FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists

Draft Final Report

MAY 2015

FTA Report No. 0084
Federal Transit Administration

PREPARED BY

Applied Engineering Management Corporation (AEM)
Portland State University (PSU)

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

Courtesy of Edwin Adilson Rodriguez, Federal Transit Administration

Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists

Draft Final Report

MAY 2015

FTA Report No. 0084

PREPARED BY

Kelley Pecheux and Jason Kennedy
Applied Engineering Management Corporation
13880 Dulles Corner Lane, Suite 300
Herndon, VA 20171

James Strathman
Portland State University
College of Urban and Public Affairs
PO Box 751
Portland, OR 97207

SPONSORED BY

Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

AVAILABLE ONLINE

http://www.fta.dot.gov/research

Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.		
1. AGENCY USE ONLY	2. REPORT DATE May 2015	3. REPORT TYPE AND DATES COVERED February 2013–May 2015
4. TITLE AND SUBTITLE Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists		5. FUNDING NUMBERS CA-26-7104
6. AUTHOR(S) Kelley Pecheux (AEM), James Strathman (PSU), Jason Kennedy (AEM)		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) Applied Engineering Management Corporation 13880 Dulles Corner Lane, Suite 300 Herndon, VA 20171 Portland State University College of Urban and Public Affairs PO Box 751 Portland, OR 97207		8. PERFORMING ORGANIZATION REPORT NUMBER FTA Report No. 0084
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration Office of Civil Rights East Building 1200 New Jersey Avenue, SE Washington, DC 20590		10. SPONSORING/MONITORING AGENCY REPORT NUMBER FTA Report No. 0084
11. SUPPLEMENTARY NOTES [http://www.fta.dot.gov/research]		
12A. DISTRIBUTION/AVAILABILITY STATEMENT Available from: National Technical Information Service (NTIS), Springfield, VA 22161. Phone 703.605.6000, Fax 703.605.6900, email [orders@ntis.gov]		12B. DISTRIBUTION CODE TRI-20
13. ABSTRACT As part of a cooperative agreement with the Federal Transit Administration (FTA), the Tri-County Metropolitan Transportation District of Oregon (TriMet) conducted a demonstration test of three commercially-available pedestrian turn warning systems for transit buses. A total of 45 buses were equipped with the turn warning systems (15 buses with each of the 3 systems) for a period of 7 months (March–September 2014). A robust evaluation of the systems was conducted, including surveys and focus groups with bus operators and the general public, a video-based analysis of pedestrian behaviors, interviews with TriMet personnel, and a benefit-cost analysis. In addition to the turn warning systems, a unique crosswalk warning sign was deployed and tested at one intersection in downtown Portland. This report documents the findings from the test and evaluation.		
14. SUBJECT TERMS Pedestrian safety, bus turn warning systems, bus turn warning technologies		15. NUMBER OF PAGES 191
16. PRICE CODE		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This work documents the approach to a demonstration test and evaluation of three pedestrian turn warning systems. The demonstration project was conducted in Portland, Oregon, between March and October 2014. The document presents the findings from analyses of the perceptions and acceptance of the systems by bus operators and pedestrians, pedestrian behaviors, and interviews with TriMet personnel. In addition, a benefit-cost analysis is presented.

The intent of this document is to assist the transit bus industry in making information decisions regarding the implementation of the turn warning systems and in understanding the shortcomings and the potential pay-off of an investment of this type. This robust assessment of bus turn warning technologies is the first of its kind and provides transit industry stakeholders with a significant amount of information not previously available in a formal, comprehensive public document.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Tri-County Metropolitan Transportation District of Oregon (TriMet). Without its hard work and commitment, this demonstration project would not have been possible. The following individuals played particularly vital roles in the project:

- Harry Saporta
- Bob Seeley
- Steve Callas
- Allen Morgan
- Young Park
- Dave Webb
- Jose Borquez
- Mark PoulsonTracy Hamer
- Mike Arronson
- Roberta Altstadt

In addition, the team acknowledges the City of Portland Bureau of Transportation for its efforts in supporting the deployment of the BUS blank-out sign, which was not originally part of the proposed effort.

Although not listed by name, the vendors of the technologies tested played an essential role in ensuring that the demonstration test was a success. They responded to numerous questions and requests and provided information critical to the project in a timely fashion.

Finally, the following individuals shared their knowledge and experiences, which helped to shape the demonstration test and evaluation:

- Ron Barron, Greater Cleveland Regional Transit Authority, Cleveland, Ohio
- Mike Conlon, Metro Transit, Minneapolis, Minnesota
- Zeb Elliott, Greater Richmond Transit Company, Richmond, Virginia
- Janet Freniere, Transportation Services, University of Connecticut
- Bill Grizard, American Public Transportation Association (APTA)
- Jim Kemp, New Jersey Transit
- Daniel Lindstrom, Los Angeles County Metropolitan Transit Authority
- Pamela McComb, Parsons Brinckerhoff
- Chris Olson, City of Madison Metro Transit, Madison, Wisconsin
- Steve Peganoff, Greater Cleveland Regional Transit Authority, Cleveland, Ohio
- Hector Serrano, Greater Richmond Transit Company, Richmond, Virginia
- Corey Surrett, Consultant for Pace Transit, Suburban Chicago
- Phillip Wallace, Washington Metropolitan Area Transit Authority, Washington, DC

Their time and input are greatly appreciated.

ABSTRACT

As part of a cooperative agreement with the Federal Transit Administration (FTA), the Tri-County Metropolitan Transportation District of Oregon (TriMet) conducted a demonstration test of three commercially-available pedestrian turn warning systems for transit buses. Forty-five buses were equipped with the turn warning systems (15 buses with each of the 3 systems) for a period of 7 months (between March and September 2014). A robust evaluation of the systems was conducted, including surveys and focus groups with bus operators and the general public, a video-based analysis of pedestrian behaviors, interviews with TriMet personnel, and a benefit-cost analysis. In addition to the turn warning systems, a unique crosswalk warning sign was deployed and tested at one intersection in Portland. This report documents the findings from the test and evaluation.

EXECUTIVE SUMMARY

Collisions between transit buses and pedestrians/cyclists are few in number relative to motor vehicle crashes; however, when a pedestrian or cyclist is injured or killed as a result of a collision with a transit bus, there is not only a very high cost to the transit agency, but intense negative media coverage that can impact the public's perception of transit safety. To help in avoiding these types of collisions, transit agencies have implemented a wide range of safety countermeasures, including technologies such as pedestrian turn warning systems. However, there is a lack of understanding of the advantages and disadvantages associated with these technologies, and there is little empirical evidence regarding their effectiveness. Thus, transit agencies lack the information needed to make informed decisions about investments as well as what they can expect in return from implementing the technologies.

As part of a cooperative agreement with the Federal Transit Administration (FTA), the Tri-County Metropolitan Transportation District of Oregon (TriMet) conducted a demonstration test of three commercially-available pedestrian turn warning systems for transit buses. This report provides the details associated with the demonstration and evaluation of three commercially-available pedestrian turn warning systems as well as a limited test of an innovative crosswalk BUS blank-out sign.

Goals of Demonstration and Evaluation

The goals of the demonstration and evaluation included the following:

- Demonstrate the ability of several commercially-available turn warning systems to provide timely warning to pedestrians/cyclists that a bus is turning, pulling into a bus stop, or pulling away from a bus stop.
- Demonstrate the ability of an innovative crosswalk warning sign to provide timely warning to pedestrians/cyclists that a bus is turning.
- Demonstrate the ability of a directional LED headlight system to increase the visibility of pedestrians at night.
- Define the environmental parameters under which turn warnings should be provided to pedestrians/cyclists at intersections and at bus stops.
- Determine the effectiveness of the various technologies in terms of the following:
  - Bus operator perceptions and acceptance.
  - General public perceptions and acceptance.
  - Perceptions and acceptance of other TriMet personnel and management
  - Getting pedestrian/cyclist attention and impacting behaviors
- Develop benefit and cost estimates associated with the turn warning systems

Test Approach

Four bus-based, auditory turn warning systems were assessed, three of which were tested and evaluated. In addition, the potential use of an infrastructure-based crosswalk warning sign was investigated.

In total, 45 buses were equipped with turn warning systems (15 buses with each of the 3 systems) and assigned to 5 pre-selected bus routes during a 7-month test period (March to September 2014). Each "test" route was assigned an equal number of buses with each turn warning system. In addition, two BUS blank-out signs were placed at either end of one crosswalk at one intersection in downtown Portland.

Evaluation Approach

The evaluation approach was developed by linking the overall goals of the demonstration test to measurable technical objectives for each technology to be evaluated (turn warning systems, LED directional headlight system, and BUS blank-out sign). To meet these technical objectives, a wide range of data collection and analysis methods were employed. Table ES-1 summarizes the evaluation approach by technical objective and by technology.

Table ES-1

Evaluation Approach

Technical Objectives	Technologies	Methods
Assess bus operator perceptions and acceptance of…	• Turn warning systems • Directional LED headlight system	• Daily survey of bus operators • Comprehensive survey of bus operators • Focus groups with bus operators
Assess pedestrian/cyclist perceptions and acceptance of …	• Turn warning systems • BUS blank-out sign	• Field intercept survey of pedestrians/ cyclists • Focus groups with pedestrians/cyclists
Assess pedestrian/cyclist behaviors associated with …	• Turn warning systems • BUS blank-out sign	• Video-based field observations of pedestrian/cyclist activity
Assess pedestrian/cyclist-bus conflicts (before-and-after and with-and-without) …	• Turn warning systems • Directional LED headlight system	• Close calls as reported by bus operators
Assess institutional issues with and acceptance of …	• Turn warning systems • Directional LED headlight system • BUS blank-out sign	• One-on-one interviews with TriMet staff/management
Develop benefit-cost estimates associated with …	• Turn warning systems	• Avoided close calls as reported by operators • Cost associated with warning systems • Monetization and other relevant information from external sources

Findings

The findings showed a range of perceptions, levels of acceptance, and recommendations for improving the technologies.

Common Themes

A number of common themes emerged across the findings from the various methods employed. These themes included the volume of the turn warnings, the sensitivity of warning activation, the warning type/content, and when/where to activate the warnings. The findings surrounding each of these issues are summarized below.

Warning Volume – Finding an Appropriate Volume Level

Getting the volume settings of the warnings right was an issue throughout the duration of the demonstration test. Based on feedback/complaints received from both operators and residents along the test routes, the initial volumes proved to be too high. Following adjustments, noise-related complaints declined, but a growing number of operators also reported in the daily surveys that the volumes had become too low to be effective. In fact, analysis of the daily survey showed that responses indicating that volumes were “too loud” trended downward over the test, while responses indicating that volumes were “too soft” trended upward. In the end, however, responses on the operator comprehensive survey showed, by a significant margin, that the warning volumes were too loud rather than too soft. Considered together, the responses recovered from the daily and comprehensive surveys seem to reveal a confounding perception among operators of the volume necessary for the systems to be effective, with an attitude that any volume above a fairly low threshold is annoying. Regarding the individual systems, operator responses showed that the “too loud” margin was significantly greater for systems with the spoken warning message than for the system with the beeping sound.

From the perspective of the public, a majority of the pedestrians surveyed did not find the warnings to be intrusive to the environment. Of those who did find the warnings intrusive, more reported that the spoken warnings were more intrusive than the beeping warnings. Participants in the pedestrian focus groups disagreed somewhat, reporting that the volumes of the spoken messages were acceptable once they were adjusted, but that the beeping warning was still too loud. At any rate, the study found a lack of consensus about what the “appropriate” warning volume level should be.

It should be noted that volume alone may have not been the only issue contributing to the noise complaints. In the focus groups, both operators and the public reported that the repetition and/or the frequency of the warnings also may have been an issue. To mitigate some of the volume issues, feedback from the focus groups was that the warnings (and the volumes) should be relative to a particular location. In addition, recommendations included the ability for operators to manually adjust the volume or to program the warnings to automatically adjust and/or turn off when and where they are not needed.

Sensitivity of Warning Activation – Finding the Right Sensitivity Setting

Another issue that proved challenging was finding the right sensitivity setting to activate the warnings. This issue was specific to the two systems that were activated by rotating the steering wheel. Initial settings produced false activations of the warnings in certain situations, including sharp roadway curves and parking with curbed wheels. These problems were mitigated somewhat through system adjustments; however, findings from the operator surveys and focus groups indicated that the problems continued, to some extent, after the adjustments. To the contrary, a few operators noted that the systems would not always activate early enough in a turn to be effective.

It should be noted that at least part of the false activation issue might have been related to the maximum speed threshold selected for warning deactivation. For both systems, a maximum speed threshold of 25 mph was selected prior to the test. While lowering the speed threshold was discussed once the test was underway, doing so would have resulted in a disruption to the test due to the need to involve the manufacturer to make the adjustments on one of the systems. Therefore, the decision was made to keep the maximum speed thresholds at 25 mph and to adjust the activation angles instead. In effect, adjusting both may have done more to mitigate the false activation problem. Given that turns as well as bus stop arrivals and departures are made at relatively slow speeds (5–10 mph, at most), setting the maximum speed threshold closer to 15 mph would eliminate at least some of the false activations.

Warning – Selecting the Right Type/Content

Warning type and content can play a critical role in the ultimate success of the turn warning systems, particularly in terms of acceptance. Selecting a warning that is too harsh, not specific enough, confusing, not long enough, or too long could turn operators and/or the public against the system, despite its ability to get pedestrian attention and improve safety. The warnings for two of the systems tested are configurable, and any message or sound could have been programmed to promote system acceptance, but there was no clear answer to the question of what warning was best.

A survey of peer practices produced a range of possible warnings. Based on these practices and discussions with TriMet staff, two different types of auditory warnings were used in the demonstration test—spoken warnings and a beeping warning—and the content of the two spoken warnings differed slightly. To supplement what could be learned about the warnings from the field test, a variety of auditory and visual warnings were presented to and discussed with participants in the pedestrian focus groups. The totality of the results showed some consensus and some disagreement as to what constitutes the best auditory and visual warnings.

Regarding warning type, operators were most divided over the beeping warning; some liked it because it was a "universal," recognizable sound and/or they felt it was more effective than the spoken warnings at getting people's attention. Other operators did not like it because it was too loud, harsh, irritating, and potentially distracting. Pedestrian perceptions of warning type were less divided, and they tended to prefer the spoken warnings over the beeping warning.

Regarding warning content, there was strong consensus among operators and pedestrians that the warning, "Caution, bus is turning," is better than the warning, "Pedestrians, bus is turning." Almost everyone liked the word "caution," while there were numerous complaints about the word "pedestrians." One recommendation that came from both operators and pedestrians was to have a combined warning that incorporated both a spoken warning and a sound/tone.

Feedback from the pedestrian focus groups was that, overall, the warning should be concise, clear in meaning, specific, direct, and long and loud enough to get the attention of pedestrians. Beyond that, pedestrians stressed that the warning be easily-recognized and unique to TriMet buses, as well as "friendly." In fact, both pedestrians and operators recommended something similar to the "ding-ding" warning of TriMet's MAX light rail vehicles. Additional operator feedback was that the messages, rather than focusing on one message, should be varied to keep attention and to make it fun for the public.

With respect to the visual warning/sign, an ideal sign would be clear in meaning, specific, big, bright, flashing, and used in conjunction with an auditory warning. The BUS TURNING sign presented to participants in the pedestrian focus group was highly favored over the other alternatives presented. While many liked the idea of a bus symbol, the particular symbol presented in the focus groups was not well-received. Alternatively, participants recommended adding the word BUS or TURNING under an improved bus symbol sign.

Application of Turn Warnings – Determining When and Where Warnings Should be Used

While not specifically designed for activating at bus stops, the two systems activated by turning the steering wheel were set to be sensitive enough to activate while servicing at least some bus stops. Due to false activations early in the demonstration, the steering angles were adjusted on one of the two systems, which may have affected the frequency with which these systems activated at bus stops. Assuming operators used their turn signals at stops, the third system tested, which was activated via the turn signal, would have activated when both pulling into and away from bus stops.

Operators overwhelmingly felt that activation of the warnings at bus stops was as important, if not more important, than at intersections. Pedestrians tended to agree. Slightly more operators reported that the warnings were more necessary when making right turns than when making left turns and when pulling into a stop than when pulling away from a stop.

Two recurring issues suggest that it would be prudent to consider selective versus ubiquitous application of the turn warnings. The first issue was the complaints received early on by some Portland residents. While these complaints were generally mitigated by adjusting the volumes, giving more thought to where the warnings should activate (and also at what times of the day) could help to reduce or avoid these types of complaints. Second, bus operators and pedestrians reported concern regarding the long-term efficacy of the turn warnings; both groups believed that the warnings would eventually blend into the background noise and/or be tuned out. This belief was driven, at least somewhat, by the perceived ubiquity of the warnings, particularly if they were activated both at intersections and at bus stops during all service hours.

Instead, both operators and pedestrians strongly recommended that the volumes vary by location and/or time of day or that the volumes adjust automatically relative to the environment. Alternatively (or additionally), participants recommended that the warnings activate only on routes and/or at specific "trouble" locations and/or intersections/locations at which there is a history of pedestrian-bus conflicts/collisions.

Outside of temporal variations and known "trouble" spots, there were differences in opinions regarding where the turn warnings might meet with greatest success, including downtown versus residential areas and transit centers. Specific locations, situations, and times suggested for application of the turn warnings included schools, parks, malls, unsignalized intersections, minor streets crossing busy streets, peak travel periods, nights, weekends, during periods of poor visibility, and special events.

The flip side of this issue, however, relates to liability—what happens if a pedestrian is struck at a location or time of the day when the warnings are inactive? Here again lies a trade-off in the application of the turn warning systems in terms of how much is too much versus too little. This is likely a decision that needs to be carefully considered and weighed by each individual transit agency based on the seriousness of the problem, the culture of the community, and potential legal implications. At the least, a transit agency will need to define a process that involves the community for determining where and when its turn warning system will be active/inactive.

Technology Effectiveness

Beyond demonstrating the technologies, a major objective of this project was to determine technology effectiveness. Another objective was to develop benefit and cost estimates associated with the turn warning systems to assist other agencies considering the acquisition of similar technologies. Subjective assessments of system effectiveness were recovered from the operator and pedestrian surveys and focus groups, interviews with TriMet management and other personnel, and an analysis of pedestrian behaviors. A more objective analysis was conducted to estimate the benefits and costs associated with the turn warning systems.

Overall, bus operators were generally less favorably impressed with the effectiveness of the systems than was the general public. From the daily surveys, fewer than half of operators thought the systems were effective at alerting pedestrians, and fewer than one third thought the systems were effective at reducing close calls. In contrast to operator perceptions, the pedestrian survey revealed that a fair majority of pedestrian respondents felt that the systems were effective at both alerting pedestrians and improving pedestrian safety.

Two caveats surfaced with respect to system effectiveness—one related to the impact of pedestrian distraction on effectiveness and the other related to the sustainability of the effectiveness of the warnings. According to most operators, pedestrians often are not paying attention and/or are engaged with electronic devices, and these behaviors render the systems ineffective. Furthermore, many operators felt that any initial effectiveness of the systems may be only temporary, as they will eventually begin to blend into the background and/or people will "tune them out." Finally, there was concern that some operators may begin to rely on the system and become less vigilant, in which case safety might be compromised rather than improved.

