Light rail transit (LRT) is increasing as a mode of transportation throughout the United States. With the new LRT systems being constructed and the expansions of existing LRT systems, there is an increased presence of LRT vehicles and a greater potential for highway-light rail crossing (crossing) crashes. This increase in LRT vehicles requires a greater need for public awareness about the specific characteristics of LRT operations. While crossings are designed with safety in mind, motorists continue to exhibit risky behavior and ignore the safety warning devices that have been installed at crossings.

Five of the crossings on the Denver Regional Transportation District (RTD) Central Corridor are located adjacent to and near the Auraria Campus, which houses the University of Colorado Denver, Metropolitan State University, and the Community College of Denver. This area is known as the Cascades and includes the crossings of the RTD Central Corridor Line with 7th Street, 9th Street, Kalamath Street, Speer Boulevard Southbound, and Speer Boulevard Northbound. These five crossings experience high traffic volumes with use by many pedestrians and bicyclists, and have shown some of the higher crash volumes on the entire RTD LRT system. Figure 1 shows the location of the five crossings in the Cascades and the location of the Auraria Campus.

The five Cascades crossings used various safety treatments to warn drivers of approaching trains including warning signs with amber beacons that would flash when a train was approaching, passive signage, and control of traffic movements through standard traffic signals. With the high number of crashes experienced at these crossings, RTD applied for, and was awarded, Federal Section 130 crossing safety improvement funds. Safety improvements made at the five crossings consisted of a number of different safety treatments. At the crossing of Speer Boulevard Northbound, the eastbound left-turning movement from Stout Street to Speer Boulevard Northbound was changed to a protected only left-turn movement. The Kalamath Street crossing is located less than 200 feet north of the intersection of Kalamath Street and Colfax Avenue. The traffic signal heads for southbound Kalamath Street were changed to programmable heads to eliminate the driver’s ability to see both the traffic signal indicators for the Kalamath Street crossing and the Kalamath Street and Colfax Avenue indication at the same time. At 9th Street, the eastbound left-turn was eliminated. As required by the 2009 Manual on Uniform Traffic Control Devices (1) advance warning signs (W10-1, W10-2, and W10-3), and crossbucks (R15-1) with number of tracks (R15-2) signs were added as needed at all five crossings, and the “No Right Turn When Flashing” signs with flashing amber beacons were removed from those crossings where they were installed.

Figure 1. Auraria Campus and Crossing Locations

In addition to the above discussed changes, new blank-out signs activated upon train detection were installed at each of the crossings. These blank-out signs
included the W10-7 “Light Rail Transit Approaching” sign at some locations, and W10-7 signs that alternate with either the R3-1 “No Right Turn” symbol sign or the R3-2 “No Left Turn” symbol sign corresponding to the posted location. These combination signs both regulate the motorist by prohibiting left-turn and right-turn movements across the tracks while at the same time warning them of approaching LRT trains.

This paper provides a preliminary analysis of the effectiveness of the safety improvements made at the Cascades crossings and conducts an analysis of motorist behavior using a “before” and “after” approach related to the new alternating blank-out signs (Figure 2).

PRELIMINARY ANALYSIS OF SAFETY MITIGATION EFFECTIVENESS

The above discussed improvements were put into operation during 2012. A “before” and “after” safety evaluation was performed using an empirical Bayes (EB) approach and calculating an Index of Effectiveness ($\theta$) as outlined by Persaud, Lan, Lyon, and Bhim (5). As shown in this paper, the EB approach shows the change in safety for a given location is equal to

$$\lambda - \pi$$  \hspace{1cm} (1)

where $\lambda$ is the expected number of crashes that would have occurred in the after period without installation of the safety treatments and $\pi$ is the number of reported crashes in the after period.

Persaud, Lan, Lyon, and Bhim (5) show that the Index of Effectiveness ($\theta$) is estimated as:

$$\theta = \left( \frac{\pi_{\text{sum}}}{\lambda_{\text{sum}}} \right) \cdot \frac{1+\text{Var}(\lambda_{\text{sum}})/\lambda_{\text{sum}}^2}{1+\text{Var}(\lambda_{\text{sum}})/\lambda_{\text{sum}}^2}$$  \hspace{1cm} (2)

Using light rail crossing crash prediction methodologies developed by Fischhaber (2), $\lambda$ was calculated for each of the five crossings in the Cascades. Those numbers were compared to the actual 2013 crash numbers ($\pi$) and $\theta$ was calculated for the group of crossings to determine the Index of Effectiveness of the safety treatments. Table 1 shows the total number of crashes that occurred from 2007 through 2011 by crossing prior to the installation of safety treatments, the number of crashes that occurred in 2013 by crossing after safety treatments were installed, the $\lambda$, $\pi$, and $\lambda$-$\pi$ for each crossing, and the $\theta$ for the group of crossings.

