Safety and Operational Assessment of Yield-to-Bus Electronic Warning Signs on Transit Buses

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Transit buses generally experience difficulties merging into traffic after stopping at off-traffic stops; this situation generates potential hazards for both the bus moving back into traffic and the surrounding vehicles. Several states have implemented yield-to-bus (YTB) laws and programs to help alleviate these hazards. One of the challenges facing YTB initiatives is the lack of quantitative data to justify effectiveness. In this paper, flashing electronic YTB signs that use light-emitting diodes (LEDs) on the back of buses were evaluated as a major effort of the Florida Department of Transportation Transit Office to assess the effectiveness of the YTB program. YTB behavior, safety conflicts, and reentry time were proposed as three performance measures to evaluate the safety and operational impacts of electronic YTB signs. It was found that electronic YTB signs had the potential to improve YTB behavior of motorists behind the bus. In addition, with the electronic YTB signs, the number of safety conflicts was either reduced or was at least no greater than those of the baseline scenario, which consisted of a YTB decal. The reentry time from pullout bays was also improved. Additional recommendations about compliance, installation, and operation of electronic YTB signs are provided.

Transit buses generally experience difficulties merging into traffic after stopping at off-traffic stops such as bus pullout bays or right-turn lanes. This situation generates potential hazards for both the bus moving back into traffic and surrounding vehicles. Several states, such as Washington, Oregon, and Florida, have implemented yield-to-bus (YTB) language in their statutes to enhance the safety of bus operations. To promote compliance with the YTB requirements in the statutes, some states took leading roles and established their YTB programs. TCRP Synthesis 49 compiled the statutes of the practice for YTB programs at the national level (1). TCRP Synthesis 49 performed a comprehensive survey of transit agencies to assess the operational and safety benefits of the most outstanding YTB programs. The study reported that no quantitative information about the safety benefits or time savings had been collected to evaluate the before-and-after performance of implementation of the YTB programs. Initiatives promoting YTB law compliance vary from one state to another. These initiatives may include public education campaigns, YTB decal display, and YTB electronic flashing signs that use light-emitting diodes (LEDs) on the back of the bus. This study focuses on assessment of the safety and operational benefits of the use of electronic YTB signs on the back of buses as an effort to promote YTB compliance in Florida.

In 2004, the Florida Department of Transportation (DOT) conducted a statewide safety study composed of a geographic information system-based analysis of crashes and a transit agency survey (2). The study aimed to find significant factors contributing to transit bus crashes. It was found that most serious crashes occurred near bus stops and were characterized by vehicles striking the back of the bus. In the survey section, most transit agencies expressed their preferences for implementation of more pullout bays, while those with reservations about this measure were concerned about the ability of the buses to merge into traffic safely. In light of these survey results, Florida DOT, through the National Center for Transit Research, has actively focused on determining the best set of treatments to promote YTB compliance.

A study by Zhou and Bromfield reviewed existing YTB treatments from a traffic engineering perspective and provided recommendations such as the use of electronic YTB flashing signs, roadside signs, and pavement markings (3). Quantitative data on the effectiveness of these treatments is still scarce, and additional research is necessary. Similar studies on bus operations and engineering recommendations for bus pullout bays were reviewed. TCRP Report 65: Evaluation of Bus Bulbs reported on before-and-after studies on the assessment of the operational benefits for pedestrian operations as a result of the implementation of bus bulbs (4). Texas Transportation Institute provided recommendations on when to implement a bay for a bus stop (5). Such recommendations included potential for auto–bus conflicts, dwell time exceeding 30 s per bus, and traffic speed greater than 40 mph, among others (6). The FTA suggested that bus-merging delay can be calculated as a function of the adjacent lane traffic flow and the critical gap length needed by the bus operator to merge (7). It was estimated that a point of significant delay is above 450 vehicles per hour per lane and (b) for a 4-mi trip, the cumulative delay could be 10 min or more.