Regarding the effectiveness of the systems in affecting pedestrian behaviors, overall, operators reported that they observed some changes, but probably not as much as hoped, which was verified through the selected observations of pedestrian-bus interactions via the field behavioral analysis. In addition, most operators agreed that the turn warning systems had far less of an effect on cyclist behaviors than on pedestrian behaviors.

The results suggest that operator assessments of the systems were driven by multiple, sometimes confounding, and (in some cases) controllable factors. In other words, as this was not a controlled test in which all combinations of factors could be tested, at least some of the decisions made at the beginning of the demonstration test likely influenced the outcomes described above. Bigger issues may have been those associated more directly with the individual systems, such as warning activation and an automatic volume adjustment feature; however, these issues emerged more as a result of the focus group discussions, as there were no significant differences between the systems, based on operator responses to the effectiveness questions on the comprehensive survey.

Regarding the BUS blank-out sign, a little more than half of the respondents found the sign to be effective at alerting pedestrians that a bus is turning and at improving pedestrian safety, and a surprising 23% reported that the sign had helped them avoid a collision with a bus.

While subjective assessments can provide some insight into the effectiveness of the systems and are certainly important for understanding the nuances of the systems, estimations of the benefits and the costs of the systems can help to interpret effectiveness in more objective terms. The benefits and costs of a generic warning system (not specific to any one system tested, but based on actual costs and overall imputed benefits) were developed for three scenarios: a baseline scenario, a minimum scenario, and a maximum scenario, which covered the maximal range of monetary outcomes that could be reasonably expected for the warning systems based on information recovered during the test and otherwise available at the time.

The results showed that the baseline scenario yielded net present value benefits approaching $3 million overall for the 45 warning systems in the demonstration test, or about $65,300 per bus/warning system. The associated internal rate of return on the warning systems investment for this scenario exceeded 34%, which translates into a payback period of about three years. All three scenarios yielded net positive benefits, covering a fairly considerable range, with net present benefits from the maximum scenario more than 12 times greater than those from the minimum scenario.

Acceptance of Technologies

Even if the technologies prove effective at increasing awareness and improving safety, their ultimate success hinges on whether they are accepted by bus operators, the general public, and transit agency personnel. As in other areas, the findings related to acceptance of the technologies were mixed.

Nearly half of the operators surveyed agreed that the potential safety benefits outweighed the drawbacks of the warning systems; however, overall, only about one-third agreed with the prospect of wider deployment. The general sentiment among the operators regarding further deployment of the turn warning systems can be described as ranging from apathetic to skeptical. Most seemed to have adapted to the presence of the warnings, but neither strongly supported nor completely rejected the idea of their continued or expanded use. When considering the prospect of system improvements, only some of the operators became more supportive of the idea. In contrast, a majority of pedestrian survey respondents agreed that the potential benefits of the systems outweighed any associated drawbacks and that more systems should be installed.

Regarding impact on quality of life, median impact ratings among operators indicated that the turn warning systems had little impact on daily work life quality, with more reporting an improvement in daily work life quality than those reporting a decline. From the public's perspective, overall, two-thirds of respondents did not find the warnings to be intrusive to the environment. Both operators and pedestrians were supportive of further deployment of the BUS blank-out sign.

Recommendations for Improving Technologies

Most operators that participated in the focus groups agreed that the manufacturers of the turn warning systems still needed to "tweak" the systems and "get the bugs out." While the desire for some level of operator control over the system was expressed, almost all agreed that total operator control was not a good idea. The requests for operator control stemmed from the desire to be able to activate the warnings in situations beyond turns and to adjust the volume of the warnings to be appropriate to the surroundings.

Additionally, the majority of operators agreed that an improved system would involve tying warning activation to the turn signal (as opposed to the rotation of the steering wheel), selecting a lower speed threshold for warning activation (to reduce or eliminate activation of the warnings in sharp curves and during lane changes), and activating the warnings only when the wheels are moving. The only counter concern expressed was that some operators may not use their turn signal to avoid hearing the warning. Beyond these recommendations, a recommendation heard from both operators and pedestrian participants was for a system that is even smarter and more "programmable" via integration with the buses' GPS/AVL system. This approach would allow an agency to program the system to activate only when/where necessary, as well as at the appropriate volume level, to avoid overuse of the warnings.

Closing Thoughts

Approaching zero deaths from pedestrian/cyclist-bus collisions will take commitments on multiple fronts. Technology is not a panacea; rather, it is one tool in an array of strategies that transit agencies should consider when working to improve safety. In addition, it is important that technologies be employed properly and updated periodically to meet the changes in the environment, including maintaining buy-in from and collaboration with the community and operators. Perhaps the collective message and take-away from this study is that, although the findings indicate that the warning technologies can make a meaningful and cost-effective contribution to safety, there is still more to be done to deal effectively with this problem.

SECTION 1

Introduction

According to the National Highway Traffic Safety Administration (NHTSA), 4,735 pedestrians died in traffic crashes in 2013.[1] Although only a small percentage of these crashes were between buses and pedestrians/cyclists, and although pedestrian and cyclist injuries and fatalities are few in number relative to those resulting from motor vehicle collisions, when a transit bus hits a pedestrian or cyclist there is generally a very high cost to the transit agency (injury claims, service interruptions, and lawsuits). In addition, pedestrian/cyclist-bus collisions usually attract intense negative media coverage and have the potential to reduce the public's perception of transit safety.

A variety of factors may contribute to bus collisions with pedestrians/cyclists, including the characteristics of bus turns, bus design features, visual obstructions, pedestrian size and speed, limited lighting, failure of operators to adequately scan for pedestrians, operator attention to opposing traffic during left turns, and pedestrian inattention and distraction, to name a few. Transit agencies have implemented a wide range of safety countermeasures to address these and other issues; however, collisions between buses and pedestrians/cyclists continue to occur.

Many agencies are looking at pedestrian warning systems as an approach to help address the issue of pedestrian/cyclist safety. For those systems that are now commercially available, there is a lack of understanding of the associated advantages and disadvantages as well as a lack of empirical evidence regarding their effectiveness. Thus, transit agencies lack the information needed to make informed decisions about investments in these systems and, if they do decide to make the investment, what they can expect in return.

In 2013, the Federal Transit Administration (FTA) entered into a cooperative agreement with Applied Engineering Management Corporation (AEM), the Tri-County Metropolitan Transportation District of Oregon (TriMet), and Portland State University (PSU) to conduct a field demonstration test and evaluation of three commercially-available vehicle-based turn warning systems and an infrastructure-based crosswalk warning sign. This report provides the details of this demonstration test and the findings from a robust evaluation of the technologies.

Goals of Demonstration Test and Evaluation

The goals of the demonstration test and evaluation included the following:

- Demonstrate the ability of several commercially-available turn warning systems to provide timely warning to pedestrians/cyclists that a bus is turning, pulling into a bus stop, or pulling out of a bus stop.
- Demonstrate the ability of an innovative crosswalk warning sign to provide timely warning to pedestrians/cyclists that a bus is turning.
- Demonstrate the ability of a directional LED headlight system to increase the visibility of pedestrians at night.
- Define the environmental parameters under which advance warning should be provided to pedestrians/cyclists at intersections and at bus stops.
- Determine the effectiveness of the various technologies in terms of the following:
  - Bus operator perceptions and acceptance
  - General public perceptions and acceptance
  - Perceptions and acceptance of other TriMet personnel and management
  - Getting pedestrian/cyclist attention and impacting behaviors
- Develop benefit and cost estimates associated with the turn warning systems.

Organization of Report

Beyond this introductive section, this report contains the following sections:

- **Section 2: Description of Technologies** provides a detailed description of each of the technologies assessed/tested and evaluated during the demonstration project.
- **Section 3: Test Approach** presents the feedback from interviews from other transit agencies that had tested/implemented turn warning systems and how this feedback impacted the approach for this demonstration test. In addition, the section details the test approach, including test routes, number of systems used in the test, and duration of the test.
- **Section 4: Evaluation Approach** presents the methodology used to evaluate the technologies that were tested. Although the methodology was similar across the different technologies, each approach was tailored to each technology.
- Section 5: Data Collection Approach presents the data collection approach(es) that corresponded to each of the evaluation objectives. In addition, each approach (bus operator and pedestrian surveys and focus groups, field observational study of pedestrian/cyclist behaviors, interviews

with other TriMet staff, and analysis of the benefits and costs associated with the turn warning systems) is described in detail.

- **Section 6: Operator Perceptions and Acceptance of Technologies** describes the findings from a daily survey of bus operators, a comprehensive survey of operators, and follow-up focus groups.
- **Section 7: Pedestrian/Cyclist Perceptions and Acceptance of Technologies** describes the findings from a field intercept survey and follow-up focus groups with pedestrians and cyclists.
- **Section 8: Pedestrian and Cyclist Behaviors** presents the findings from the analysis of pedestrian/cyclist behaviors via videos taken at selected intersections in Portland.
- **Section 9: TriMet Perceptions, Acceptance, and Institutional Issues Associated with Technologies** summarizes the feedback received from interviews with TriMet staff that played a critical role in the demonstration test and evaluation.
- **Section 10: Analysis of Costs and Benefits** presents the findings from a benefit-cost analysis of the turn warning systems for three scenarios (baseline, minimum, and maximum), as well as current market cost estimates for a generic turn warning system.
- **Section 11: Summary Discussion** brings together the findings of the demonstration, information gained from other agencies' experiences with turn warning systems, and a scan of the potential offered by emerging technologies. Together, the integration of knowledge gained from these sources should assist the reader in understanding the full spectrum of implications associated with the implementation of the technologies.

SECTION

2

Description of Technologies

This project included the assessment, testing, and evaluation of several bus-based technologies and one infrastructure-based technology for warning pedestrians of a turning bus. In this section, each technology is described as it was at the time of assessment and testing in 2013. Recognizing that advancements have been made in some of the technologies since that time, these advancements are described briefly in Appendix A, which also addresses current system costs.

Bus-Based Technologies – Turn Warning Systems

Four bus-based turn warning systems were assessed, three of which were tested and evaluated as part of this demonstration project. This section presents a description of the different technology approaches employed for each of the four systems, as well as the various components associated with the systems. It should be noted that it is the intent of this report to present an objective look at the various technologies available, from technology approach to cost to findings; as such, the names of the manufacturers of each system have been excluded.

System A

System A is a commercially-available turn warning system that provides an external auditory warning to pedestrians and other road users when a bus makes a left or right turn. Using sensors attached near the pitman arm (Figure 2-1), the system automatically plays the auditory warning when the bus steering wheel turns the pitman arm past a pre-selected angle, which can be customized through mechanical adjustments under the bus.[2]

Figure 2-1

Pitman arm sensor associated with System A

The type, length, and frequency of the auditory warning also can be customized. Using standard computer sound files, the warning can be developed by an agency and installed onto the system's electronic computer unit (ECU), which is housed inside the bus behind the bus operator cabin. The auditory warning can be a verbal message or a sound/tone, can vary in length, and can be set to play only once or multiple times during the turn.

This system also has a maximum speed threshold feature that can be used to prevent the warning from being broadcast during a normal lane change or other turn of the steering wheel that might move the pitman arm past the system sensors. In this case, the system would be deactivated at speeds over a pre-set maximum speeds threshold.[3]

System A uses one or more external speakers. The system can be installed to work with existing external speakers, or speakers can be installed with the system.[4] Additionally, the system has an automatic outside speaker volume adjustment feature. Based on four ambient noise levels, a microphone measures the ambient noise and adjusts the volume of the warning accordingly.

System A also features optional LED warning strobe lights on the sides of the bus (Figure 2-2). The strobe lights flash simultaneously with the auditory warning.[5]

Figure 2-2

LED strobe light associated with System A

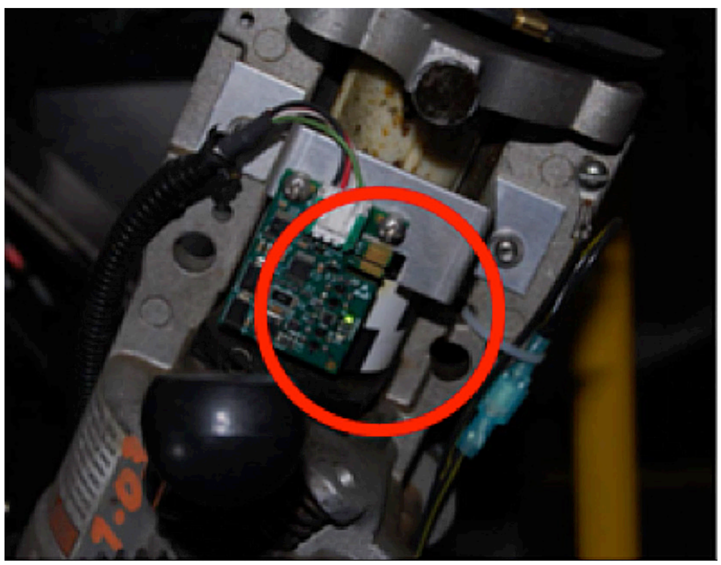
In addition to the system/features described, other features of System A were available but were not included in the demonstration. These features included an internal auditory warning for bus operators and geo-fencing capabilities. The purpose of the internal auditory warning is to remind bus operators to look for pedestrians or to be aware of potential conflicts while turning. The geo-fencing feature allows an agency to disable the auditory warning in specified geographic areas using an infrastructure-based radio-frequency (RF) antenna or a connection to an existing on-board global positioning system (GPS).

System B

System B is a commercially-available turn warning system that provides an external auditory warning to pedestrians and other road users when a bus makes a left or right turn. System B differs from System A in the way in which the auditory warning is activated. System B uses an optical sensor and a sticker with a checkboard pattern that is affixed to the column of the steering wheel (Figure 2-3). The auditory warning is triggered when the steering column rotates past a pre-determined angle and the vehicle speed is below a maximum threshold. The angles represent the number of degrees that the steering wheel turns clockwise (right turn) or counterclockwise (left turn). Different checkerboard patterns are used to activate the warning at more/less rotation of the steering wheel; adjustments to the activation angles can be made by replacing the checkerboard sticker on the steering column with a different pattern.[6]

Figure 2-3

Steering column optical sensor associated with System B



The type, length, and frequency of the auditory warning can be customized. Using standard computer sound files, the warning can be developed by an agency and installed onto the system's ECU, which is housed inside the bus behind the bus operator cabin. The auditory warning can be a verbal message or a sound/tone, can vary in length, and can be set to play only once or multiple times during the turn.

As previously mentioned, this system has a maximum speed threshold feature that is used in combination with the rotation of the steering column to trigger the auditory warning. This feature prevents the warning from being broadcast during a normal lane change or other turn of the steering wheel that otherwise would actuate the warning.

System B uses one or more external speakers. The system can be installed to work with existing external speakers, or speakers can be installed with the system.[7] Additionally, the system has an outside speaker volume adjustment feature that uses temporal zone inputs or spatial inputs from GPS. This feature can be used to automatically adjust the volume of the warning or to completely disable the warning based on the time of day or the geographic location of the bus.[8]

In addition to the system/features described, other features of System B were available but not included in the demonstration. These features, which are similar to those of System A, include an internal auditory warning for bus operators, an automatic volume adjustment feature based on ambient noise levels,[9] and geo-fencing capabilities using GPS.[10]

System C

System C is commercially-available and is primarily a directional LED headlight system. The directional LED headlights are housed with the main headlights and are activated via use of the turn signal (Figure 2-4). When illuminated, these LED headlights aim in the direction of the turn (either right or left) and provide an additional 35-degree viewing angle (Figure 2-5). The directional LED headlights also provide illumination on the pavement up to 35 feet without causing any glare to oncoming vehicles.

Figure 2-4

Directional LED headlights associated with System C

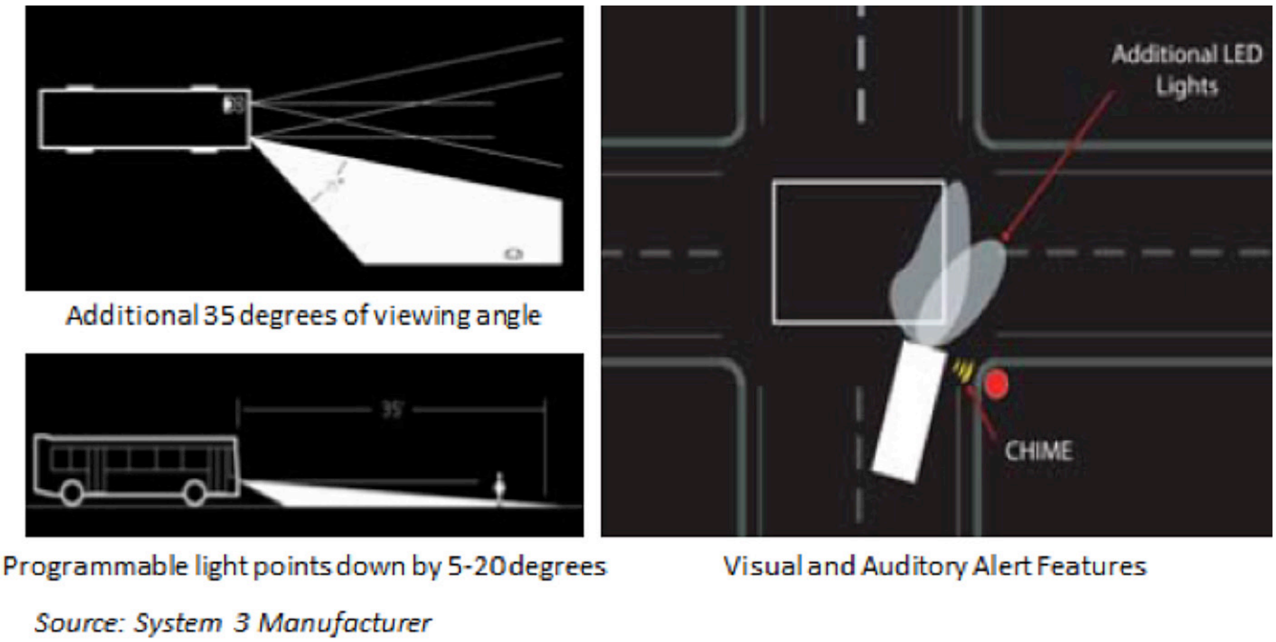


Figure 2-5

Auditory warning and visual enhancement system associated with System C

In addition to the directional LED headlights, System C also features an auditory turn warning system, which can be left inactive, if desired. When the turn warning feature is active, the auditory warning is triggered via use of the turn signal. The auditory warning will not activate when the brake pedal is depressed. This feature allows the bus operator to engage the turn signal while waiting at a traffic signal without the auditory warning being activated. The directional LED headlights are always active when the main headlights and turn signal are active.