Table 1: Cascades Crossings Safety Calculations

<table>
<thead>
<tr>
<th>Crossing</th>
<th>2007-2011 crashes</th>
<th>2013 crashes</th>
<th>$\lambda$</th>
<th>$\pi$</th>
<th>$\lambda$-$\pi$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7th St.</td>
<td>12</td>
<td>3</td>
<td>2.374</td>
<td>3</td>
<td>-0.63</td>
<td></td>
</tr>
<tr>
<td>9th St.</td>
<td>3</td>
<td>0</td>
<td>0.576</td>
<td>0</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Kalamath</td>
<td>20</td>
<td>0</td>
<td>3.973</td>
<td>0</td>
<td>3.97</td>
<td></td>
</tr>
<tr>
<td>Speer NB</td>
<td>8</td>
<td>2</td>
<td>1.576</td>
<td>2</td>
<td>-0.42</td>
<td></td>
</tr>
<tr>
<td>Speer SB</td>
<td>19</td>
<td>0</td>
<td>3.77</td>
<td>0</td>
<td>3.77</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>5</td>
<td>12.269</td>
<td>5</td>
<td>7.269</td>
<td>0.387</td>
</tr>
</tbody>
</table>

Based on the one year of available after data, there is a 61.3% preliminary reduction in crashes at the subject crossings. By using the EB approach, effects for regression-to-the-mean should be accounted for in the calculations. However, given that only one year of after data is currently available, the $\theta$ will need to be calculated again in a few years to determine the long-term safety effects of the installed safety treatments.

“BEFORE” AND “AFTER” STUDY DATA GATHERING METHODS
A wide range of safety mitigation and design features incorporated into the design of an LRT alignment should be considered as key factors to address and acknowledge safety concerns. Existing sites should be analyzed with the aim of increasing safety of future at-grade crossings.

One approach of accomplishing data gathering of “before” and “after” motorist behavior data safety screening of at-grade crossings is to conduct a field review. Some restrictions of conducting a field review are as follows:

- Limited manpower
- Poor weather conditions
- Safety of the monitors
- Technical difficulties
- Motorists may alter behavior if monitors are present

Due to the above limitations, surveillance cameras are the preferable tool for gathering “before” and “after” motorist behavior data at existing at-grade crossings. Conclusions drawn from detailed examination of recordings from surveillance cameras can assist in determining whether adverse safety conditions exist and to what extent.

**CASE STUDY**

While crash frequencies are often used to assess risk at road crossings, actual vehicle collisions at crossings are rare events, thus limiting statistical analyses intended for suitable sample sizes. Therefore, the analysis of potential conflicts due to motorist behavior is an additional method to study safety at grade crossing and the effectiveness of the traffic engineering treatments at crossings. Risky behaviors are maneuvers by motorists that create potential collisions whether or not a collision actually occurs. Because such near collision situations are more frequent than the number of actual collisions, they can be used as an effective safety indicator.

**Objectives**

Based on the research conducted in 2006 by Grechka and Janson (3) regarding the violations of the right turn movements vs. through and left turn movements combined, it was determined that there were significantly more violations when the vehicles were turning right. The study was conducted at the same intersection as the current analysis, consequently the southbound right turn movement data was chosen as the base for this case study.

The goal of this case study is to evaluate the behavior of motorists making a Right Turn on Red before and after the installation of the new blank-out sign that illuminates and alternates the W10-7 and R3-1 symbols when activated by an approaching train. The pooled datasets include recordings of 15 hours each day for two days, from 7 AM to 10 PM. One day of data was collected before the installation of the new blank-out sign and one day of data was collected after the installation. The camera is operated by the City and County of Denver’s Transportation Management Center. The camera is unnoticed by motorists and it was in the exact same position during “before” and “after” periods. Thus, there were no conditions to cause motorists to behave differently in either of the two data recording periods.

**Site Description: 7th Street and Colfax Avenue**

Generally, traffic control devices for at-grade crossings are categorized as either passive control devices or active control devices. Passive control devices include traffic signs and pavement markings that identify and direct motorists, bicyclists, and pedestrians to the location of an at-grade crossing. Crossbuck signs and railroad crossing pavement markings are examples of passive control devices. Active control devices inform motorists, bicyclists and pedestrians of an approaching or existing train. Flashing light signals with or without gates, bells, and traffic signals are examples of active control devices.

Both passive and active traffic control devices are in place at the 7th Street and Colfax at-grade crossing. In addition to the traffic signal control, the southbound right turn (RT) lane was also previously controlled with the R3-1 “No Right Turn” blank-out sign activated when a train was present. In addition to the traffic signal control, the southbound RT lane is now controlled by an active blank-out sign that alternates the W10-7 “Light Rail Transit Approaching” sign with the R3-1 “No Right Turn”. The southbound through and left turn lanes are controlled by a traffic signal. **Figure 3** shows the traffic control devices used at the 7th Street and Colfax at-grade crossing.