In this paper, two electronic YTB signs were tested in the field and compared with the baseline treatment of a YTB decal only. This study focuses on the assessment of the safety and operational benefits of the use of electronic YTB signs that use LEDs on the back of buses. The main objectives of this study are (a) to determine
if the use of electronic YTB signs has an effect on the yielding behavior of motorists behind the bus, (b) to assess the potential effects of the use of electronic YTB signs on traffic safety, (c) to establish the operational benefits of electronic YTB signs, and (d) to provide recommendations for implementation of electronic YTB signs. The remainder of this paper is organized as follows: first, the performance measures used to evaluate the safety and operational impacts of flashing electronic YTB signs are defined. Then, the data collection strategy and general description of the data collection sites are provided. Recommendations on the installation and compliance of the electronic YTB signs are provided next. That is followed by an analysis of both the observed YTB behavior and quantitative data collected in the field. The last section provides a summary of the findings from this work and recommendations for implementation of flashing electronic YTB signs.

METHODOLOGY

Performance Measures

From the findings of the literature review, three main performance measures were used to determine the impact of installing flashing electronic YTB signs on the back of buses:

- Quantitative indicator of YTB behavior for the traffic behind the bus,
- Safety conflicts, and
- Reentry time.

In traffic operations, a yield action consists of slowing and giving the right-of-way to the main traffic stream. In a yield action, the driver must be prepared to stop if necessary, but, in general, such an action is not required (8). The yield concept can be applied to transit buses at bus stops that require a merging maneuver. Right-turn lanes and bus bays are the most common locations for bus stops where buses must make a merging maneuver to return to the traffic stream. A merging maneuver is finalized when the bus completely returns to the travel lane after a stop. This return can occur in three ways with respect to the traffic in the adjacent lane:

- Yield (Y). A vehicle in the adjacent lane slows or stops to give the bus the right-of-way to get into the traffic,
- Lane change (L). A vehicle in the traffic lane safely changes lanes to give the bus the right-of-way to get into the traffic, and
- Gap (G). No yield or lane change occurs, and the bus waits for an acceptable gap in traffic to merge. This event is the complement of the previous two (Y + L).

The bus merging maneuver can be quantified by the binary variables Y, L, and G as defined above. Because these maneuvers are all the possible ways for a merge to be finalized, their sum must equal 1. This equality ensures that the yield and the no-yield events are captured in the data collection. Y and L are two YTB behaviors that yield the right-of-way a bus and allow it to merge into the traffic.

The Highway Capacity Manual defines “bus start-up time” as the point at which “a bus starts moving and travels its own length while exiting an off-traffic bus stop” (9). The “reentry time” is defined as “the time experienced while waiting for a sufficient gap in traffic to allow the bus to merge back into the travel lane,” as presented in

Figure 1. Reentry time definition.

The Highway Capacity Manual reports that typical values for start-up times range from 2 to 5 s.

A before-and-after evaluation of YTB treatments by means of traffic accident data requires extensive collection of those data before a reliable analysis can be performed. Traffic conflicts often are used in lieu of accident data when data for a complete before-and-after analysis are not available. According to Parker and Zegeer, a “traffic conflict” can be defined as a traffic event involving the interaction of two or more road users, usually motor vehicles, in which one or both drivers take evasive action, such as braking or swerving, to avoid a collision (10). From the definitions of conflicts and the conflict types, five main conflicts were derived to evaluate the safety of YTB treatments (10). These conflicts are described and illustrated in Figure 2.