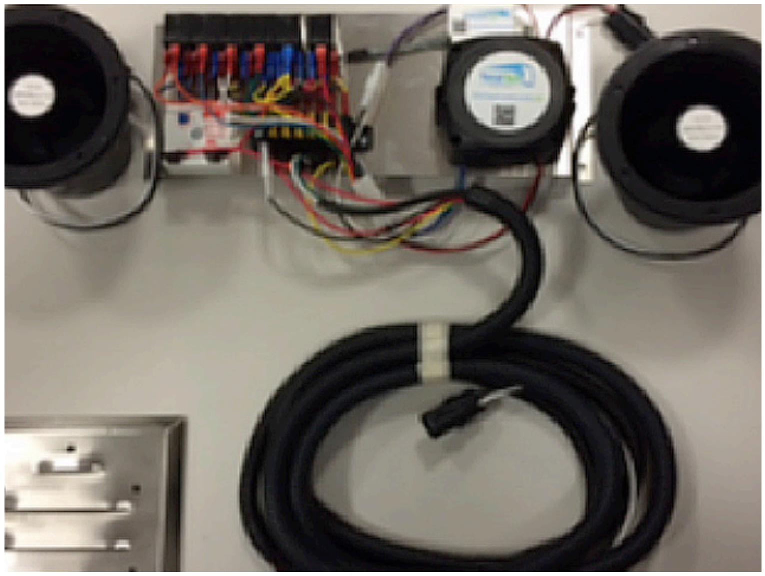
As this system comes installed on new buses and is not available for retrofit, the auditory warning is customizable only at the time of order (i.e., it is hardwired into the system). Ordinarily, the warning is a "chime" similar to that of a door bell. If this chime is not included in the bus order, the turn warning system can be tied into any hardware system on the bus that has associated noises and then can be activated with a simple computer program. Prior to the demonstration, TriMet already had buses installed with System C and was using the directional LED headlights, but not the turn warning feature. As the chime warning had not been included on the buses, for this demonstration, the system was tied into the ADA system, and the auditory warning was the same "beeping" sound that is used when deploying the lift/ramp or when the bus is kneeling.

System D

System D is a commercially-available turn warning system that provides an external auditory warning to pedestrians and other road users when a bus is making a left or right turn. The auditory turn warning is triggered via use of the turn signal. This system is hardware-based and ties directly into a bus's existing electronic system (Figure 2-6).

Figure 2-6

Hardware associated with System D



The type, length, and frequency of the auditory warning can be customized. The auditory warning can be a verbal message or a sound/tone, can vary in length, and can be set to play only once or multiple times during the turn. As these changes can be made only via hard programming by the manufacturer, the agency must determine the initial warning specifications prior to shipment. If the agency determines a change is needed to the type, length, or frequency of the warning after installation on the bus, it must return the ECU portion of the system to the manufacturer to be reprogrammed.

This system has a maximum speed threshold feature that can be used in combination with the turn signal to prevent the warning from being broadcast during a normal lane change or in other situations when the turn signal is in use but the bus is not turning. Additionally, the system will not activate the auditory warning when the brake pedal is depressed. This feature allows the bus operator to engage the turn signal while waiting at a traffic signal without the auditory warning being activated.

Two external speakers come with the ECU; however the system can accommodate more than two speakers if desired. The volume of the speakers can be manually adjusted using a dial on the back of the ECU.

System D was developed by a transit agency with requirements to address the specific needs of the agency. In particular, the agency was looking for a simple, inexpensive technology approach to improve pedestrian safety. It was designed to be a stand-alone system and was meant to be used with the speakers that come with the system. As such, the system is not easily integrated with speakers already existing on a bus. This issue prevented TriMet from including this system in the demonstration test.

Infrastructure-Based Technology – BUS Blank-Out Sign

In addition to the bus-based systems, the potential use of an infrastructure-based technology to warn pedestrians and cyclists of a turning bus also was investigated. The concept behind the BUS blank-out sign is to provide a visual warning to pedestrians that a bus is turning at an intersection through the subject crosswalk. The researchers conceived of the sign, and TriMet designed and built the sign in cooperation with the City of Portland Bureau of Transportation.

When power is supplied to the unit, the word "BUS" is displayed with 68 yellow LEDs set on 0.5-inch centers with a character height of 4 inches (Figure 2-7). The word "BUS" flashes at a rate of once per second (0.5 seconds on, 0.5 seconds off). Two prototype signs were built for this demonstration project. The signs were mounted in standard 12-inch signal heads, which had a clear-finish, polycarbonate, protective lens. The signs were positioned above the pedestrian signal heads on either end of one crosswalk (Figure 2-8). The signs were activated using standard traffic control equipment at the intersection.

Figure 2-7

Drawing of LED blank-out warning sign

Figure 2-8

Prototype BUS blank-out sign mounted above pedestrian signal head

The signs could be configured to activate during protected left turns, permissive left turns, right turns, or all of the above, depending on the intersection and movements of interest. If the signs were used to warn pedestrians of a protected left-turn movement through a crosswalk, they would be active during the pedestrian DON'T WALK. On the other hand, if the signs were used to warn pedestrians of permissive left turns and/or right-turns (on green), they would be active during the pedestrian WALK and/or flashing DON'T WALK. For this demonstration test, the BUS blank-out signs were used only to warn pedestrians that a bus was making a protected left turn through the treated crosswalk (Figure 2-9).

Figure 2-9

BUS blank-out sign at SW 5th and W Burnside.

SECTION

3

Test Approach

This section describes the approach that was used for the demonstration test. The general approach was to operate a number of buses equipped with each of the turn warning systems previously described across the TriMet service area for a period of not less than six months. The approach was driven by a number of issues, including:

- The burden placed on TriMet to install and maintain the turn warning systems, as well as to manage the assignment of the equipped buses daily throughout the test period
- Equipping a sufficient number of buses for a long enough period of time to provide sufficient exposure of the systems
- Overall project budget
- Overall length of project
- Experiences of other transit agencies that tested/implemented these and other similar technologies

Turn Warning Systems

The first step was to conduct telephone interviews with transit agencies that had experience with turn warning system technologies. In some cases, the transit agencies had purchased and tested a small number of systems, while in other cases the transit agencies had installed large numbers of systems, including fleet-wide implementations. In either case, the experiences and lessons learned by the agencies were helpful in identifying important issues for consideration prior to and during this demonstration test.

Six agencies were selected for interviews based on the type of turn warning system tested or used, as well as the size and location of the agency. These agencies included:

- Greater Cleveland Regional Transit Agency (GCRTA), Cleveland, Ohio
- Greater Richmond Transit Company (GRTC), Richmond, Virginia
- New Jersey Transit (NJT), New Jersey
- Washington Metropolitan Area Transit Authority (WMATA), Washington, DC
- PACE Transit, suburban Chicago, Illinois
- Metro Transit, Madison, Wisconsin

Telephone interviews were conducted with all six agencies in May and June 2013. A brief overview of responses is shown in Table 3-1. All responses represent information that was reported at the time of the interviews (e.g., system costs, years installed).

The interview information provided a baseline for what could be expected in terms of system costs, operator and public response to the systems, maintenance issues, and considerations for improving system effectiveness. The interviews also provided options for warning messages, as the warning messages for System A and System B were customizable.

Table 3-1

Overview of Agency Responses

Agency	# of Units	Time Since Installation	Costs (per bus)	Warning	Findings	Maintenance	Ways to Improve
GCRTA	380	3 yrs	~$1,600	"Caution, look both ways. Pedestrians, bus is approaching; bus is approaching."	Activation issues – if set too tight, comes on all the time. Improper turns trigger warning too early. No LT or RT collisions since installation. Operators ~80% acceptance.	As an early adopter of the technology, worked through "bugs" (processor, failures, roadside speaker microphone). Updates have resolved most issues.	Have speakers only on left and right. Also need them in front for better coverage.
GCRTA	2	1 yr	~$1,900	"Caution, look both ways. Pedestrians, bus is approaching; bus is approaching."	In testing	No information provided.	None offered.
GRTC	120	2 yrs	$300	"Caution, bus moving left/right. Pedestrians look both ways."	Operators initially complained about volume. Customer feedback was positive. Favorable media coverage.	No information provided.	None offered.
NJ Transit	2,500	< 1 yr	$900 (already had speakers and ECU)	"Caution, bus turning."	Public complaints from residential areas at night.	No repairs. Some operator vandalism. Adjusted ambient noise sensors due to complaints.	Tied into CAD/ AVL, so agency has capability to log data and monitor system. Should be available in stand-alone systems.
WMATA	10	2 yrs	$2,500, $489 installation	"Caution, pedestrians, bus is approaching." "Pedestrians, bus is turning." Clicking noise	Operators ~70 approval. Public complaints about noise and WMATA not spending money wisely.	No repairs. Some operator vandalism.	Improve auto ambient noise adjustment. Fine line for timing of warning activation. Evaluating strobe light.
PACE	50	7 mos	Not provided	"Caution, bus is turning."	In testing	No repairs. Adjustments/ fine-tuning.	None offered.
Metro	35	1 yr	$61 parts, $329 labor	Beeping noise	Not long enough to say if improves safety but people do look up and notice if not distracted.	None. Trying to find a balance between volume and location of speakers to optimize noise level.	Would like option of voice message.

After discussions with TriMet and FTA, the specific approach to the demonstration test was to equip 15 buses with each of the 3 turn warning systems (45 total buses) and to assign these 45 buses daily on pre-selected routes during a 7-month test period. This approach balanced the burden placed on TriMet to conduct/manage the demonstration with the total exposure of the systems in an operational environment, as well as the overall project budget and timeframe.

Several criteria were used to select the routes on which to test the 45 turn warning systems:

- Routes served by buses deployed from TriMet's Center Street maintenance facility
- Number of left/right/total turns on route
- Passenger boarding and alighting counts
- Environmental characteristics of route
- Level of pedestrian activity

The primary criterion for route selection was the number of new buses assigned to TriMet's Center Street maintenance facility. Just prior to developing the test approach, TriMet received a new bus order, and a majority of those buses were assigned to the Center Street facility. This new fleet of buses came equipped with System C. TriMet made the decision to install System A and System B on the new buses. Therefore, the routes served from the Center Street maintenance facility were the best candidates from which to select test routes. As all new buses were equipped with System C, both the directional LED headlights and the auditory turn warning feature were disabled on the buses that were equipped with Systems A and B.

Beyond the maintenance facility, the number of left/right/total turns was the most important criterion for selecting test routes—the more turns along a route, the more times the turn warning systems would be activated. An analysis of TriMet's bus routes served by the Center Street maintenance facility yielded five routes that offered a balance of turns, passenger activity, and environmental characteristics, including pedestrian activity. A summary of the characteristics of the selected test routes is shown in Table 3-2. A map of the test routes is shown in Figure 3-1.

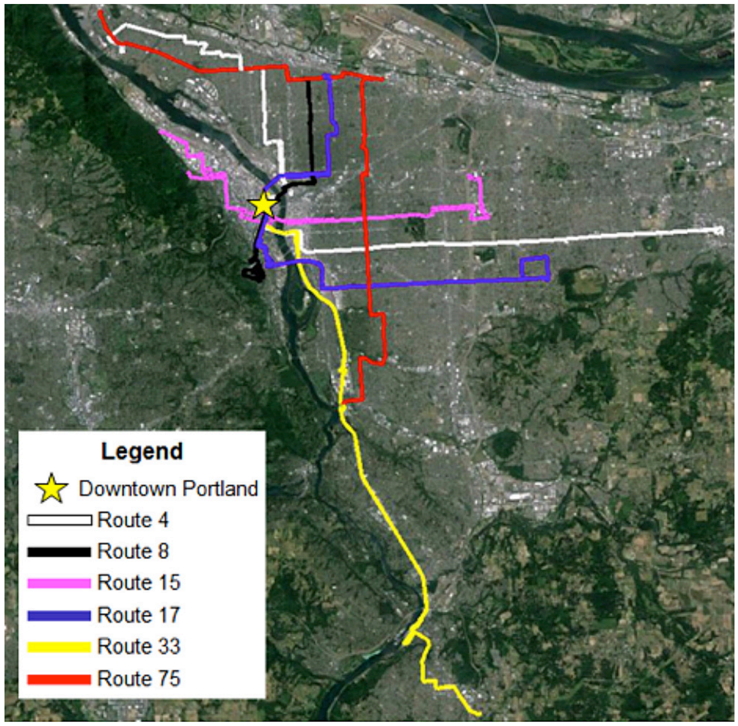
Table 3-2

Characteristics of Selected Test Routes

Bus Routes	Buses from Center Street Maintenance Facility	Buses from Other Maintenance Facilities	Total Buses	Weekly Left Turns (avg. per bus)	Weekly Right Turns (avg. per bus)	Total Weekly Turns (avg. per bus)	Weekly Passenger Counts	Environmental Characteristics
8	17	0	17	594	251	845	6,466	Generally north-south route that traverses transit mall. Main residential areas are in north section of route, remaining portions generally through central business district (CBD) and other commercial/ non-residential areas; southern portion at medical complex.
15	6	15	21	558	209	768	4,667	Generally east-west route that traverses CBD. Covers mix of residential and commercial areas. Residential areas in eastern and northwestern portions of route, commercial areas mostly in middle of route (CBD).
33	12	0	12	1,016	468	1,484	7,483	North-south route that traverses transit mall. North end of route in CBD, south end of route outside of Portland in Oregon City, with some residential areas in between.
4	12	22	34	743	231	975	8,908	Route covers northern parts of city, CBD, far eastern portions of city, and suburban areas beyond city limits. Has mix of residential (north and eastern portions of route) and businesses.
75	24	0	24	948	261	1,208	6,211	North-south route on east side of Portland, extending east-west on north side of city. Generally traverses residential portions east of downtown business district.
Total	*71*	*37*	*108*	*3,859*	*1,421*	*5,280*	*33,735*	

Figure 3-1

Map of selected test routes



After selecting the test routes, the 45 test buses were distributed across the routes. Each route was assigned an equal number of each of the turn warning systems; however, this number was not consistent across the routes. Rather, the total number of test buses had to be balanced with the total number of buses on the route and the number of buses deployed daily from the Center Street maintenance facility. Table 3-3 shows the daily bus assignments for each bus route.

Table 3-3

Daily Bus Assignments

Bus Routes	Buses per Route	Buses with System A	Buses with System B	Buses with System C	Total Buses with Turn Warning Systems
Route 8	17	3	3	3	9
Route 15	21	2	2	2	6
Route 33	12	3	3	3	9
Route 4	34	3	3	3	9
Route 75	24	4	4	4	12
Total	*108*	*15*	*15*	*15*	*45*

This bus assignment table was provided to the TriMet bus yard spotters to increase the likelihood that the planned number of test buses would be assigned to each test route each day. Although every effort was made to assign buses according to the test plan, there were days, due to required maintenance and/or or fleet management needs, when one or more test buses were assigned to a non-test route or not assigned at all. During the course of the evaluation, the bus assignments were monitored to ensure that a majority of the test buses was being assigned according to the test plan. Overall, most of the buses were assigned appropriately, with a low non-assignment rate.

About midway through the test period (end of June 2014), TriMet re-assigned the test buses from Route 8 to Route 17. This reassignment was due to public complaints, most of which originated from one particular neighborhood along Route 8.[11] Table 3-4 summarizes the characteristics of Route 17 in terms of weekly turns, passenger counts, and environmental characteristics.

Table 3-4

Route 17 Characteristics

Buses from center street maintenance facility	13
Buses from other maintenance facilities	4
Total buses	17
Weekly left turns (avg. per bus)	479
Weekly right turns (avg. per bus)	317
Total weekly turns (avg. per bus)	796
Weekly passenger counts	5,509
Environmental characteristics	Route is mix of NS and EW; northern portion in residential areas not far from airport. Traverses transit mall (and CBD), runs through southeastern residential areas on east side of river.

In addition to defining the number of systems to be tested and the routes on which to test the systems, more specific decisions were made regarding system features and configurations. Features such as warning message, trigger angles, speed thresholds, and volume level were defined by TriMet, some before the systems left the manufacturer. To help inform these decisions, the research team looked to the experiences of the six transit agencies that were interviewed prior to the test. For example, TriMet was not sure of what warning message to use for systems whose warnings were customizable. Based on the warnings used by other agencies, how the messages had evolved, and the agencies' experiences, the following messages were selected for each system:

- System A – "Pedestrians, bus is turning" (customizable)
- System B – "Caution, bus is turning" (customizable)
- System C – Beeping noise associated with ADA system (not customizable)

The volume setting was also an important variable that was considered by TriMet and the research team. The factory volume level setting of about 80 decibels was used initially. Shortly after the demonstration test began, TriMet began receiving complaints from both the bus operators and residents along some of the routes regarding the warning volumes. In response, and with assistance from the City of Portland's Noise Control Program, which handles the evaluation of residential noise complaints, the volume was set to about 70 decibels as measured 25 feet from the bus. Complaints continued during the evening hours; therefore, the volume for System B was lowered to about 60 decibels between the hours of 9:00 PM and 7:00

AM. Because System A did not have a nighttime mode at the time of the test, the volume was set to about 60 decibels for all hours of operation.

BUS Blank-Out Sign

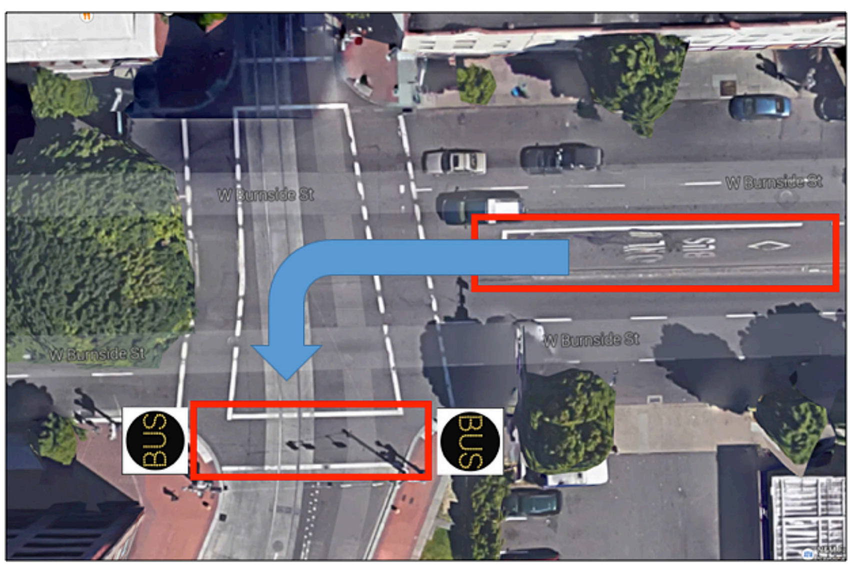
The test approach for the BUS blank-out sign was to install two signs at one crosswalk at one signalized intersection in Portland. The selection criteria for the signalized intersection included:

- High level of pedestrian activity
- Presence of left- and right-turning buses with and without turn warning systems
- Protected left-turn phase for buses

The site selected for the installation and evaluation of the BUS blank-out sign was the intersection of SW 5th Avenue and W Burnside Street, which was selected because it met all of the selection criteria. The intersection is located in the CBD and experiences high pedestrian volumes. In addition, buses make both left turns and right turns at this intersection—eastbound buses on Burnside Street make right turns onto southbound 5th Avenue, and westbound buses on Burnside Street make left turns onto southbound 5th Avenue. In the latter case, there is a bus-only left-turn lane. When buses are in this lane, they are detected via an inductive loop detector, which sends a message to the signal controller that a bus is waiting to turn. This provided a straight-forward way to also activate the BUS blank-out signs. In the case of a protected left turn, the corresponding pedestrian signal head displays DON'T WALK. Figure 3-2 is an aerial photo of the intersection indicating the bus-only left-turn lane, the treated crosswalk, and the location of the signs.