![Figure 3. Traffic control devices at 7th Street](image-url)
When a train approaches the crossing, the traffic signal shows a red indication requiring motorists to stop at the stop bar, and the blank-out sign prohibits motorists from making a RT movement over the tracks at the crossing.

Statistical Method

Table 2 shows the number of RT lane group violations when the blank-out sign is active. During the 15 hour “before” period observations, \( x = 13 \) vehicles did not stop at the stop bar or stopped on tracks in the RT lane when the LRT blank-out sign was active. During the 15 hour “after” period observations, \( y = 2 \) vehicles did not stop at the stop bar or stopped on tracks in the RT lane when the LRT alternating blank-out sign was active.

<table>
<thead>
<tr>
<th>Traffic violations per category</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not stop at stop bar</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Stopped on track</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total RT traffic violations</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

The estimate of \( \hat{p}_A \), the proportion of traffic violations during the “before” study, is therefore

\[
\hat{p}_A = \frac{x}{n} = \frac{13}{181} = 0.0718
\]

and the estimate of \( \hat{p}_B \), the proportion of the traffic violations during the “after” study, is therefore

\[
\hat{p}_B = \frac{y}{m} = \frac{2}{293} = 0.0068
\]

Does the behavior of the motorists when the blank-out sign is active differ between the two groups? This question can be examined with two-sided hypothesis

\( H_0 : p_A = p_B \) versus \( H_a : p_A \neq p_B \)

The pooled estimate of a common proportion is

\[
\hat{p} = \frac{x + y}{n + m} = \frac{13 + 2}{181 + 293} = 0.0316
\]

where \( n \) and \( m \) are the number of times when the blank-out sign is active during the “before” and “after” respectively.

Calculating a z-statistic from the data:

\[
z_{\text{observed}} = \frac{\hat{p}_A - \hat{p}_B}{\sqrt{\hat{p}(1 - \hat{p})\left(\frac{1}{n} + \frac{1}{m}\right)}} = 3.93
\]

p-value = 2 \( \times \) \( \Phi(-|z|) = 2 \times \Phi(-3.93) \approx 0 \)

Consequently, the null hypothesis is not plausible. The result demonstrates a difference in motorist behavior between “before” and “after” groups. In fact, a two-sided 95% confidence interval for the difference between two group proportions, and with \( z_{.025} = 1.96 \), is

\[
p_A - p_B \in \left( \hat{p}_A - \hat{p}_B \pm z_{.025} \sqrt{\frac{x(n - x)}{n^3} + \frac{y(m - y)}{m^3}} \right) = (0.02, 0.11)
\]

The above test of proportions indicates that the proportion of motorists in the southbound RT lane who did not stop when the old blank-out sign was active during the “before” study are between 2% to 11% greater than the proportion of those who did not stop when new alternating blank-out sign is active during “after” study.

FURTHER RESEARCH AND ANALYSIS OF THE 7TH STREET CROSSING

The “before” and “after” analysis of the 7th Street crossing indicates that motorists in the southbound RT lane group are exhibiting less risky behavior with the addition of the new alternating blank-out sign than they were prior to the installation of this sign. However, the number or crashes that occurred at this crossing after the installation of the new alternating blank-out signs is approximately the same as the average number of crashes that occurred at this crossing prior to installing the alternating blank-out signs. Further research and analysis of the types of crashes occurring at this specific crossing is needed to determine the specific causes of crashes at this crossing and to see if any additional mitigation measures can be made at the crossing to reduce the number of collisions.

CONCLUSIONS AND RECOMMENDATIONS

Based on a preliminary calculation of the Index of Effectiveness based on a single year of after crash data, there was a preliminary reduction in crashes of 61.3% at the five study crossings in the Cascades after installation of the new alternating blank-out signs. While the preliminary analysis is promising, it is based on only a
single year of data. The Index of Effectiveness needs to be calculated again in the future to determine the long-term safety effects of the installed safety treatments.

From this case study, it appears that the new alternating blank-out signs are effective in decreasing the frequency of violations and risky behaviors at at-grade crossings as they provide a clearer message to motorists of the risk of making a turn while providing an explanation of that risk.

Case studies such as this one are beneficial in pinpointing effective methods to decrease frequency of traffic violations and risky behaviors. Similar traffic control devices should be analyzed on a case by case basis and implemented with future designs. RTD is currently looking at the use of these types of alternating blank-out signs on the I-25 Corridor project at some crossings and at pedestrian/bicycle only crossings to prohibit pedestrian and bicycle users from crossing the tracks when a train is approaching.

Acknowledgements

The authors would like to thank the Denver Regional Transportation District in Denver, Colorado for use of their crash data for the study locations. The authors also wish to thank the City and County of Denver for their cooperation and assistance in gathering video data for this study.

REFERENCES