Data Collection Strategy, Test Signs, and Sites

To maximize the number of potential YTB scenarios, a rearview camera looking to the traffic behind the bus was installed on the buses of the participating agencies. In this way, a wide range of bus stops, different roadway geometries, and traffic conditions were covered. Two Florida transit agencies participated in the study: Hillsborough Area Regional Transit in Tampa, and Lee Transit in Fort Myers. Because not all the bus stops along the routes had the required features, only qualified corridors were selected. In both the Tampa and Fort Myers sites, a 3-mi section of selected bus routes was studied. These segments are referred to as the test corridors. The test corridor in Tampa consisted of a two-lane, undivided, urban minor arterial with a posted speed limit of 35 mph. The test corridor in Fort Myers is a six-lane, divided, urban principal arterial with a posted speed limit of 45 mph. The test corridor in Tampa has many pullout bays, while the majority of the bus stops in the Fort Myers corridor are in right-turn lanes.

In this study, two off-the-shelf electronic YTB signs that use LEDs were compared with the baseline treatment of decal only. The decal has the yield symbol with the text, “Yield to Bus. It’s the Law.” The first test of electronic YTB signs consisted of triangular signs with the word “Yield” in LEDs in the center. Whether the sign is amber or red depends on applicable state laws. Some transit agencies such as TriMet in Oregon and Santa Clara Valley Transportation Authority in California implemented triangular, flashing signs in red LEDs. In Florida, Lee Transit and Votran (in Volusia County) installed amber triangular yield signs on some of their buses. The second YTB test sign consisted of an electronic sign showing the word “Merging,” a small yield sign, and an arrow in two-phase flashing mode, all in LEDs. The triangular YTB sign was tested in the Tampa site. Both the “Merging” and triangular YTB signs were tested in the Fort Myers site for this study.

The sketch of the data collection strategy and the test signs are shown in Figure 3. At selected locations on the test corridor in Tampa, 138 merging maneuvers were recorded, with 235 recorded in Fort Myers. Of these maneuvers, 71 were performed when traffic
TABLE 1  YTB conflict definitions.

<table>
<thead>
<tr>
<th>Conflict</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car and Merging Bus: This is a direct conflict involving a bus leaving a bus bay or right turn lane in which the bus gets too close to a car in the travel lane.</td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>Car and Accelerating Bus: This is a direct conflict in which a bus enters the traffic lane at low speed and the car behind has to brake to avoid a collision.</td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Lane-Changing Car and Car: This is a secondary conflict caused by a car in the travel lane performing an unsafe lane change in an attempt to avoid yielding to a bus entering the traffic.</td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>Cut-in Car and Car: This is a secondary conflict in which a car changes lanes after the bus has entered the traffic and the conflicts with the car on the adjacent lane traveling at a lower speed.</td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Car and Yielding Car: This is a secondary conflict in which a car that yielded the right-of-way to the bus experiences a conflict with a close-following car.</td>
<td><img src="image5" alt="Diagram" /></td>
</tr>
</tbody>
</table>

FIGURE 2  YTB conflict definitions.

was present on the test corridor in Tampa and 154 in Fort Myers. Examples of yield maneuvers and observed conflicts captured with the data collection equipment are presented in Figure 4.

Sign Compliance and Installation

Before installation of the signs for the tests, questions about compliance and installation of the electronic YTB signs had to be answered. In this section, an overview of the existing regulations and how they applied to the installation and operation of the flashing electronic YTB signs is provided.

According to the NHTSA, the applicable regulations for flashing electronic YTB signs are found in Federal Motor Vehicle Safety Standard (FMVSS) No. 108, U.S.C. 49, Chapter 301. State regulations can also be applicable to electronic YTB signs. Applicable standards and the NHTSA repository for interpretation letters state that, before an initial sale, electronic YTB signs cannot be installed.

FIGURE 3  Data collection strategy.
(a) on transit buses as an item of original equipment or (b) by any manufacturer or dealer (11, 12). In addition, flashing lamps on buses are restricted to those for signaling purposes. However, these regulations do not apply to flashing electronic YTB signs that use LEDs if they are installed as aftermarket equipment. The applicable standard for aftermarket equipment indicates that any equipment installed on a vehicle must not make inoperative any of the required safety equipment, which, in this case, refers to the lamps required by FMVSS No. 108. In addition to federal laws, state laws also apply. For Florida, the applicable standard dictates that only amber lights are allowed to flash for nonofficial vehicles.