Figure 3-2

BUS blank-out signs at SW 5th & W Burnside



Originally, the test approach was to also include testing the sign during right turns, which would correspond to the WALK and the flashing DON'T WALK (or clearance phase) of the pedestrian signal head. However, as there were no existing communications between the bus and the traffic signal controller, there was no straightforward way to activate the BUS blank-out signs for right-turning buses. Although a few options were explored both by TriMet and the City of Portland, all proved to be too costly or time-consuming for this demonstration test.

SECTION 4

Evaluation Approach

This section provides the details of the approaches used to evaluate the turn warning systems and the BUS blank-out sign.

Goals of Demonstration and Evaluation

In addition to demonstrating the technologies, a major goal of this project was to conduct a detailed evaluation, including both quantitative and qualitative analyses, of the effectiveness of the technologies and to identify lessons learned. As previously stated, the specific goals of the demonstration test and evaluation included the following:

- Demonstrate the ability of the selected turn warning systems to provide timely warning to pedestrians/cyclists that a bus is turning, pulling into a bus stop, or pulling away of a bus stop.
- Demonstrate the ability of an innovative warning sign to provide timely warning to pedestrians/cyclists that a bus is about to turn.
- Demonstrate the ability of a directional LED headlight system to increase the visibility of pedestrians at night.
- Define the environmental parameters under which advance warning should be provided to pedestrians/cyclists at intersections and at bus stops.
- Determine the effectiveness of the various technologies in terms of the following:
  - Bus operator perceptions and acceptance.
  - General public perceptions and acceptance.
  - Getting pedestrian/cyclist attention and impacting behaviors.
- Develop benefit-cost estimates associated with the turn warning systems.

The evaluation approach was developed by linking the overall goals of the demonstration test to measurable technical objectives for each technology to be evaluated (turn warning systems, LED directional headlight system, and BUS blank-out sign). To meet these technical objectives, a wide range of data collection and analysis methods was employed. A slightly different evaluation approach was developed for each technology. Each approach is presented below.

Evaluation of Turn Warning Systems

All three turn warning systems tested provide an auditory warning to pedestrians when a bus is making a left or right turn and, depending on the system and/or bus stop configuration, the systems also may provide warnings when pulling into and/or away from bus stops. These systems were designed to increase the safety of pedestrians by making them more aware of the presence of turning buses. Although a pedestrian has the right-of-way when crossing in the crosswalk during the pedestrian WALK phase or at uncontrolled intersections, a number of factors can contribute to either the bus operator not being aware of the pedestrian or the pedestrian not being aware of the bus. Therefore, the turn warning systems can help alert pedestrians of turning buses and potentially reduce the number of bus-pedestrian conflicts and collisions.

The technical objectives of the evaluation of the turn warning systems were to:

- Assess bus operator perceptions and acceptance of the systems.
- Assess pedestrian and cyclist perceptions and acceptance of the systems.
- Assess pedestrian and cyclist behaviors associated with the systems.
- Assess pedestrian/cyclist-bus conflicts before-and-after and with-and-without the systems.
- Assess institutional issues with and acceptance of turn warning systems among TriMet management.
- Develop benefit and cost estimates associated with the systems.

Table 4-1 presents the hypotheses tested and the measures of evaluation (MOEs) and data sources used to evaluate each evaluation objective.

Table 4-1

Evaluation of Turn Warning Systems

Evaluation Objectives	Hypotheses	MOEs	Data Sources
Assess bus operator perceptions and acceptance of turn warning systems.	Systems will be perceived positively and accepted/ welcomed by operators.	Acceptance ratings. Perceptions/ ratings of system effectiveness.	Surveys of bus operators. Focus groups with bus operators.
Assess public perceptions and acceptance of turn ning systems.	Systems will be perceived positively and accepted/ welcomed by pedestrians, cyclists, and general public.	Perceptions/ ratings of system effectiveness. Acceptance ratings. Number/frequency of public complaints.	Intercept survey of pedestrians/cyclists. Focus groups with pedestrians/ cyclists. TriMet record of public complaints.
Assess pedestrian and cyclist behaviors associated with turn warning systems.	Systems will increase pedestrian/cyclist awareness of turning buses. Systems will increase pedestrian/ cyclist compliance with traffic signals and laws.	Number/percentage of pedestrians/ cyclists that look at bus before entering or while crossing. Subsequent behaviors after seeing bus (stopping, running, etc.). Compliance with signals/laws.	Naturalistic observations of pedestrian/cyclist behaviors (including observations with and without turn warning systems).
Assess pedestrian/ cyclist-bus conflicts before-and-after and with-and-without turn warning systems.	Systems will reduce number of pedestrian/ cyclist-bus conflicts during left and right turns at intersections and pulling into/out of bus stops.	Number of pedestrian/ cyclist-bus conflicts before-and-after and with-and-without systems.	Operator-reported conflicts before-and-after and with-and-without systems.
Develop benefit and cost estimates associated with turn warning systems.	Systems will have positive net benefit.	Lifecycle costs of systems (including capital costs, installation, maintenance). Number of systems requiring maintenance.	TriMet maintenance records. Supplier costs. TriMet costs to install and maintain systems. Monetary value associated with system benefits (imputed reduction in collisions).
Assess institutional issues with and acceptance of turn warning systems among TriMet management.	Systems will be perceived favorably by TriMet management.	Perceptions of TriMet managers/ representatives regarding performance and effectiveness of systems.	Interviews with TriMet managers/ representatives.

Evaluation of Direction LED Headlights

Activated with the turn signal, directional LED headlights are designed to assist bus operators with turns at night or in reduced lighting situations, providing them with an additional 35-degree viewing angle during left and right turns, up to a distance of 35 feet on the pavement. In addition to assisting operators during turns, the headlights also should assist operators when pulling into bus stops at night by illuminating the sidewalk on the right side of the bus where pedestrians are waiting. An additional benefit may be realized when pulling out of bus stops at night by illuminating the area to the front and left of the bus where pedestrians might be crossing in front of the bus.

Directional LED headlights come installed on new buses and designed to provide greater visibility, in general. Therefore, the bus operator is in a better position to observe potential conflicts and take appropriate action both during the day and at night with the newly-designed buses.

The technical objectives of the evaluation of the directional LED headlights were to:

- Assess bus operator perceptions and acceptance of the directional LED headlights.
- Assess pedestrian/cyclist-bus conflicts before-and-after and with-and-without the directional LED headlights.
- Assess institutional issues with and acceptance of LED headlights among TriMet management.

Table 4-2 presents the hypotheses tested and the MOEs and data sources used to evaluate each evaluation objective.

Table 4-2

Evaluation of Directional LED Headlights

Evaluation Objectives	Hypotheses	MOEs	Data Sources
Assess bus operator perceptions and acceptance of directional LED headlights.	Directional LED headlights will be perceived positively and accepted/ welcomed by operators.	Acceptance ratings. Perceptions/ratings of system effectiveness.	Surveys of bus operators. Focus groups with bus operators.
Assess pedestrian/, cyclist-bus conflicts before-and-after and with-and-without directional LED headlights.	Directional LED headlights will reduce number of bus-pedestrian/cyclist conflicts during left and right turns at intersections and when pulling into/out of bus stops at night.	Number of pedestrian/ cyclist-bus conflicts before-and-after and with-and-without headlights.	Operator-reported conflicts before -and-after and with-and-without system. Observations of conflicts after implementation (with-and-without system).
Assess institutional issues with and acceptance of directional LED headlights among TriMet management.	Directional LED headlights will be perceived favorably by TriMet management.	Perceptions of TriMet managers/ representatives regarding performance and effectiveness of directional LED headlights.	Interviews with TriMet managers/ representatives.

Evaluation of BUS Blank-Out Sign

The purpose of the BUS blank-out sign is the same as that of the turn warning systems—to provide advance warning to pedestrians and cyclists that a bus is turning. The different is that the BUS blank-out sign is an infrastructure-based, visual warning as opposed to a vehicle-based, auditory warning. The technical objectives of the evaluation of the BUS blank-out sign were to:

- Assess pedestrian and cyclist perceptions and acceptance of the sign.
- Assess pedestrian and cyclist behaviors associated with the sign.
- Assess institutional issues with and acceptance of sign among TriMet and the City of Portland Bureau of Transportation management.

Table 4-3 presents the hypotheses tested and the MOEs and data sources used to evaluate each evaluation objective.

Table 4-3

Evaluation of BUS Blank-Out Sign

Evaluation Objectives	Hypotheses	MOEs	Data Sources
Assess public perceptions and acceptance of sign.	Signs will be perceived positively and accepted/ welcomed by pedestrians, cyclists, and general public	Perceptions/ratings of sign effectiveness. Acceptance ratings.	Intercept survey of pedestrians/cyclists. Focus groups with pedestrians/cyclists. TriMet record of public complaints.
Assess pedestrian and cyclist behaviors associated with sign.	Signs will increase pedestrian/cyclist awareness of turning buses. Signs will increase pedestrian/ cyclist compliance with traffic signals and laws.	Number/percentage of pedestrians/ cyclists that look at bus before entering or while crossing. Subsequent behaviors after seeing sign/bus (stopping, running, etc.). Compliance with signals/ laws.	Naturalistic observations of pedestrian/cyclist behaviors (including observations both with and without signs).
Assess institutional issues with and acceptance of sign among TriMet and City of Portland Bureau of Transportation management.	Signs will be perceived favorably by TriMet and City of Portland Bureau of Transportation management.	Perceptions of TriMet and City of Portland managers/ representatives.	Interviews with TriMet and City of Portland managers/representatives during and after test.

SECTION 5

Data Collection Approach

This section presents the data collection and analysis methods that correspond to each of the evaluation objectives outlined in Section 4. As there were overlapping evaluation objectives across the different technologies, the unique evaluation objectives are listed below:

- Assess bus operator perceptions and acceptance of the technologies (turn warning systems and directional LED headlights).
- Assess public perceptions and acceptance of the technologies (turn warning systems and BUS blank-out sign).
- Assess pedestrian and cyclist behaviors associated with the technologies (turn warning systems and BUS blank-out sign).
- Assess before-and-after and/or with-and-without bus-pedestrian and bus-cyclist conflicts (turn warning systems and directional LED headlights).
- Assess institutional issues with and acceptance of the technologies (turn warning systems, directional LED headlights, and BUS blank-out sign).
- Develop benefit and cost estimated associated with the technologies (turn warning systems).

Assess Bus Operator Perceptions and Acceptance of Technologies

A multi-step approach was employed to assess bus operator perceptions and acceptance of the systems. Two surveys of bus operators were conducted—a daily survey, which was conducted systematically during the first three months of the test period, and a comprehensive survey, which was conducted at the end of the demonstration test. In addition, follow-up focus groups were conducted with a selected number of operators. In general, surveys inquired about bus operators' perceptions and ratings of the performance and effectiveness of the systems, as well as any effects on their day-to-day duties. As follow-up to the surveys, the focus groups provided an opportunity to explore important issues in more depth.

Daily Survey of Bus Operators

The purpose of the daily survey was to uncover operator perceptions of the effectiveness of the turn warning systems immediately following the completion of their assigned daily runs. The survey also helped to identify critical issues associated with the performance and reliability of the systems throughout the test. The survey was administered three days each week over three months of the test period, from the beginning of April 2014 through the end of June 2014. A systematic random sampling approach was used to select the three days each week on which to administer the survey. Surveys were placed in the operators' data packs and, when completed, were returned to the station agent. Operators were asked to respond to questions on the survey based strictly on the experience with the system they had on that day. A copy of the survey instrument is provided in Appendix B.

Over the 3-month survey period, operators of buses equipped with System A and System B were surveyed on 38 sample days. As the deployment of System C was delayed until May 7, 2014, the number of survey sample days for System C was 21. Each day, surveys were placed in all of the available test buses. Overall, 1,234 surveys were distributed, and 436 (35%) were completed and returned. Of these, 177 surveys were completed for System A, 153 for System B, and 106 for System C.

Operator responses to the daily survey were anonymous. Daily bus assignment records, however, provided some information on the respondents and their exposure to the three turn warning systems. Over the 3-month period, 522 operators drove a test bus at least once, and 338 operators drove buses with all 3 of the turn warning systems.

Also, although the identity of respondents was unknown, each completed survey contained the bus identification number, which, in turn, enabled identification of which of the three turn warning systems was installed on a respondent's bus. Knowing this information allowed the research team to assess system-specific differences in the operators' perceptions of the performance and effectiveness of the system on their bus on the survey day. Differences in perceptions were statistically tested using contingency analysis.

The survey date also was included on the survey form, which allowed for trend analyses of the responses over the three-month period. Trends were analyzed through linear regression. Finally, responses from the initial days of survey administration were examined to identify correctable problems with the warning systems (e.g., calibration of the warning activation points or the volume level of the warning itself).

Results from the daily bus operator survey are presented in Section 6.

Comprehensive Survey of Bus Operators

The comprehensive operator survey was administered in late September 2014 at the conclusion of the seven-month field demonstration test. The target sample size for the survey was 200 operators. The operators were selected from run assignment data, which was sorted to identify the "preferred" operators, those with the greatest exposure across the three warning systems and the directional LED headlights during the test period. A two-phased survey approach was employed.

First, a pencil-and-paper version of the survey was administered several hours per day over a one-week period. To make operators aware and request their participation in the survey, TriMet sent out a broadcast, posted a message on reader boards in the operator reporting areas, and set up signs in the operator report area directing operators to the survey station (Figure 5-1). TriMet staff distributed the surveys to the preferred operators as they entered the operators' lounge. To encourage participation, operators were paid for 15 minutes for their time, were offered candy, and were enrolled in a drawing to win one of five $10 gift cards. With this approach, 139 surveys were completed.

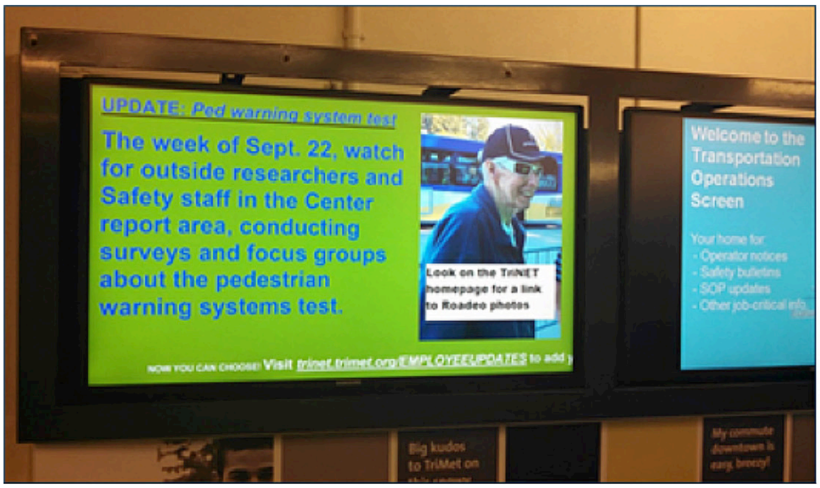


Figure 5-1

Outreach to operators regarding comprehensive survey

Second, 200 surveys were mailed to the residences of the preferred operators that had not already submitted a survey. Incentives included the 15 minutes of pay and enrollment in the drawing for the gift cards. With this approach, 78 additional surveys were completed; however, several were received after the survey period was closed. A total of 208 completed surveys were used in the analyses. All surveys were self-administered. Although operators were identified as having completed the survey, their identity was not connected to individual survey responses.

A copy of the survey instrument is provided in Appendix B.

As with the daily survey, the comprehensive survey served to measure operators' perceptions/ratings of system reliability, effectiveness, and acceptance; however, the objective of the comprehensive survey differed from that of the daily survey in a number of important ways. First, the scope of the survey's questions covered the entire seven-month test period rather than just the operators' assigned runs on the day of administration. Second, the operators who completed the comprehensive survey had the most exposure and, thus, the most experience with all three systems, which enabled them to make direct comparisons of the three warning systems. Third, in addition to the three turn warning systems covered in the daily survey, the comprehensive survey also addressed operator perceptions and acceptance of the direction LED headlights.[12]

Results from the comprehensive bus operator survey are presented in Section 6.

Focus Groups with Bus Operators

The purpose of the focus groups was to further explore the most important issues associated with the systems and, in particular, those issues that stood out from responses on the daily bus operator surveys. Four focus groups were conducted with a selected group of bus operators in September 2014. TriMet selected bus operators for the focus groups, as potential participants were "on the clock." A TriMet bus operations manager determined which operators would be available and assigned them to one of four different focus groups. Operators with the most exposure to the turn warning systems were selected first, when available. A total of 27 operators participated in the four focus groups, which were held at TriMet's Center Street maintenance and operations facilities. Each focus group lasted about 90 minutes, and the operators were paid at their normal hourly rate for their time.

A structured focus group guide was developed to assist the facilitator in keeping the participants focused on the issues and topics at hand. A slide deck, which followed the focus group guide, was developed and presented to the participants to help guide the discussion. The discussion was recorded with a microphone on a laptop, and the focus group facilitator took notes on the white board walls in the conference room.

A copy of the bus operator focus group guide is provided in Appendix C. Results from the bus operator focus groups are presented in Section 6.

Assess Public Perceptions and Acceptance of Technologies

A multi-step approach was also employed to assess the public's perceptions and acceptance of the bus- and infrastructure-based technologies. First, as assessment was made of the complaints received by TriMet regarding the turn warning systems. Second, field intercept surveys of pedestrians and cyclists were conducted at five intersections in July 2014. Finally, follow-up focus groups were conducted with a selected number of pedestrians/cyclists who had completed the field survey. The survey inquired about pedestrian and cyclist perceptions/ratings and acceptance of the technologies. As follow-up to the surveys, focus groups provided an opportunity to explore in more depth the most importance issues as identified in the field survey responses.

Assessment of Public Complaints

During the demonstration test, TriMet kept records of the complaints received from the general public regarding the turn warning systems. These complaints were collected and sent to the researchers on a weekly basis throughout the demonstration test period. The complaints were monitored as they occurred, and TriMet responded accordingly to the complaints. At the end of the test period, the complaints were compiled and summarized. The results are presented in Section 7.

Field Intercept Survey

The pedestrian surveys were administered in July 2014, approximately three months after the systems were operational, which allowed time for the public to notice and experience the systems in operation. In addition, this timeframe allowed time for TriMet and/or the City of Portland to make any adjustments to the systems/signs in response to community feedback/complaints after first deploying the technologies. A copy of the survey instrument is provided in Appendix D.

The field locations encompassed a variety of intersections and bus routes, including intersections with both left turns and right turns. Surveys were administered at five different intersections, including the intersection with the BUS blank-out signs. For administration, surveyors were positioned at both ends of the crosswalk(s) through which the test buses turned. At intersections with adjacent bus stops, surveys also were administered to pedestrians and cyclists waiting for a bus. Every effort was made to survey pedestrians and cyclists that were crossing while a test bus was turning. Surveyors watched for approaching buses and may have opted not to survey a pedestrian crossing when the bus was approaching in favor of waiting to survey a pedestrian present during the turn.

