulting in a loose marker or due to marker surface failure (i.e., cracked marker). However, these failures increased dramatically after about a year of operation eventually leading to the need to replace the entire system. The system was replaced with an updated system from the same vendor, but individual marker failures again forced METRO to replace the system, this time using a different vendor with a next generation system and a five year parts and labor warranty. This same system was installed at all of the LSBS sites after the pilot study. These next generation systems went through four upgrades and are still in use today.

These markers require fewer repairs and less maintenance than those at the original pilot installation; however, the markers are not maintenance...
free. Maintenance issues are typically related to damage from vehicular traffic, particularly in situations where the marker lies in the wheel path of a particular lane. Failures caused by the in-pavement wiring or controller module in the traffic signal cabinet have been repaired by the manufacturer. Durability experience is limited to high temperatures, high traffic volumes, and heavy rain, and the markers and wiring have performed acceptably under these conditions. Because of the climate in Houston, Texas, there has been no experience with snow conditions, and damage due to snowplows is not a consideration. The markers can be damaged by heavy equipment during road construction; however, these markers have a very low profile and should avoid damage from snowplows. In the event that an individual marker does fail, that marker can be replaced relatively quickly and easily by having maintenance personnel remove two security screws, lift out the damaged marker, and drop in a replacement one.

**Crash Experience**

The anticipated impact of both the LSBS and LED outlined backplate devices at the pilot intersections was to reduce RLR running crashes at the approach to Main Street (and the METRO rail line); therefore, the most relevant crashes for this analysis are the cross street “Ran Red Light” crashes.

In the 24 months before the activation of the LSBS at the Jefferson Street approach to Main Street, there were four crashes involving cross street vehicles running a red light at Jefferson. There was only one crash of this type in the 24 months after the LSBS was implemented. At the Gray Street at Main Street intersection, there were 2 crashes involving a cross street vehicle running a red light in the 24 months before the LED backplates were installed, but there were not any of this type of crash during the 24 months after the installation of the backplates.

This data shows that the number of crashes over time has reduced since the LSBS and LED outlined backplates were installed. Although the total number of crashes is relatively small, there is a reduction in crash frequency, so these devices appear to be leading to a reduction in the number of cross street RLR crashes.

In addition to the two pilot intersections, an additional 13 intersections outfitted in late 2006 and 2007 were also monitored for crash experience. Most of these additional intersections were outfitted with LSBS and/or backplates in mid-2007, so the period prior to this installation would include the years 2004 through 2006. The period after installation would include most of 2007 and all of 2008 and 2009.

The METRORail began revenue operation in January 2004, and crash records were recorded for all 15 intersections outfitted with LSBSs or LED backplates during 2006 and 2007. At these 15 intersections, there were a total of 12 crashes involving cross street traffic running a red light in 2004. That number was 14 in 2005, and eight in 2006. From 2007 through 2009 (approximately the time period after the LSBSs and LED backplates were installed), the number of cross street red light running crashes reduced from four in 2007, to two in 2008, and down to only one in 2009.

This reduction in cross street red light running crashes occurred over time, and it is possible that drivers became more aware of the METRO-Rail line and changed their driving behavior to drive more cautiously when near the Red Line. Certainly, driver familiarity with the Red Line increased over time, but it is surmised that a majority of these changes in driver behavior had occurred before most of the LSBSs and LED backplates were installed in 2007.

Figures 5 and 6 (on page 50) show the yearly crash totals for all 15 intersections from 2004 through 2009 for two groupings of crash types. When looking at the cross street ran red light crashes, there is a downward trend from 2006 through 2009, which corresponds with the installation of the LSBSs and LED Backplates. There is not the same downward trend with all other crashes recorded for these intersections. Based on this information, it appears that the LSBSs and LED backplates may have significantly contributed to reducing red light running crashes on the approaches to Main Street since the time they were installed.
Conclusions
The study results from the pilot installation of the LED outlined traffic signal backplate were positive. Installation of the backplates was attributed to a statistically significant reduction in RLR violations and a minor reduction in RTOR violations. The backplates have operated without problems and nearly maintenance-free for several years.

The first LSBS installation used an early lighted pavement marker system, which operated in a steady burn mode and had frequent problems with individual marker failure. The evaluation of this LSBS showed that the installation of the lighted stop bar led to a statistically significant reduction in RTOR violations, but only a minor reduction in RLR violations.

The additional LSBS sites added after the pilot site used a newer, next generation system of pavement markers. These LSBSs operated in an alternating wig-wag mode instead of the steady burn mode used at the pilot site, and these LSBSs also operated with fewer problems due to marker failures. The evaluation of three of these sites showed statistically significant reductions in RLR violations at two of the three treatment sites and statistically significant reductions in RTOR violations at all three treatment sites. Conversely, there was no notable change and no statistically significant change in the number of RLR or RTOR violations at the non-treatment site. Based on the data collected for this evaluation, it can be concluded that these LSBSs helped to reduce both RLR and RTOR violations at the three treatment sites.

While the results of these evaluations may be positive, they are limited to the specific applications evaluated. These devices may have similar effectiveness at signalized intersections without a light rail line, but our evaluations were limited to signalized downtown intersections with a light rail line running parallel to motor vehicle lanes. In order for either of these devices to be considered for inclusion in the MUTCD, a more diverse data pool is required. This requires not only more implementation (with FHWA approval) of these devices in a variety of locations and settings, but more importantly, it requires that quantitative evaluations of the effectiveness also be completed for these installations.

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