On the basis of the existing regulations, the following practices are suggested for the implementation of electronic YTB signs on transit buses:

- Electronic YTB signs can be installed on buses as aftermarket equipment by bus owners without the assistance of a manufacturer, distributor, or dealer.
- Electronic YTB signs can be wired to flash if done in conjunction with the regulatory turning lamps for the purpose of signaling. This practice implies that the YTB sign cannot flash independently of the left-turn lamp, but the left-turn lamp can be activated independently of the YTB sign (e.g., left turns at intersections).
- Electronic YTB signs cannot impair the effectiveness of any of the regulatory lamps.
- Electronic YTB signs should comply with local regulations for color and configuration.
- Electronic YTB signs can be used only to merge into traffic after a stop. They cannot be used to change lanes or to signal a turn.
It is always a good practice to request an interpretation from NHTSA before engaging in major initiatives involving new lamps on buses. Figure 5 shows the operation sequence of an electronic YTB sign for a bus entering and leaving a bus bay. At Stage 1, the bus is traveling in the traffic lane, and no lamp is active. As the bus approaches the bay, the right-turn lamp is activated, signaling motorists behind the bus (Stage 2). At Stage 3, tail lights and right-turn lamps are active, indicating that the bus is stopping. A stop light may also be present at this stage. At Stage 4, stop lights are active for a full stop. At Stage 5, the bus is ready to merge into traffic. The left-turn lamp is active, as is the electronic YTB sign. In this case, the YTB sign assists the left-turn lamp in effectively delivering the signaling message to motorists behind the bus. Once the bus is back in traffic, all the lights are off (Stage 6). If used as suggested by Figure 5, the electronic YTB signs do not impair any regulatory lamps.

RESULTS

YTB Behavior

For YTB behavior, the hypothesis to be tested is that electronic YTB signs that use LEDs have no effect on the yielding behavior of motorists behind the bus in comparison with the YTB decal.

For the test corridor in Tampa, the proportion of bus merging maneuvers that ended in a yield of the right-of-way with the decal was 58% and with the “Merging” sign was 80%. The use of the electronic merging sign had a significant effect on the YTB behavior of motorists behind the bus (p-value = .04). The 95% upper confidence bound for the difference in proportions (one-sided) between the decal and the electronic merging signal was −.04. This means that the increase in the proportion of maneuvers ending in a yield of right-
of-way will be 4% or more when the electronic merging sign is used than when the YTB decal is used on the test corridor in Tampa (the actual difference in proportions is .22).

For the test corridor in Fort Myers, safe lane changes were considered to be yielding behavior. The percentage of merging maneuvers that ended in a yield was 70% with the YTB decal only and 88% with the electronic YTB signs. The statistical analysis provides evidence that the use of electronic YTB signs had a significant effect on the yield-to-bus behavior, with a p-value of .017. On the basis of the one-sided 95% confidence bound for the difference in proportions, the increase in the percentage of maneuvers that ended in a yield will be 4.1% or more when the electronic YTB sign is used than when the YTB decal is used on the test corridor in Fort Myers. On the basis of the average difference in proportions, the improvements are 14%. The results for the YTB behavior of motorists behind the bus for both test corridors are summarized in Figure 6.

Safety

For YTB safety, the hypothesis to be tested is that electronic YTB signs do not increase the number of conflicts on merging maneuvers in comparison with the YTB decal treatment.