To encourage participation, the survey was designed to take between 5–10 minutes to complete. Surveys were administered using electronic tablets provided by TriMet. The survey was developed using word processing software and, once finalized, was programmed into the survey software loaded onto the tablets. Surveyors held the tablets, read the questions and answers aloud, and recorded participant responses. The use of tablets to administer the survey greatly expedited data reduction and analysis, as there was no need for data entry following survey administration. Spot checks were conducted by surveyors to verify that the data were being collected and stored correctly. This protocol reduced data entry error and increased the overall efficiency of data collection. At the end of each day, the survey data were uploaded to a secure server.

The survey plan called for surveys to be administered for approximately eight hours each day for four days during one week—three hours in the morning (~7:00–10:00 AM), two hours around noon (~11:00 AM–1:00 PM), and three hours in the afternoon/evening (~4:00–7:00 PM). Due to inclement weather on two of the planned survey days, the times and locations were altered slightly. Table 5-1 summarizes the days and times of survey administration by location.

Table 5-1

Number of Survey Data Collectors by Day, Time, and Location

Days	Locations	Test Routes	Turns	Number of Surveyors by Time Period
1	46th Ave & Woodstock Blvd	75	Right turns, permissive left turns	4 AM, 4 noon, 4 PM
2	23rd Ave & Burnside St	15	Right turns, protected left turns	4 AM, 4 noon, 4 PM
3	5th Ave & Burnside St	17	Right turns	4 AM, 4 noon, 4 PM
4	5th Ave & Madison St	4, 33	Left turns (one-way to one-way)	2 AM, 2 noon, 2 PM
4	6th Ave & Everett St	4	Right turns	2 AM, 2 noon, 2 PM
5	5th Ave & Burnside St	17	Right turns	2 PM
6	5th Ave & Burnside St	17	Right turns	2 noon

Whereas pedestrians were the main focus for the surveyors, an attempt was made to include cyclists in the survey sample; however, unless cyclists were walking their bicycles through the intersection, they were difficult to survey. With the number of pedestrians and cyclists in the Portland area, it was anticipated that surveys would capture respondents that were frequently pedestrians and cyclists, and the survey included questions directed at both pedestrians and cyclists to capture their perceptions and feedback.

At NW 6th Avenue and NW Everett Street, buses equipped with the systems made right turns from northbound 6th Avenue onto eastbound Everett Street. Therefore, there was only one crosswalk impacted by the turn warning systems, and there is no bus stop at this intersection. To intercept pedestrians at this intersection, one surveyor stood on the southeast corner of the intersection near the beginning of the crosswalk, and the other surveyor stood on the northeast corner of the intersection near the beginning of the crosswalk (as shown in Figure 5-2).

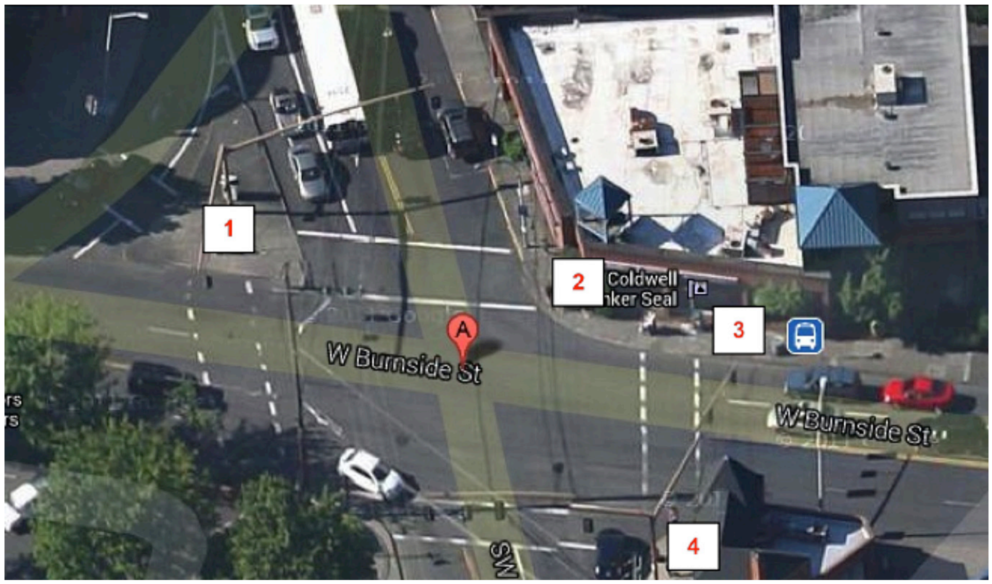
Figure 5-2

Surveyor positions at NW 6th & NW Everett

At NW 23rd Avenue and W Burnside Street, buses equipped with the turn warning systems made right turns from westbound Burnside Street onto northbound 23rd Ave, as well as left turns from southbound 23rd Avenue onto eastbound Burnside Street. There is a bus stop on the northeast corner of the intersection. Therefore, one surveyor stood on the northwest corner of the intersection near the beginning of the crosswalk, two surveyors stood on the northeast corner of the intersection (one near the beginning of both crosswalks and one near the bus stop), and one surveyor stood on the southeast corner of the intersection near the beginning of the crosswalk (as shown in Figure 5-3).

Figure 5-3

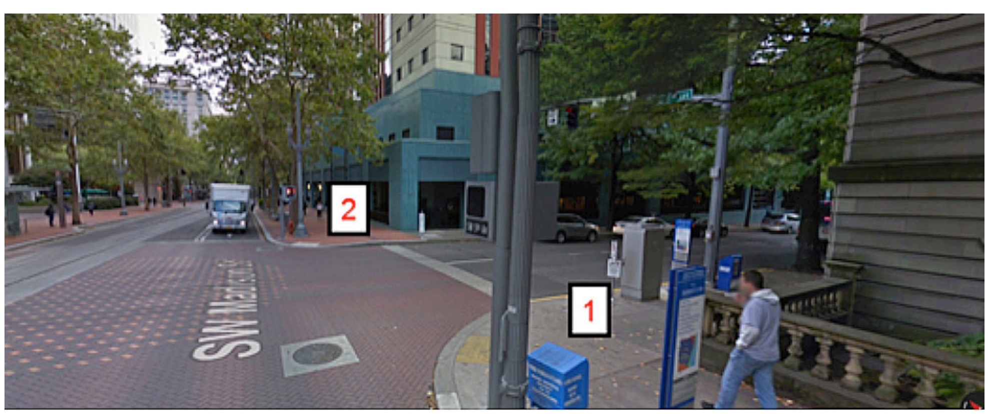
Surveyor positions at NW 23rd & W Burnside



At SW 5th Avenue and SW Madison Street, buses equipped with the turn warning systems made left turns from southbound 5th Avenue onto eastbound Madison Street. As such, there was only one crosswalk of interest, and there is no bus stop at this intersection. Therefore, only two surveyors administered surveys at this intersection; one stood on the southeast corner of the intersection near the beginning of the crosswalk, and the other stood on the northeast corner of the intersection near the beginning of the crosswalk (as shown in Figure 5-4).

Figure 5-4

Surveyor positions at SW 5th & SW Madison



At SE 46th Avenue and SE Woodstock Boulevard, buses equipped with the turn warning systems made right turns from eastbound Woodstock Boulevard onto southbound 46th Avenue and left turns from northbound 46th Avenue onto westbound Woodstock Boulevard (see Figure 5-5). One surveyor stood on the northwest corner of the intersection, two surveyors stood on the southwest corner of the intersection, and one surveyor stood on the southeast corner of the intersection. There is a bus stop at this intersection; however, it is on the opposite corner of the intersection and therefore was not on a test route.

Figure 5-5

Surveyor positions at SE 46th & SE Woodstock

At SW 5th Avenue and W Burnside Street, buses equipped with the turn warning systems made right turns from eastbound Burnside Street onto southbound 5th Avenue. In addition, this intersection was also the deployment site for the prototype BUS blank-out signs. Buses making left turns from westbound Burnside Street onto southbound 5th Avenue activated the BUS blank-out warning sign in the crosswalk on the southern let of the intersection. There is a bus stop near the southwest corner of the intersection. Therefore, two surveyors stood on the southwest corner of the intersection, one near the beginning of the crosswalk and one near the bus stop, and two surveyors stood on the southeast corner of the intersection near the beginning of the crosswalk (as shown in Figure 5-6). The survey administered at this intersection had an additional set of questions inquiring about pedestrian/cyclists perceptions of the blank-out signs.

Figure 5-6

Surveyor positions at SW 5th & W Burnside

The results from the pedestrian survey are presented in Section 7.

Focus Groups with Pedestrians

The purpose of the pedestrian focus groups was to delve deeper into the most important issues associated with the systems and to explore the perceptions of alternative auditory and visual warnings that could not be tested in the field or assessed via the intercept surveys. Three focus groups were conducted with a self-selected group of pedestrians in September 2014. Focus group participants were initially identified during the field intercept survey. After completing a survey, respondents were asked if they would be interested in participating in a follow-up focus group. If they agreed, they were asked to complete a separate form with the appropriate contact information. In early September 2014, the research team prioritized these individuals based on reported exposure to the systems and contacted them regarding participation in the focus groups. Although 36 people were recruited to participate in the 3 focus groups, only 27 actually participated. The focus groups were held at TriMet's Center Street maintenance and operations facilities. Each focus group lasted about 90 minutes, and participants were given a stipend for their time.

A structured focus group guide was developed to assist the facilitator in keeping the participants focused on the issues and topics at hand. Participants viewed a series of short video clips and photos with a variety of alternative turn warnings and blank-out signs, respectively. Participants also were provided with rating sheets, which were used in combination with the video clips and photos. The discussions were recorded with a microphone on a laptop, and the focus group facilitator took notes on the white board walls in the conference room. The pedestrian focus group guide is shown in Appendix E.

The results from the pedestrian focus groups are presented in Section 7.

Assess Pedestrian and Cyclist Behaviors Associated with Technologies

To assess pedestrian and cyclist behaviors associated with the warning systems, a video-based observational study of pedestrian/cyclist activity was conducted at four intersections. The video was reviewed and reduced *post hoc* for pedestrian/cyclist behaviors while approaching/crossing at intersections when a bus was turning. The types of behaviors or actions of pedestrians/bicyclists that were of interest were pedestrian/cyclist:

- Turns head toward bus/sign.
- Points at bus/sign.
- Moves more quickly in same direction.

- Moves more slowly in same direction.
- Stops/waits until bus turns/passes.
- Starts and then stops.
- Reverses direction.

Other characteristics of the site were noted, such as the type of bus, type of turn, and the pedestrian walk phase (when possible).

A local firm experienced in traffic data collection mounted video cameras equipped with audio capture capabilities at the following four intersections, which generally corresponded to the locations at which pedestrian/cyclist surveys were administered:

- SW 5th & SW Madison
- SW 5th & W Burnside
- NW 6th & NW Everett
- SE 46th & SE Woodstock

Cameras were installed for a 20-hour data collection period, which included both daytime and nighttime conditions. The video was post-processed and transferred from the cameras to a hard drive for reduction and analysis.

The general locations where video equipment was mounted at each intersection are shown in Figure 5-7 through Figure 5-10. The exact locations of the cameras were determined through preliminary site visits and were dependent on factors such as line-of-sight and available infrastructure on which to mount the equipment.

Figure 5-7

Video equipment location at SW 5th & SW Madison

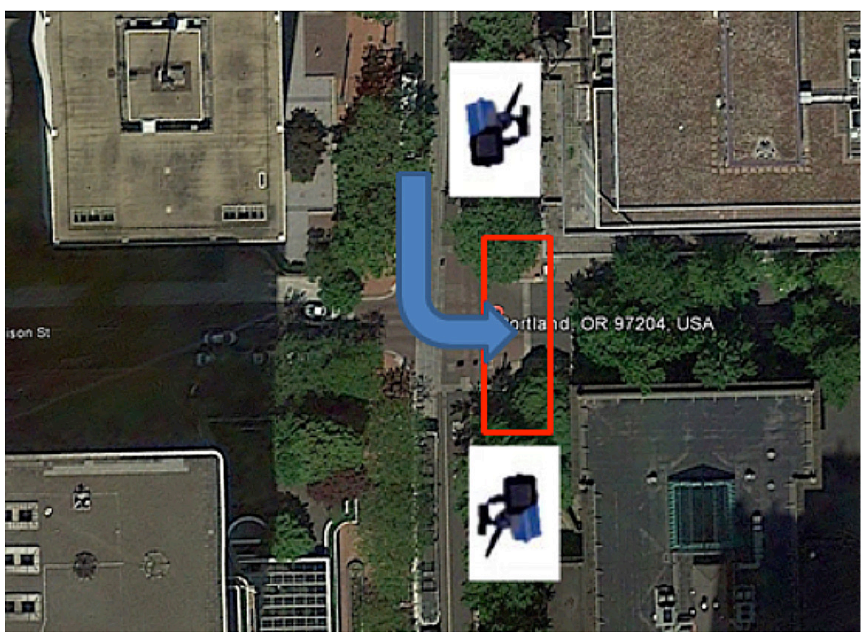


Figure 5-8

Video equipment location at SW 5th & W Burnside

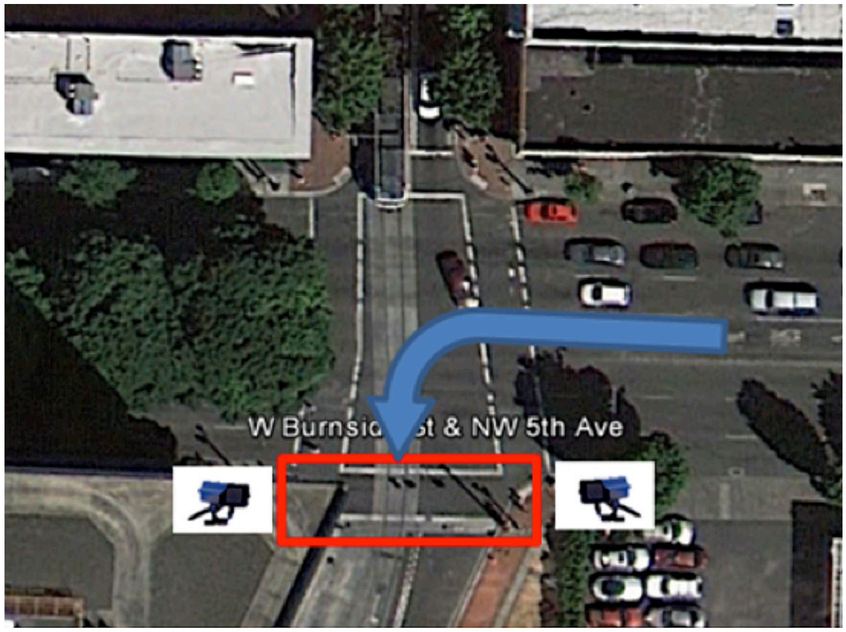


Figure 5-9

Video equipment location at NW 6th & NW Everett

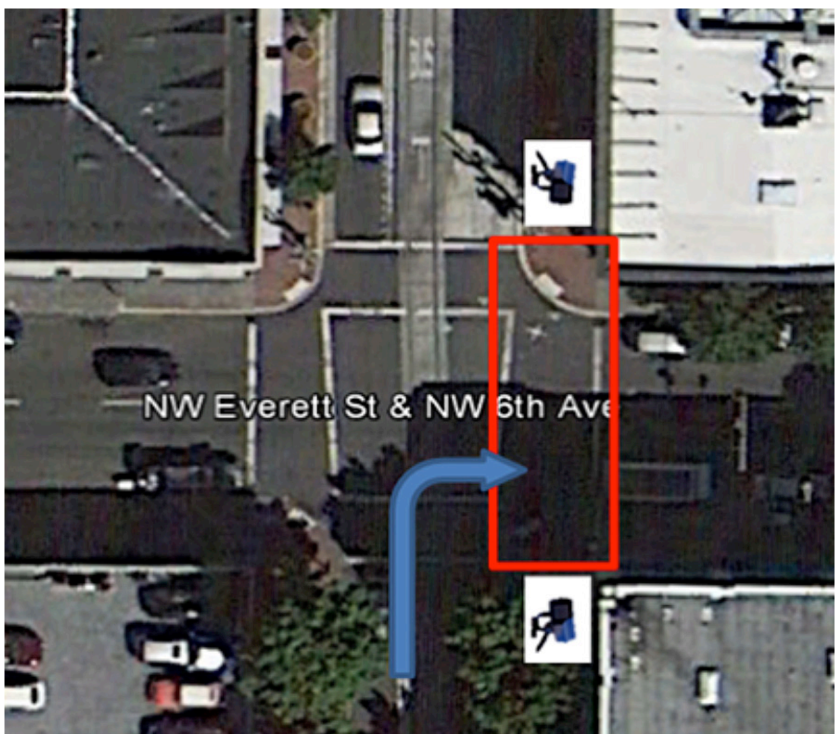
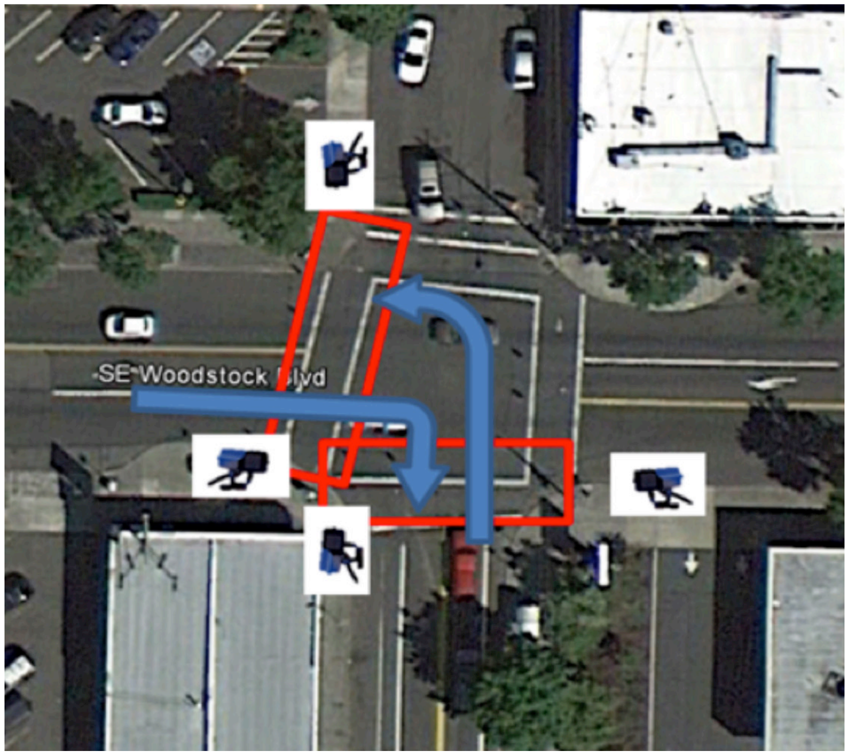


Figure 5-10

Video equipment location at SE 46th & SE Woodstock



Results were summarized in terms of total counts, rates of events, and other basic descriptive statistics. Due to the small sample size of the "with turn warning system" condition, inferential statistics were not appropriate.

The findings from the observational studies are presented in Section 8.