Traffic conflicts were analyzed from the video-based data for both corridors. For the test corridor in Tampa, a merge from a bus bay into a two-way roadway is a conflict-prone maneuver; because the bus is restricted by the pullout bay, it cannot gain speed to merge into traffic quickly. This situation led to primary conflicts such as bus–car accelerating and bus–car merging, as shown in Figure 7. Not many secondary conflicts (car–car) were observed, in part, because the test corridor was a low-speed, urban, undivided road with little room for sudden lane changes that could lead to secondary car–car conflicts. Posted speed also made braking distance generally shorter and helped to avoid rear-end-type conflicts. Each maneuver was assigned the most clearly defined conflict such that the proportion of maneuvers ending in a conflict could be analyzed as a performance measure. For the test corridor in Tampa, the proportion of merging maneuvers presenting conflicts was 54% with the decal-only treatment and 15% with the electronic YTB sign. The difference in proportions was statistically significant, with a p-value of .0003. On the basis of one-sided tests, the reduction in conflicts that can be obtained through the use of electronic YTB signs could be .22 or more. In the context of the previous results, it can be concluded that the use of electronic YTB signs improves the yielding behavior in the Tampa test corridor and also reduces the number of conflicts with respect to the decal-only treatment.

Figure 7 also shows the observed traffic conflicts on the test corridor in Fort Myers. Because the test corridor’s posted speed limit is 45 mph, chances of car–accelerating bus and car–yielding car conflicts are greater than on the Tampa test corridor. Car–merging bus conflicts are expected to decrease in right-turn lanes compared with bus bays because of the opportunity of the bus to gain speed before merging into traffic. The car–accelerating bus conflict occurs when the bus is gaining speed after merging into traffic. This situation can be alleviated from both the motorist and the bus operator standpoints. From the motorist standpoint, an education campaign might improve YTB behavior. From the bus operator perspective, the use of the electronic YTB sign may give a false sense of confidence, leading to conflicting maneuvers. Periodic reminders on the correct use of YTB signs can help to overcome this issue. The car–yielding and car–conflict types of maneuvers have the potential to increase if YTB signs are introduced without a proper public awareness campaign because of their novelty. Improvement in YTB behavior in a particular corridor implies the use of different strategies, such as education, YTB treatments, and enforcement.

For the test corridor in Fort Myers, the proportion of merging maneuvers that presented conflicts was 8.4% with the decal-only treatment and 6.25% with the electronic YTB sign. No evidence existed to disprove the hypothesis that the use of electronic YTB signs generates the same number of conflicts as the YTB-only treatment. The p-value of the test was .64. In the context of the previous results, it can be concluded that the use of electronic YTB signs improves the yielding behavior in the Fort Myers test corridor without an increase in the number of conflicts with respect to the decal-only treatment.

![Figure 6: YTB behavior on test corridors.](image-url)
Reentry Time

For reentry time, the hypothesis to be tested is that electronic YTB signs do not have an effect on the reentry time of the buses in comparison with the YTB decal treatment.

Reentry time was measured for both test corridors. The results of the reentry time for the test corridor in Tampa are summarized graphically in the box plot in Figure 8, which shows that the use of the “Merging” sign decreased the mean of the reentry time in the test corridor. The mean reentry time for the decal-only treatment was 8.15 s and for the “Merging” sign was 6.28 s. Another important observable effect is that the variance can be potentially reduced. The 95% confidence interval for the difference in reentry times for the two YTB treatments ranged from 0.26 to 3.49 s, with a mean value of 1.87. The one-sided 95% confidence interval gave a lower bound of 1.08 for the difference in reentry times between the YTB treatments. This result means that the use of the electronic YTB sign is expected to reduce reentry time by 1.08 s or more. Although the magnitude of the change may seem negligible, a 1.08-s reduction compared with the original mean of 8.67 s gives a reduction of at least 13%. In more-congested urban corridors, greater reentry time efficiencies can potentially be obtained.