Assess Bus-and-Pedestrian/Cyclist Conflicts

To assess pedestrian/cyclist-bus conflicts, "close calls" as reported by bus operators via TriMet's CAD/AVL system were to be used as the measure of effectiveness. The CAD/AVL system allowed for operators to push buttons on a control head in the cabin to mark the occurrence of different types of events, including a close call with a pedestrian or a cyclist. The purpose of this test was to determine whether implementation of the turn warning systems resulted in a change in the close calls reported by operators. The months prior to the beginning of the test were to serve as the "before" phase, during which baseline close-call data would be collected prior to implementation of the turn warning systems. The subsequent seven-month test period was to serve as the "after" phase, during which the systems would be operational on the test routes. In addition, throughout the testing or "after" phase, a subset of non-test buses serving the study routes were to serve as control buses (i.e., the "without" condition) and would be compared against the close-call data from the test buses (i.e., "with" condition).

TriMet's new CAD/AVL system became fully operational in 2013. Although operators were encouraged to use the close-call buttons without the threat of consequences, analysis of the data showed that, in fact, very few operators had used the buttons. Therefore, these data were not available for use in evaluating changes in pedestrian/cyclist-bus conflicts. Instead, operator responses from the daily survey were used to document and impute avoided conflicts. Specifically, one question on the daily survey read, "Was there a particular situation where you think the turn warning system helped avoid a close call or collision with a pedestrian?" Operators responded either "yes" or "no." If their response was "yes," they were asked to describe what happened.

The avoided close-call data represent a vital element in the benefit-cost analysis of the warning systems, which is addressed in Section 10.

Assess Institutional Issues with and Acceptance of Technologies

To assess institutional issues with and acceptance of the technologies among TriMet management, interviews were conducted with seven TriMet managers and staff involved in the demonstration project. Each interviewee had a different role and responsibility and provided feedback regarding his or her experience with the systems and the overall project. The interviews took approximately 30–45 minutes and were conducted either in-person or by telephone. The list below indicates the title of each of the interviewees:

- Safety Executive
- Assistant Manager, Transportation
- Maintenance Manager
- Maintenance Trainer
- Assistant Supervisor, Maintenance
- Manager, Operations Training
- Public Information Officer

A summary of the interview findings is presented in Section 9.

Develop Benefit and Cost Estimates Associated with Technologies

The purpose of the benefit-cost analysis was to provide a monetary accounting of the costs associated with acquiring the warning systems and maintaining them over their design life, along with the savings to society that follow from warning system-related reductions in bus-pedestrian incidents of varying levels of severity. Although both cost and benefit estimates are subject to uncertainty, the uncertainties associated with the latter are particularly challenging. This challenge springs mainly from the fact that bus-pedestrian collisions are rare events. Thus, the likelihood of observing such collisions or, in the case of the present study, a reduction in collisions, is small.

Alternatively, close calls involving buses and pedestrians occur much more frequently than collisions. By itself, an avoided close call represents an outcome with no monetary impact; however, given sufficiently large safety risk exposure, it is possible to determine the relative frequencies of outcomes ranging from close calls to fatalities. Thus, an initial step in the benefit-cost analysis involved the determination of the relative frequency of increasingly severe outcomes resulting from hazardous encounters between buses and pedestrians. Once these frequencies were determined, it became possible to impute the likelihood of avoided incidents of increasing severity from documented reductions in close-call events attributable to the pedestrian warning systems.

The risk exposure sufficient for determining the relative frequencies of the most severe outcomes from bus-pedestrian incidents is the industry level. This level ensures that the frequency of the rarest outcome—a pedestrian fatality—can be robustly determined in relation to outcomes of lesser severity. Thus, the National Transit Database (NTD) provided the basis for determining the relative frequencies of fatalities and injuries requiring transport. The relative frequencies of the less severe bus-pedestrian incidents that were below the NTD reporting threshold—covering minor injuries and close calls—were determined from archived TriMet incident files and operator survey data, respectively.

The benefit-cost analysis is organized around benchmark, upper bound, and lower bound scenarios, whose ranges reflect uncertainties associated with warning system costs, bus-pedestrian outcome frequencies, and the monetization of benefits. Outputs from the analysis include net present values, benefit-cost ratios, and internal rates of return.

The results of the benefit-cost analysis are presented in Section 10.

SECTION

6

Operator Perceptions and Acceptance of Technologies

As indicated previously, a multi-step approach was employed to assess bus operator perceptions and acceptance of the technologies. This approach included conducting:

- A daily survey
- A comprehensive survey
- Four focus groups

This section presents the findings from the surveys and the focus groups.

Daily Operator Survey

The purpose of the daily survey was to uncover operator perceptions of the effectiveness of the turn warning systems immediately following the completion of their assigned daily runs. The survey also helped to identify critical issues associated with the performance and reliability of the systems throughout the test.

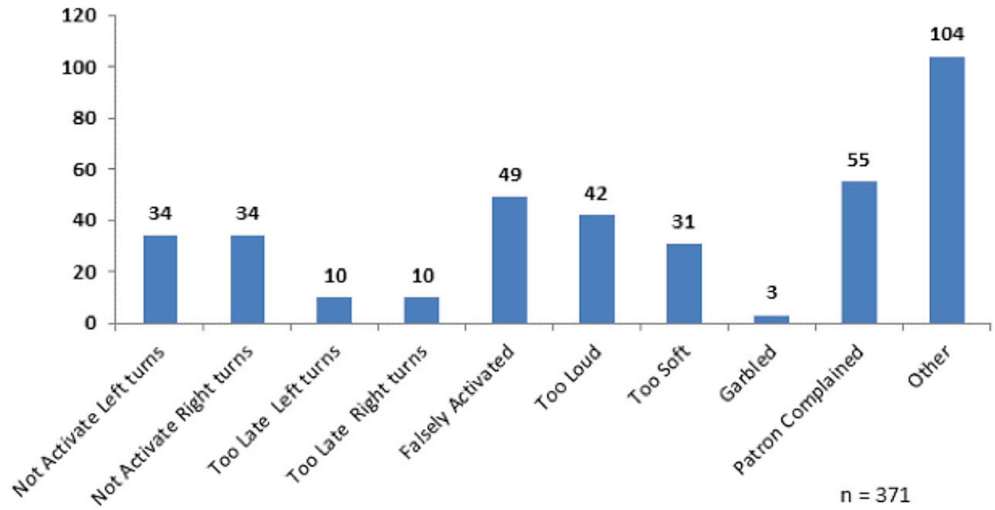
System Performance and Operational Issues

The survey initially asked whether operators had experienced any problems with the turn warning system on their bus that day. Overall, 48.2% of the responding operators indicated that they had experienced a problem. Contingency analysis revealed significant differences ($p < 0.001$) in the percentage of positive responses among the three warning systems (System A, 55.6%; System B, 35.0%; System C, 59.4%).

The types of problems reported by operators are shown in Figure 6-1. More than one-third of the 371 reported problems concerned turn warning system activation issues, which included not activating, activating too late, or falsely activating (e.g., activating multiple times while navigating a curve or during a layover). Another one-fifth of the reported problems addressed perceptions that the messages were too loud, too soft, or difficult to understand. The final two categories, accounting for about two-fifths of the reported problems, included complaints by patrons and by the operators themselves. More than 80% of the patron complaints involved characterizations of the warning as "distracting," "annoying," and "noise pollution," with the remainder mainly questioning the effectiveness or cost of the technology. Operators also complained most frequently about distractions, annoyances, and effectiveness, but nearly as frequently, also elaborated further on the warning activation and message volume problems they had previously noted.

Figure 6-1

Problems reported by operators



The response frequencies for each of the categories in Figure 6-1 were too small to permit meaningful contingency analysis across the three warning systems. However, an inspection of the responses does suggest selected instances where given problems appeared to be over-represented for each of the systems. For example, the warnings from System B were relatively more likely to be characterized as too soft, System C warnings were relatively more likely to draw complaints from both patrons and operators, and System A was relatively more likely to both experience false activations and draw complaints about its warning message being too loud.

When initial responses identified false activation and excessive volume problems, the warning activation and volume thresholds were adjusted by maintenance personnel. Thus regression analysis estimated a downward trend in the reporting of false activations ($p < 0.001$) and excessive noise ($p < 0.09$) problems over the full survey period. However, a significant ($p < 0.004$) upward trend was also estimated for reported problems with the warning message being too soft. These offsetting trends suggest a lack of consensus among operators about what volume level is necessary to be effective, yet not so great as to distract and annoy those on the bus.

Warning System Effectiveness

The main body of the survey sought operator perceptions of the effectiveness of the turn warning systems in alerting pedestrians or avoiding close calls during turns and when pulling into or away from bus stops. For each question, operators marked their responses on a four-point scale whose categories ranged from Very Successful to Not At All Successful. Table 6-1 provides information on the combined percentage of Very Successful/Somewhat Successful and Not Very/Not At All Successful responses to each of the pertinent survey questions. Warning system-specific results are shown only for instances where contingency analysis found significant differences.

Table 6-1

Breakdown of Operator Responses to Questions Regarding System Effectiveness

Questions	Affirmative Responses: Somewhat/Very Successful	Negative Responses: Not Very/Not at all Successful	Not Sure
Was the system successful in alerting pedestrians that the bus was turning?			
Overall	47.7%	41.3%	13.9%
System A	39.1%	42.1%	18.8%
System B	53.1%	34.2%	12.7%
System C	38.2%	52.8%	9.0%
Was the system successful in reducing close calls during turns?			
Overall	29.8%	47.7%	22.5%
System A	NA	NA	NA
System B	NA	NA	NA
System C	NA	NA	NA
Was the system successful in alerting pedestrians that the bus was pulling into or away from a stop?			
Overall	43.2%	43.2%	13.6%
System A	41.5%	36.4%	22.0%
System B	47.3%	41.9%	10.9%
System C	39.0%	41.9%	5.2%
Was the system successful in reducing close calls at stops?			
Overall	30.1%	47.8%	22.2%
System A	23.3%	49.1%	27.6%
System B	39.5%	39.5%	21.0%
System C	25.0%	59.2%	15.8%

Generally, operators thought the turn warning systems were relatively more effective at alerting pedestrians to the presence of the bus than in reducing close calls, both when making turns and when servicing stops.[13] In either case, however, it is apparent that operators were fairly divided in their overall assessments of the effectiveness of the systems, with a marginally greater number perceiving them to be effective in alerting pedestrians during turns and an even split in alerting pedestrians at stops. With respect to avoiding close calls, a clear and near-equivalent percentage of operators perceived the systems to be ineffective both in making turns and in servicing stops.

In their responses to each of the four questions, operators were also able to indicate whether they were unsure of the effectiveness of the warning systems. As one might expect, operators were generally less sure of the systems' effectiveness in avoiding close calls than in the effectiveness in alerting pedestrians to the presence of the bus.

Contingency analysis identified significant differences in perceived effectiveness among the three warning systems in the responses to three of the four questions. In each instance, significantly more operators perceived System B as being effective as compared to the other two systems. In contrast, a relatively larger percentage of operators was unsure about the effectiveness of System A. It is noteworthy that this system was most frequently associated with excessive volume complaints early in the survey period, and the downward adjustments made in response to complaints may have made it more difficult for operators to determine whether the system was performing effectively.

On the subject of close calls, operators were asked directly if they could recall and describe an instance during their run that day where the warning actually helped avert such a close call or incident. Only 5.6% of operators responded affirmatively, and the circumstances they described commonly involved either a pedestrian reacting to the warning by stepping back to the curb in an intersection while the bus was turning or a patron stepping back from the edge (or from over the edge in some instances) of the stop platform as the bus was pulling in. Contingency analysis found no significant differences in responses across the warning systems, and regression analysis found no evidence of trending.

The final survey item asked operators to indicate their level of support for wider deployment of the turn warning systems across TriMet's bus fleet. Their responses are presented in Table 6-2. Overall, about one-third of the operators somewhat agreed or strongly agreed with the prospect of wider deployment, while nearly half somewhat disagreed or strongly disagreed. Contingency analysis revealed significant differences in the level of support across the systems. System B gained substantially greater favor among operators over the other two systems. Or, put another way, this is the only system of the three that did not encounter majority opposition to the prospect of wider deployment. Operator views on this issue were stable, as regression analysis found no evidence of trending over the survey period.

Table 6-2

Level of Operator Support for Wider Deployment

I would like to see this turn warning system installed on more or all TriMet buses.	Somewhat/ Strongly Agree	Neither Agree Nor Disagree	Somewhat/ Strongly Disagree	Not Sure
Overall	33.8%	12.6%	49.6%	4.0%
System A	26.1%	9.2%	60.6%	4.2%
System B	45.2%	13.9%	36.1%	4.8%
System C	25.8%	15.5%	56.7%	2.1%

Comprehensive Operator Survey

Like the daily survey, the comprehensive survey served to measure operator perceptions/ratings of system reliability, effectiveness, and acceptance. While many of the questions were the same across both surveys, the scope of the comprehensive survey included the entire seven-month test period, as well as questions that addressed operator perceptions and acceptance of the directional LED headlights.

The comprehensive survey was completed by 208 operators. Among the respondents, 39.7% were female and 56.9% were junior operators (i.e., with less than six years of experience). Both breakdowns are generally representative of TriMet's bus operator population.

The questions in the survey were organized around each of the turn warning systems and the directional LED headlights. Some survey questions were common to all of the systems, while others were specific to several or only one of the alternatives. The presentation of the results thus groups responses where commonality exists.

The first question asked operators whether there were occasions where a given system did not work properly. The responses to this question are shown in Table 6-3. Overall, nearly 53% of the responses were positive. Contingency analysis indicated that the two systems that were activated by turning the steering wheel (System A and System B) were reported to be significantly more likely to experience problems than the other turn warning system or the directional LED headlights, which were activated by the turn signal. Moreover, for System C, the directional LED headlights were significantly less likely to have reported problems than the turn warning component.

The reported incidence of problems in the comprehensive survey, by comparison, was generally greater than that reported in the daily survey, not surprising given the 7-month scope of the comprehensive survey. It is noteworthy, however, that the system with the most frequently reported incidence of problems in the daily survey (System C) was considered to be least problematic in the comprehensive survey.

Table 6-3
Incidence of Problems with Systems

Did you experience problems with the system not working properly?	Yes	No
Overall	52.9%	47.1%
System A	69.5%	30.5%
System B	67.2%	32.8%
System C – turn warning system	52.8%	47.2%
System C – directional LED headlights	14.9%	85.1%

Contingency analysis revealed no significant differences in the responses to this question by gender; however, senior operators were found to report a problem more often than junior operators (59.9% versus 47.8%).

For operators who responded affirmatively to the occurrence of a problem with a given system, a follow-up item in the survey provided a list of specific types of problems and asked operators to indicate how frequently each type of problem had occurred. Most of the problems listed for respondents in this survey item related to the activation sensitivity of the given systems (e.g., too early, too late, not at all). Operator responses to problems with system activation are shown in Table 6-4. For the two systems activated by turning the steering wheel (System A and System B), a majority of the respondents indicated that the systems activated too early, and a substantial majority noted the same for roadway curves. This finding likely reflects the calibration of these systems to activate when making turns and when pulling into and away from stops. Failure to activate was much less of a problem for the system activated by the turn signal.[14]

Table 6-4

Breakdown of Operator Responses to Questions Regarding Problems with System Activation

Statement	Affirmative Responses: Sometimes, Frequently, or Almost Always	Negative Responses: Rarely or Almost Never	Not Sure (NS)
The warning activated too early.			
System A	55.4%	39.2%	5.4%
System B	61.8%	35.5%	2.6%
The warning activated too late.			
System A	31.0%	60.6%	8.4%
System B	33.8%	57.1%	9.1%
The warning did not activate at all.			
System A	23.5%	69.1%	7.4%
System B	26.4%	69.4%	4.2%
System C – turn warning system	35.8%	59.7%	4.5%
System C – directional LED headlights	15.0%	70.0%	15.0%
The warning activated in roadway curves.			
System A	86.0%	10.3%	3.7%
System B	87.2%	9.2%	3.6%
The turn warning activated when I did not use the turn signal.			
System C	29.7%	64.0%	6.3%
The directional LED headlights activated when I did not use the turn signal.			
System C	20.0%	62.5%	17.5%

Operator responses to problems with warning volumes are shown in Table 6-5. By a significant margin, operators indicated that the volumes of the warnings were too loud rather than too soft. This outcome is similar to that of the daily survey. Moreover, it indicates that even following the reduction in volume levels in the early part of the field test period in response to resident and operator complaints, the problem of finding the right balance between warnings that were "too loud" versus "too soft" persisted. More fundamentally, the responses may also represent a confounding among operators of the perceived volume necessary for the systems to be effective and the perception that any volume beyond a fairly low threshold is annoying. A similar type of confounding may underlie the finding that the "too loud" margin was significantly greater for systems with the spoken warning message than the system with the beeping sound, where, in this case, operators may have been more annoyed by a repeating voice.

Table 6-5

Breakdown of Operator Responses to Questions Regarding Problems with Volume

Statements	Affirmative Responses: Sometimes, Frequently, or Almost Always	Negative Responses: Rarely or Almost Never	Not Sure
The warning was too loud.			
System A	76.7%	19.4%	3.9%
System B	78.6%	19.4%	2.0%
System C	70.1%	27.6%	2.3%
The warning was not loud enough for pedestrians to hear.			
System A	38.9%	50.0%	11.1%
System B	42.5%	47.9%	9.6%
System C	43.5%	49.3%	7.2%

Operators were then asked how frequently they saw pedestrians noticing the auditory warnings, both at intersections and at bus stops. Their responses are presented in Table 6-6. Whether in making turns or serving stops, a majority of operators indicated that pedestrians noticed the warnings, with somewhat greater awareness of the warnings when making right turns versus left turns, and when pulling into a stop versus when pulling away from a stop.

Table 6-6

Breakdown of Operator Responses to Questions Regarding Effectiveness of Warnings in Gaining Pedestrian Attention

Situations	Affirmative Responses: Sometimes, Frequently, or Almost Always	Negative Responses: Rarely or Almost Never	Not Sure
Turning left at an intersection.			
System A	60.1%	36.2%	3.7%
System B	57.5%	38.9%	3.6%
System C	54.5%	41.2%	4.3%
Turning right at an intersection.			
System A	67.5%	30.9%	1.6%
System B	68.9%	28.5%	2.6%
System C	63.5%	33.9%	2.6%
Pulling into a stop.			
System A	68.4%	27.3%	4.3%
System B	66.2%	31.3%	2.5%
System C	63.0%	32.3%	4.7%
Pulling away from a stop.			
System A	52.4%	36.9%	10.7%
System B	51.0%	38.7%	10.3%
System C	52.1%	41.0%	6.9%

Operators were then asked how effective they thought each system was in reducing close calls between buses and pedestrians when making turns and when serving stops. Their responses are presented in Table 6-7. Recognizing that the directional LED headlights were evaluated only for nighttime operations, contingency analysis found that operators rated the headlights as being significantly more effective than the turn warning systems. Nevertheless, generally anywhere from about 28–43% of operators reported that the turn warning systems were sometimes, frequently, or almost always effective at reducing close calls, while just over half reported they were rarely or almost never effective at doing so. The remaining portion were unsure. No significant differences were found among the turn warning systems. Comparable to the findings for alerting pedestrians, operators generally perceived all the systems to be more effective in reducing close calls for right turns versus left turns, and when pulling into a stop versus pulling away from a stop.