For the test corridor in Fort Myers, the minimum observed reentry time was 6.1 s, and the maximum was 46.35 s for all YTB treatments. A graphical summary of reentry time is presented in Figure 9, which shows that reentry time has a similar average value. Transit buses with the decal-only treatment experienced more above-average reentry time than the electronic YTB treatments. This result indicates that electronic YTB signs can help the bus to signal to reenter the travel lane under heavy traffic situations during peak periods (e.g., long
traffic lines). An analysis of variance was applied to reentry time data. The results of the analysis of variance indicate that the use of electronic YTB signs does not cause a statistically significant change in reentry time ($p$-value = .17). Average reentry times were 19.05, 16.89, and 17.03 s, respectively, for the decal-only, triangular sign, and “Merging” sign. Reentry time was not significantly affected by implementation of electronic YTB signs because of the location of bus stops in right-turn lanes. This feature gave bus drivers more room to accelerate and merge into traffic safely. Another contributing factor is the presence of multiple travel lanes. This feature allowed motorists to change lanes safely when they approached a bus leaving a stop.

**CONCLUSION**

This study focused on the assessment of the safety and operational benefits of the use of electronic YTB signs that use LEDs on the back of the buses as part of YTB programs. Three basic performance measures were proposed and evaluated in the field: number of merging maneuvers that ended in yield of right-of-way to the buses, safety conflicts, and reentry time. The collected data provides statistical evidence that the use of electronic YTB signs will have a positive effect on the YTB behavior of motorists behind a bus. In both the Tampa and the Fort Myers test corridors, the proportion of maneuvers that involved yielding to the bus increased with implementation of electronic YTB signs compared with those of YTB decal only. Improvements of 14% or more in the number of merging maneuvers that ended in a yield of right-of-way to merging buses can be obtained by implementation of electronic YTB flashing signs. For the safety conflict performance measure, the use of electronic YTB signs significantly reduced the conflicts between buses and other vehicles for the Tampa site compared with those of YTB decal only. It showed no increase in conflicts for the Fort Myers site. For the reentry time performance measure, the use of electronic YTB signs also showed the potential to reduce reentry time of buses getting back into traffic.

When safety conflicts between the bus stop locations were compared, it was found that bus bays are more likely to experience direct conflicts (bus-car) than bus stops at right-turn lanes. This difference is mainly because the bus cannot gain enough speed in a bus bay to facilitate the merging maneuver. Longer bus bays could potentially alleviate this issue. In addition, it was observed that the number of lanes plays a major role in safety conflicts. The test corridor in Tampa presented more conflicts from this issue because motorists did not have an option to change lanes safely and thereby allow the bus to merge into the travel lane. It was found that the implementation of electronic YTB signs has the potential to reduce safety conflicts by warning motorists behind the bus that the bus is planning to merge into traffic. The use of electronic YTB signs on the back of buses can help in reducing reentry time of buses in pullout bays. For bus stops in right-turn lanes, the effect on reentry time was insignificant.

These test results reflected the perception of motorists to the electronic YTB sign, with neither enforcement nor a public education campaign. It is expected that, if the electronic YTB signs are properly introduced to the public, then the benefits could be greater. Electronic YTB signs can be installed on the back of buses to promote YTB law compliance and thereby increase highway safety for transit buses. If implemented, electronic YTB signs should be installed as aftermarket equipment. The signs should be wired to operate only when the left-turn signal is active. However, the left-turn signal must still operate independently. The YTB sign cannot be used for signaling maneuvers other than merging into traffic at a bus stop. Electronic YTB signs can be activated manually or automatically by linking their operation to activation of the left-turn signal or to positional information of the bus via Global Positioning System or radio frequency identification beacons at bus stops.

It is recommended that users keep track of the usage of the electronic YTB by recording its operation on the bus’s event logger. Doing so will provide data to evaluate YTB initiatives. Evaluation of YTB programs is vital for justifying their continuing support. Bus operator training and proper public campaigns can make electronic YTB signs a viable alternative for enhancing the traffic safety of transit buses.

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REFERENCES


Responsibility for the content of this paper, including all results and conclusions, rests solely with its authors.

The Bus Transit Systems Committee peer-reviewed this paper.