Table 6-7

Breakdown of Operator Responses to Questions Regarding Effectiveness in Reducing Close Calls[15]

Situations	Affirmative Responses: Sometimes, Frequently, or Almost Always	Negative Responses: Rarely or Almost Never	Not Sure
Turning left at an intersection.			
System A	33.7%	56.1%	10.2%
System B	28.4%	62.4%	9.2%
System C – turn warning system	31.9%	57.6%	10.5%
System C – directional LED headlights	64.9%	26.6%	8.4%
Turning right at an intersection.			
System A	43.3%	48.1%	8.6%
System B	38.1%	54.6%	7.3%
System C – turn warning system	40.6%	52.1%	7.3%
System C – directional LED headlights	70.8%	22.1%	7.1%
Pulling into a stop.			
System A	42.2%	49.7%	8.1%
System B	37.6%	55.7%	6.7%
System C – turn warning system	38.0%	54.2%	7.8%
System C – directional LED headlights	72.1%	21.4%	6.5%
Pulling away from a stop.			
System A	32.1%	54.0%	13.9%
System B	28.4%	60.3%	11.3%
System C – turn warning system	26.6%	62.5%	10.9%
System C – directional LED headlights	61.7%	27.9%	10.4%

Beyond close calls, operators were asked specifically whether they thought each of the systems actually helped avoid a collision with a pedestrian or bicyclist during the demonstration period, and 10.9% responded that it had done so. While contingency analysis found no significant differences among the systems or with respect to seniority, the analysis did find the percentage of affirmative responses among female operators (15.0%) to be significantly greater than among male operators (7.7%).

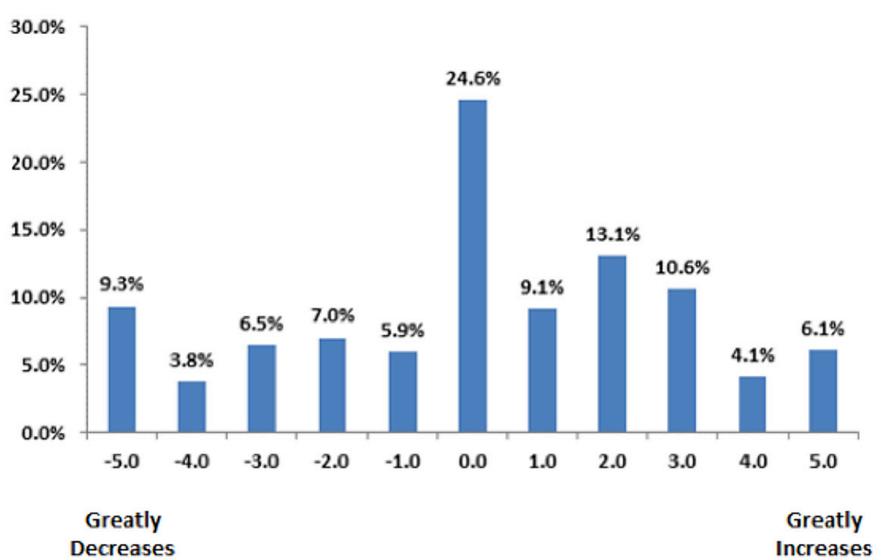
To put the overall affirmative response to this question into context, operators indicated that the systems collectively helped to avoid 78 pedestrian/bicycle collisions during the seven-month field demonstration period. By comparison, a query of TriMet's safety information system for collisions involving pedestrians and bicyclists found that there were 70 such incidents that occurred on the entire bus system between December 2010 and October 2014. Thus, for a comparable seven-month time frame, the survey's responses yielded a quantity of avoided collisions on the six study routes that exceeds the actual average for the 70-route system by a factor of about 8.

This discrepancy can be explained, at least in part, by operator responses to a follow-up survey item that asked them to describe the situation in which the actual collision was avoided. Virtually all of the responses involved either generalized statements addressing the effectiveness of the warning systems in reducing hazardous behavior among pedestrians and cyclists, or, to a lesser extent, descriptions of specific hazardous encounters that would seem to be better characterized as an avoided close call rather than an avoided collision.

Next, operators were asked to indicate the effect that each of the three warning systems had on the quality of their daily work life. Their overall responses, rated on an 11-point scale, are illustrated in Figure 6-2. While the median response in Figure 6-2 indicates no change in daily work life quality, 43% of the operators reported an improvement in daily work life quality and 32.5% reported a decline. Also, a non-trivial share of the responses were loaded at the polar extremes of the scale, with 9.3% indicating a great decline in daily work life quality and 6.1% indicating a great improvement.

Figure 6-2

Effect of warning systems on operator quality of work life



Behind the overall responses, there were significant gender and seniority-based differences in operator assessments of the effects of the warning systems on daily work life quality. A significantly larger percentage of the male operator responses indicated a reduction in daily work life quality (35.5% vs. 28.6% among female operators). The distinction was even greater with respect to seniority, with 40.3% of senior operators indicating a reduction in daily work life quality, versus 26.6% among junior operators.

The next survey item asked operators to indicate the extent to which they agreed that the potential safety benefits of each warning system outweighed its drawbacks. A follow-up item also asked operators to indicate the extent to which they agreed with the prospect of deploying each system more widely throughout TriMet's bus fleet. Their responses to these items are presented in Table 6-8.

Table 6-8

Perception of System Benefits and Support for Wider Deployment

Statements	Agree: Somewhat/ Strongly Agree	Neither Agree nor Disagree (Neutral)	Disagree: Somewhat/ Strongly Disagree	Not Sure
The potential benefits of this turn warning system outweigh any of its associated drawbacks.				
Overall	46.6%	18.6%	30.3%	4.5%
System A	43.0%	21.0%	30.6%	5.4%
System B	52.4%	14.8%	29.1%	3.7%
System C	44.4%	20.1%	31.2%	4.3%
I would like to see this system installed on more TriMet buses.				
Overall	52.0%	14.2%	32.5%	1.3%
System A	39.4%	18.6%	41.5%	0.5%
System B	48.1%	15.9%	34.4%	1.6%
System C – turn warning system	39.9%	16.0%	42.6%	1.5%
System C – directional LED headlights	87.0%	4.5%	7.1%	1.4%

Overall, a substantially greater percentage of operators (although not a majority) agreed or strongly agreed that the potential safety benefits outweighed the drawbacks of the warning systems. A slight majority did agree with the statement in the case of the System B. Nevertheless, contingency analysis found no significant difference in the responses across the three systems, nor did it find a significant gender-based difference in the level of agreement with the statement. However, a significant difference was found with respect to seniority. A greater percentage of junior operators agreed that the warning systems' potential safety benefits outweighed their drawbacks (58.0%, vs. 31.5% among senior operators).

While a majority of operators agreed overall with the statement posing wider deployment across TriMet's bus fleet, the response is mainly a consequence of their significantly greater support for the directional LED headlights. Significant differences were also observed with respect to seniority, with 60.7% of junior operators supporting wider deployment versus 40.8% of senior operators.

Given operators' very strong support for wider deployment of the directional LED headlights, a contingency analysis was also done separately for the three warning systems. Overall, there were no significant differences found across the three systems, although, again, the percentage of junior operators favoring deployment was significantly greater than it was for senior operators (51.9% vs. 30.5%).

Next, operators were asked to rank the three warning systems based on their overall experience during the field demonstration test. Their responses are presented in Table 6-9. Based on the mean rankings, the System B was ranked highest, followed by System C and then System A. However, the distribution of operator rankings for each of the systems presents a more complicated picture. For instance, 42.2% of rankings "cast" for System C were for first place, which is notably greater than the first place rankings received by either of the other two systems. At the same time, System C's favorability at the top was slightly more than offset by its percentage of third place rankings. This suggests that operators were much more divided over the assessment of their experience with System C compared to the other systems.

Table 6-9

Operator Rankings of Warning Systems

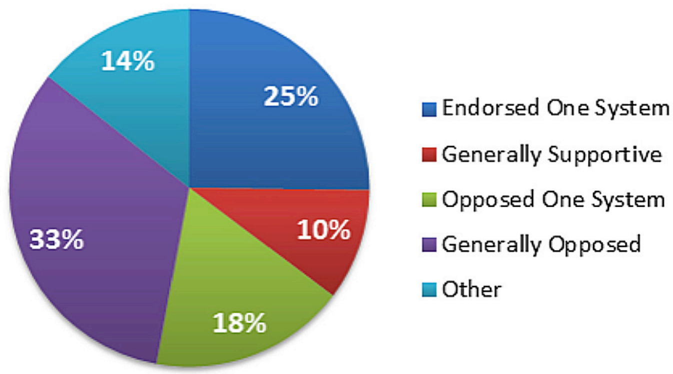
Warning System	Mean Rank	Ranked First	Ranked Second	Ranked Third
System B	1.83	32.3%	52.9%	14.8%
System C	2.01	42.2%	14.4%	43.4%
System A	2.25	20.5%	33.5%	46.0%

Contingency analysis found a significant difference in the distribution of rankings across the three systems. The only other significant difference for any of the specific systems involved gender, with female operators casting a greater percentage of first place rankings System B (43.3% vs. 25.2% for male operators).

The final item in the survey was an open-ended question inviting operators to comment about their experience with any of the systems. More than 57% of the operators responded with comments, which are summarized in Figure 6-3. One-fourth of the respondents offered an endorsement of a specific system, of which 70% related to the directional LED headlights. Another 10% of the respondents provided a general endorsement of all of the systems as a potentially effective means of addressing a safety problem. Alternatively, 18% of the respondents voiced opposition to a specific system, of which 76% targeted problems they or others had with System C. This focused opposition underscores the negative side of the division among operators in the rankings of this particular system. Another one-third of the respondents expressed general opposition to all of the warning systems, and most frequently commented about the systems' ineffectiveness, distractions, or annoyances. The final ("Other") group, comprising 14% of the respondents, offered suggestions for changing the functionality of the systems. In order of frequency, the most common of these suggestions addressed providing operators more control over adjusting the warning volume, setting a lower speed threshold (e.g., 10 mph) for activating the warnings, and limiting the functionality of the warning systems to turns at intersections.

Figure 6-3

Breakdown of responses to "Is there anything else you'd like to say about any of the systems or your experience with them?"



More generally, the responses to this question indicate an almost equal division among the operators with respect to their experiences with the systems, with just over half falling in opposition and just under half providing support or qualified support. However, in the narrower context of the three turn warning systems (i.e., deleting responses addressing the directional LED headlights), operator responses in general or specific opposition increase to about 61% of the total. It is noteworthy that this outcome is in contrast to the marginally favorable responses to the question of wider deployment of the three warning systems. This contrast suggests that operators with negative views about the warning systems were likely more inclined to respond to the open-ended question.

Summary/Conclusions

There are several general observations that can be drawn from the findings of the daily and comprehensive surveys in relation to operator perceptions of the performance and effectiveness of the three turn warning systems. First, efforts to calibrate System A and System B to activate sufficiently early during turning maneuverers to alert pedestrians proved problematic, drawing complaints from operators about "false" activations, as well as activations that occurred "too early." Although the two surveys are not directly comparable on this issue, it appears that while attempts to address this problem early in the demonstration test period reduced the subsequent number of false activation complaints, early activation remained a concern throughout the test period.

Second, the surveys found a lack of consensus among operators about what the "appropriate" warning volume level should be, even though adjustments were made in response to initial complaints. Related to this, there appears to be a lack of consensus about whether a spoken or beeping warning would be better.

Third, despite the various problems reported by operators, most thought the warning systems successfully alerted pedestrians, indicating that the systems are effectively achieving their purpose. In turn, however, operators were less confident that greater alertness among pedestrians would then translate into fewer close calls. Nevertheless, about 1 in 20 daily survey respondents identified an instance during their run where the warning system made a difference in avoiding a close call. About 1 in 10 comprehensive survey respondents offered what can be considered a similar endorsement.

Fourth, operator experiences with the warning systems appears to have left a majority of them either supportive or "on the fence" with the idea of wider deployment. Skepticism is clearly evident in their responses to selected open-ended survey questions. This skepticism appears to be primarily motivated by the pervasiveness of unsafe acts among pedestrians that they reported encountering, coupled with a belief that no single remedy can effectively "solve the problem." At least partly in consequence, a fair number of operators (more among senior operators) considered the warning systems to be unnecessarily intrusive.

Operator Focus Groups

Following the operators surveys, four focus groups were conducted in September 2014 with a smaller set of operators. TriMet selected operators based on availability on the days of the focus groups. In all, 27 operators participated across the four focus groups.

At the start of each focus group, introductions were made, including years of experience operating a bus and overall experience with the three turn warning systems. Next, the focus group facilitator provided the background and overview of the project. Then, the goals of the focus group, which included developing a general sense of the operator impressions about the systems and delving deeper into the issue of system effectiveness and the specifics associated with the warnings, were shared with the participants. Figure 6-4 shows photos taken during two of the bus operator focus groups.

Figure 6-4

Bus operator focus groups

Focus group discussions were recorded, and detailed notes were taken. Following the focus groups, the notes were compiled and qualitative analyses were conducted. This section presents the findings from the focus groups in terms of effectiveness of the turn warning systems and ideal turn warning system. The findings are discussed in detail below.

Effectiveness of Turn Warning Systems

A primary part of the operator focus groups centered on operator perceptions surrounding the effectiveness of the turn warning systems. A series of questions were posed to operators to better understand this issue. These questions included the following:

- In general, do you think this type of technology offers potential to improve pedestrian safety (i.e., reduce the number of collisions with pedestrians)? Why or why not?
- Observationally, did you witness pedestrians/cyclists who changed/modified their behavior during/after the warning (compared to your experience before the test, i.e., do you think the warning made a difference in an actual situation you encountered)?
- Early on, the systems drew a lot of complaints due to the volume of the warnings. Do you think it was the higher volume that people were complaining about or was it something else?
- From your experience, what are the advantages of these systems? Based on your experience, what are the biggest problems with these systems? If these problems were corrected, would the systems be more effective?
- In the daily surveys, operators consistently preferred the System B over the other two systems. Can you think of reasons why operators preferred this system?
- In some cases, the warnings activated while pulling into/out of bus stops. Is this necessary? Are the warnings effective in this situation?

Impacts on Pedestrian Safety

Overall, the majority of operators believed that the systems were effective at getting pedestrian attention, but some operators reported that the effectiveness was "low," with "20%" being offered up in one of the focus groups. The majority of operators felt that the alerts were effective at getting some people to look up, particularly in cases where the buses "sneak up" on pedestrians. One operator, however, reported that pedestrians have already seen the bus prior to the turn, so the systems are not needed.

Two caveats surfaced with respect to system effectiveness—one related to the impact of pedestrian distraction on effectiveness and the other related to the sustainability of the effectiveness of the warnings. According to most operators, many pedestrians are not paying attention and/or are using electronic devices, including headphones and ear buds. In these cases, the operators thought that the systems did not get pedestrian attention. One operator commented that the beeping alert, so loud to the point of being borderline distracting to drivers, still did not get the attention of people with ear buds. Therefore, theoretically, the systems could work, but only when pedestrians are not completely distracted. Further, although the systems may be effective in some cases, many of the operators felt that this is only temporary. With people being inundated with noises, operators felt that eventually the alerts will blend into the background and/or people will "tune them out" (e.g., like with car alarms). Finally, operators reported a concern that some operators may begin to rely on the system and become less vigilant, in which case safety might be compromised rather than improved. Others warned that the warning systems cannot fix/do everything.

A few operators offered some specific examples of perceived system effective/ineffectiveness. One operator reported that the systems were effective "a couple of times," not when turning but when pedestrians were jaywalking on the mall when he was pulling away from a stop. To the contrary, operators reported that the systems would not be effective at transit centers as there are too many buses and therefore would be too many warnings sounding. All operators agreed that the directional LED headlights associated with System C were very effective at night, allowing them to see better in the direction of the turn. However, most operators did not feel that the LED strobe lights, installed as part of System A, were very effective during the day.

Most operators agreed that the systems are not the "be-all-end-all" to reducing pedestrian-bus collisions and that the manufacturers need to "tweak" the systems and "get the bugs out." One group thought that many operators would be supportive of an improved system; however, they also felt that, no matter what, a small number of operators may not be supportive, including more senior/experienced operators that are "stuck in their ways" and are unwilling to accept new technologies, a sentiment that supports the findings from the comprehensive survey regarding the perceptions of more senior operators.

Impacts on Pedestrian and Cyclist Behaviors

Overall, operators reported that they observed some changes in pedestrian behaviors, but probably not as much as hoped (25–50 instances estimated by one group). Operators provided a few examples, most of which involved a pedestrian or pedestrians looking up after hearing a warning. One operator offered that people do look up, but that they do not change their behavior because they know they have the right-of-way. Another operator reported that a pedestrian did not walk in front of the bus after alighting and hearing the message annunciate while the bus was pulling away from the stop. Another operator reported that two people approaching the crosswalk stopped after hearing the warning. Finally, one operator witnessed two pedestrians that were jaywalking turn, look, and hurry across the street after hearing the warning.

With respect to cyclists, one operator felt that System B was effective at warning cyclists when approaching in the new, quieter buses; however, overall, most operators agreed that the turn warning systems had far less effect on cyclist behaviors than on pedestrian behaviors. Instead, they felt that the turn signal better informs cyclists of what the bus is doing. Operators reported a number of reasons why the turn warning systems are less effective for cyclists than for pedestrians, including that cyclists are "in their own world" (e.g., wearing headphones) even more so than pedestrians; they move more fluidly than pedestrians and too fast for an auditory warning to be effective; and they plan their paths/maneuvers differently than pedestrians, as they can maneuver around buses to avoid them.

Advantages and Disadvantages of the Systems

System advantages and disadvantages, as reported by operators, generally fell into the following five categories:

- Automatism of systems
- Warning messages/tones
- Volume of warnings
- Lighting
- Impact of systems on job

Table 6-10 summarizes the advantages and disadvantages from the operators' perspectives. Overall, the automatism of the warning systems was viewed as both advantageous and disadvantageous. Operators in two of the focus groups felt that the automated nature of the systems provided consistency in when the warnings were activated, and they expressed concerns that some operators would turn the systems off if they could. On the other hand, operators in one of the focus groups felt the automated nature of the systems was a disadvantage, particularly with regard to warning volume. Operators in all focus groups felt that the fixed volume was a disadvantage and that the volume was either too loud or not loud enough. Although the volumes were too high at first, adjustments were made due to public complaints; however, volumes may now be too low to be effective. Operators noted that it would be good to be able to turn the volume up or down, depending on the location or time of day. It should be noted that one of the systems was supposed to automatically adjust to the ambient noise; however, it was not clear if this feature was working properly.

Table 6-10

System Advantages and Disadvantages as Reported by Operators

Categories	Advantages	Disadvantages
Automatism	• Provides consi cy in when warnings are activated (operators might turn them off otherwise). • System activated with turn-signal does provide operators with some control (when system is on/off).	• Lack of control (e.g., would be good to be able to turn up/down volume): – Either too loud or not loud enough. Too loud at first. After adjusting due to public complaints, may now be too low to be effective. Can no longer hear the spoken warnings inside bus. • Warnings sound when not needed: – Beeping warning tied to turn signal sometimes activates during lane changes and in curves. – One of the systems tied to steering angle would continue to make the announcement when parked with curbed wheels. – Systems tied to steering angle do not always come on soon enough. • Operators may not use turn signal when they should (to purposefully avoid activating the beeping warning).
Warning messages/ tones	• Spoken warning could help the visually impaired: – Sight impaired passenger asked about warning and reported liking it. • Beeping warning: – Universal/recognized sound. – "Piercing tone" more effective than spoken warnings at getting people's attention; they can hear it. – Have direct control over when it comes on/off. • Spoken warnings: – Tell pedestrians specifically what is happening.	• Beeping warning: – Sounds too much like ADA/kneeling bus/backing truck; blends in as one thing; might get tuned out. – Very irritating hearing it all day. – Not as obvious for sight impaired, spoken warnings are better. • Spoken warnings: – "Caution bus is turning"—goes off only once. Needs to repeat during whole turn.
Volume	Loud, because needs to be heard.	Beeping is very loud, even distracting to a driver.
Lighting	LED cornering headlights help operators at night to see in the direction that the bus is turning; need more lights on buses. LED strobes help at night.	None noted.
Job impact	Helps with job.	Repetition/volume can be distracting.

The purely automated nature of the systems created certain issues that operators found to be erroneous and/or annoying. For example, the systems tied to the turn of the wheel sometimes would activate when navigating sharp roadway curves or during lane changes, and one of these systems would continue to make the announcement when parked with curbed wheels. These problems were mitigated somewhat via system adjustments, but both continued to happen in some cases. In addition, a few operators noted that the systems tied to the steering angle would not always activate early enough in a turn to be effective.

The system that activates with the turn signal also was thought to have its own advantages and disadvantages. One operator noted that he had used the system to warn bicyclists (in one specific location where they are often not paying attention) that the bus was approaching from behind. Even though the bus was not turning or changing lanes, a quick activation of the turn signal would initiate the beeping to warn the cyclists. Alternatively, other operators felt that the turn-signal activation could be a drawback, as operators may not use their turn signals when they should just to avoid hearing the beeping or to avoid the system activating during lane changes.

There was a variety of viewpoints regarding the advantages and disadvantages of the individual warnings. Operators felt the advantages of the beeping warning were that it was more effective than the spoken warnings at getting people's attention, it is a "universal," recognizable sound, and they had more direct control over it, as it is activated by the turn signal. On the other hand, operators felt a disadvantage of the beeping warning is that it sounds too much like the noise used when the bus is kneeling and/or that of a backing truck, and that the warning might blend in or get tuned out. Other disadvantages noted with respect to the beeping warning were that it gets irritating and that its meaning is not obvious for people with sight impairments; however, an operator from one focus group noted that a blind passenger did inquire about what the beeping and reportedly liked it once he/she was told what it was for.

Operators felt that the advantage of the spoken warnings is that they tell people specifically what is happening (i.e., that the bus is turning). On the other hand, operators in one focus group felt that a disadvantage of one of the spoken messages was that it went off just once; they thought that it should repeat throughout the entire turn.

Operators in one focus group felt the higher volume warnings were an advantage because they need to be heard; however, some operators felt that if the volume is too loud, the warnings could become distracting to drivers (particularly the beeping warning).

Operators overwhelming reported the direction LED headlights as an advantage to one of the systems, as operators "need more lights on the buses." Operators unanimously agreed that the headlights helped to see in the direction of the turn at night. Most operators felt that the LED strobe lights were somewhat effective at night, but they did not feel like they were effective during the day.

A final advantage noted of the systems in one focus group was that the systems help the operators with their jobs; on the contrary, operators in two focus groups noted that the repetition of the warnings can be distracting.

Following the discussion on System D disadvantages, operators were asked if the identified problems were corrected, would the systems be more effective.

Overall, operators were divided on whether improvements to the systems would increase their effectiveness. The majority seemed to agree that addressing the problems would be a "plus," but that the systems are still not going to work in every situation. While some felt that improvements to the volume, added operator controls, and addition training might help, others felt like the systems are as effective as they are going to be. This sentiment seemed to be associated with the level of pedestrian distraction witnessed daily by operators, and that the systems cannot make up for pedestrian distraction/use of headphones/earbuds. Operators reported that pedestrians also need to be accountable for their own safety. One operator noted that the systems "address a problem that should not be there; either way it is on the operator to stop."

Warning Volume and Messages

The two primary issues associated with the warnings were the volume of the warnings and the actual warning/message used. Each of these issues was discussed with the operators during the focus groups. The findings are summarized below.

Warning Volume

Getting the volume settings of the warnings right was an issue throughout the duration of the demonstration test. After early complaints by operators, passengers, and residents along the routes, the volumes were turned down. Noise complaints then declined, but a growing number of operators also reported in the daily surveys that the volume had become too low to be effective. To explore this issue further, operators were asked if they thought it was the higher volume that people were complaining about or if it was something else.

The majority of operators agreed that the volume setting was at least part of the problem, as the operators, as well as passengers inside the bus, could hear the warnings. Many operators also felt that the repetition and/or the frequency of the warnings may have also been an issue. Warning repetition was more likely an issue for the operators themselves, as well as passengers; hearing the warning at every turn, particularly with the warning that repeated throughout the turn ("Pedestrians, bus is turning"). Warning frequency was more likely an issue for residents along the bus routes, particularly routes or times with frequent bus service.

Operators felt that at least some of the complaints were cultural in nature. For example, many of the complaints came from one particular neighborhood from which TriMet has received complaints from in the past. In addition, operators reported that, in their opinion, Portland is "a city of complainers." Valid or not, one operator pointed out that, as this is a safety issue that is being addressed, he/she would rather have 50 complaints than 1 injury.

Warning Messages/Tones

Operators in all four focus groups agreed that the message, "Caution, bus is turning" is better than the message, "Pedestrians, bus is turning." Reasons for this preference were numerous, and included the following:

- Overall, the word "caution" is better than the word "pedestrians" for the following reasons noted by operators:
  - "Caution" means "warning."
  - "Caution" is more universal, less specific.
  - "Caution" pulls more attention.
  - "Caution" gets the point across.
  - "Pedestrians" is not as clear.
  - "Pedestrians" is too specific; does not include bicyclists, others.
  - "Pedestrians" is too "sensitive."
  - "Pedestrians" (or possibly the tone used) is "rude."
- The repetition of the message, "Pedestrians, bus is turning" was not well-received by some operators:
  - Repeating is not good; it gives operators headaches.
  - Announcing the warning just once is preferred.
- Somewhat surprisingly, and despite its drawbacks, many operators preferred the beeping warning, including reasons beyond the warning itself:
  - Beeping is a universal warning/tone.
  - Beeping may be better for non-English speakers.
  - Beeping is best because it is noticeable/gets attention.
  - Beeping warning system offered some level of operator control (via the turn signal).
  - When the bus was stopped, the warning stopped.
  - Increased/faster tone from idling at intersections into acceleration and turn.

Effectiveness at Bus Stops

While not specifically designed for activating at bus stops, many agencies do experience pedestrian-bus collisions when pulling into and/or out of stops. Initially, the two turn warning systems activated by the steering angle were set to be sensitive enough to activate at some service stops, depending on the nature of the stop (e.g., when pulling out of the travel lane versus stopping in travel lane). Due to false activations in sharp roadway curves early on in the demonstration, the steering angles were adjusted on one of the two systems, which may have affected the frequency with which these systems activated at stops. Assuming operators used their turn signals at stops, the system activated by the turn signal would activate both into and out of these stops.

During the focus groups, operators reported that most of the time the spoken warnings (those activated by the steering angle) were not activated at service stops, but that the beeping warning (activated by the turn signal) was usually activated. Operators were asked if they felt the warnings were necessary and/or effective in these situations.

Operators overwhelmingly felt that the warnings were effective at service stops, with some reporting that the warnings may be as or more effective at service stops than at intersections. Most felt that the warnings were necessary/effective both when pulling into a stop and when pulling away from a stop. Some operators felt the warnings were more necessary/effective when pulling into a stop, particularly in getting the attention of people (especially children) standing too close to the curb. A few operators did not like the idea of the warnings activating at bus stops, as they felt the warnings came on too frequently. One operator reported that if people are standing too close to the curb he/she would pull into another location or use the horn.

While both of the spoken messages indicated that the "bus is turning" for this demonstration project, theoretically, the messages used at bus stops could be different than those used at intersections. Operators in one focus group suggested the message: "Caution, bus is moving." Other options included "Caution, bus is approaching" (when pulling into a stop) and "Caution, bus is moving right/left" (when pulling into/out of a stop).

Ideal Turn Warning System

To better understand what they might be looking for in terms of a better system, operators were asked the following questions: "If you could start from scratch, what would your ideal turn warning system look like? What features would it have?" In addition, to more thoroughly explore the issue of operator control, operators were asked, "Do you think some kind of operator control should be designed into the system?" "If so, how would that work?"

The discussions surrounding these questions resulted in a variety of suggestions and recommendations for improved systems, which can be grouped in the following categories:

- Warning messages/tones
- Activation of warnings
- Operator control
- Lighting

Beyond the pros, cons, and comparisons of the warning messages/tones already discussed, operators made some specific recommendations for an "ideal" turn warning system message. With respect to warning message, operators offered some interesting and creative suggestions. There was a lot of discussion about coming up with unique, easily-recognizable sounds that would be associated with buses. Operators likened this to the "bong-bong" alerts of the MAX trains. In addition, like the "bong-bong" of the Max trains, this unique bus sound should be "friendly" so as not to be irritating to pedestrians or operators.

To get people's attention and to prevent people from tuning out the warnings, many operators agreed that the messages should vary day-to-day or week-to-week. This approach might include changing the tone, message, and/or voices. One particularly comedic operator even offered some celebrity impressions with comical messages regarding pedestrian awareness and safety. Most operators agreed that making it "fun" would also potentially make the systems more effective.

With respect to repetition, there were mixed recommendations. Some operators recommended that the message (whatever it is) sound at least two times, while others were adamant that the warning only sound once. Operators in favor of repetition suggested that the first announcement be loud, followed by a second, lower-volume announcement or that a spoken warning be followed by a chime or tone (or vice versa).

Finally, operators in two of the groups recommended that the speakers be better located (e.g., front and side) and/or that warnings only sound in the direction of turn.

The majority of operators agreed that a more ideal system would involve tying the system to the turn signal (as opposed to the rotation of the steering column), selecting a lower speed threshold for warning activation (to reduce or eliminate activation of the warnings in sharp curves and during lane changes), and activating the system only when wheels are moving. Beyond the current features of the systems tested, operators in all of the groups offered some higher-tech solutions, including using sensors that read movement or body temperature and a system that could send an instant message to a pedestrian's/ cyclist's electronic device. Operators in a couple of the groups got into some detailed recommendations for a more "programmable," smarter system via integration with the buses' automatic vehicle location (AVL) system. Because the systems tested activated at every turn (and more), a primary concern for operators was that the warnings would either begin to blend into the background noise and/or that pedestrians would eventually tune them out altogether. Operators felt that this potential outcome might be avoided by programming the system to activate only when/ where necessary. Examples included programming the volumes to be louder in certain areas and during certain times of the day than others, activating the warnings only on routes and/or at intersections/locations with previous safety issues or pedestrian activity that might be problematic. In the end, a system that incorporates all of these suggestions is likely to be viewed as more effective by most operators.

The issue of operator control also generated mixed recommendations from operators. Most operators agreed that total operator control over the system is not a good idea; however, some operators advocated for some level of control in an ideal system. This control included the option to adjust the volume to a more appropriate level depending on conditions and/or to activate the system to send a targeted warning (prior to or outside of turning altogether, e.g., to people not paying attention and/or standing too close to the corner. Other operators strongly recommended that the operator be given no control over the system, stating that operators will not use the system correctly and/or they may take advantage of or abuse the system. Some operators felt strongly that operators should not be able to cover up or adjust speakers or change the volume of the warnings. In the end, an operator in one group noted that if the system was integrated with the CAD/AVL system and properly programmed, then no operator control features would be necessary.

Finally, operators offered a few suggestions regarding lighting. All operators wanted to see the directional LED headlights as part of an ideal system. Some advocated that an ideal system incorporate the LED strobe lights that were part of one of the systems tested and even suggested that brighter lights or a different color of lights might be more effective during the day. Improved forward headlights were also recommended. Finally, one operator recommended a "light show" under front bumper that changes continuously.

Summary/Conclusions

In summary, operators tended to agree on the following:

- Overall system effectiveness—As they were for the test, the turn warning systems are only somewhat effective at improving pedestrian safety, and pedestrians may eventually end up tuning out the warnings. Improvements, programming/customization, and some added operator control features could make the systems more effective. However, the systems are not the "be-all-end-all" to reducing pedestrian-bus collisions. Operators are still responsible for scanning for and yielding to pedestrians. Pedestrians also need to be accountable for their own safety (e.g., being more alert, respecting rules of the road), and this might be addressed through more public outreach and education.
- System effectiveness at bus stops—The warnings are as or more effective at stops than they are at intersections, both pulling into and pulling out of a stop, with pulling into a stop being the more critical movement for warning pedestrians.

- Effectiveness with cyclists—The turn warning systems are less effective with cyclists than with pedestrians primarily due to the way in which cyclists plan their paths, move, and maneuver within the traffic stream, as well as the speed at which they travel, as compared to pedestrians.
- Spoken message—"Caution, bus is turning" is a better warning/message than "Pedestrians, bus is turning."
- LED cornering headlights—The LED cornering lights are highly effective at allowing operators to see in the direction of the turn.

Operators did not always agree on the following:

- Beeping warning—Operators either liked or did not like the beeping warning. Some operators preferred it over the spoken messages because they felt it was more effective at getting people's attention. Other operators did not like it because it was too loud, harsh, irritating, and potentially distracting.
- Repetition of warning message/tone—As with the beeping warning, operators tended to sit firmly on one side or the other of the repetition issue. Some operators recommended that the message (whatever it is) needs to sound at least two times, while others were more adamant that the warning only sound once.
- Operator control—Most operators agreed that total operator control over the system is not a good idea; however, some operators advocated for some level of control, and others strongly recommended that operators be given no control over the system.

SECTION 7

Pedestrian/Cyclist Perceptions and Acceptance of the Technologies

As previously discussed, a three-step process was employed to assess the public's perceptions and acceptance of the technologies. This approach included conducting:

- Assessment of public complaints
- Field intercept survey of pedestrians and cyclists
- Focus groups with pedestrians and cyclists

This section presents the findings from the survey and the focus groups.

Assessment of Public Complaints

TriMet customer information maintained a log of complaints received from community members relating to the pedestrian warning systems. As shown in Figure 7-1, 42 complaints were logged over the seven-month test period. Complaints peaked in April following the first full month of deployment, and their frequency fell off fairly abruptly after that. This decline may be partly attributable to the lowering of warning volumes that took place in May. No complaints were logged during September, the final month of the test.

Figure 7-1

Public complaints about pedestrian warning systems by month

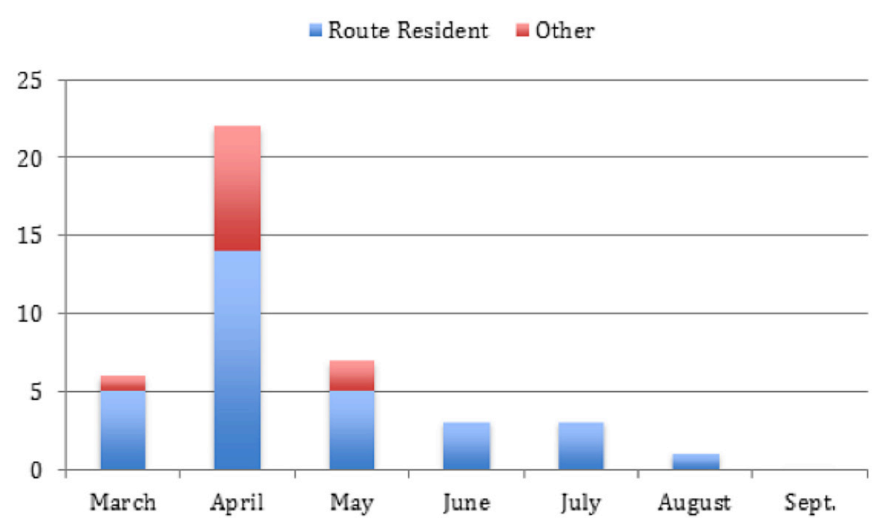


Figure 7-1 also distinguishes between complaints from persons who identified themselves as living along one of the test routes and those who did not. For those living along a test route, the 31 associated complaints consistently referred to the excessive volume of the warnings. The remaining 11 complaints included references to the warning systems as a waste of money, bus riders reacting to warning-related annoyances during their trip, characterizations of the demonstration as an over-reaction to a multiple fatality incident that had occurred four years prior, and references to false activations on curves.

Field Intercept Survey

The purpose of the field intercept survey was to collect data on pedestrian and cyclists perceptions of the effectiveness of the turn warning systems based on their exposure to the systems in an operational environment. Surveys were administered at five different intersections, including the intersection with the BUS blank-out signs. Figure 7-2 shows photo taken during the field intercept survey.

Figure 7-2
Administration of field intercept survey

A total of 454 surveys were administered at the 5 data collection sites previously described. The number of questions each respondent was asked depended mostly on where they took the survey. For example, respondents were asked questions only about the BUS blank-out sign at 5th and Burnside. Additionally, for those at 5th and Burnside, the number of questions depended on which turn warning system type the respondents had previous exposure to (auditory, BUS blank-out sign, or both). Therefore, the sample size associated with each survey question will vary. Table 7-1 shows the number of completed surveys by location and by warning type.

Table 7-1

Number of Completed Surveys by Location and Warning Type

Locations	Auditory Warning and BUS Blank-Out Sign	Auditory Warning Only	BUS Blank-Out Sign Only	Total
23rd Ave & Burnside St NW	N/A	67	N/A	67
46th Ave & Woodstock St SE	N/A	110	N/A	110
5th Ave & Burnside St NW	40	63	49	152
5th Ave & Madison St SW	N/A	58	N/A	58
6th Ave & Everett St NW	N/A	67	N/A	67
Total	*40*	*365*	*49*	*454*

Participants

Tables 7-2, 7-3, and 7-4 summarize respondent gender, age, and frequency of travel mode, including walking, cycling, and riding the bus. Table 7-2 shows that the survey sample over-represents male respondents (73%); however, the sample was distributed fairly evenly across age categories (Table 7-3). Table 7-4 breaks down how often respondents travel on foot, by bike, and by bus. A large majority of respondents (85%) reported that they walk at least once or twice a week, if not daily, while almost as many reported almost never or rarely cycling. Thus, relatively few cyclists were captured in the survey sample.[16] About 43% of survey respondents reported that they rode the bus at least once or twice a week, if not daily, with another 26% riding the bus less frequently. Therefore, a good portion of the survey sample was familiar with being a pedestrian around bus activity (e.g., at bus stops and intersections near bus stops).

Table 7-2

Gender Distribution of Respondents

Gender	Count (%)
Female	192 (27%)
Male	262 (73%)
Total	*454 (100%)*

Table 7-3

Age Distribution of Respondents

Age Categories	Count (%)
Under 25	53 (12%)
25–34	103 (23%)
35–44	98 (22%)
45–55	105 (23%)
56–64	56 (12%)
65 or older	39 (9%)
Total	*454 (100%)*

Table 7-4

Travel Mode Frequency Distribution of Respondents

Frequency of Travel	Number (%) as a Pedestrian	Number (%) as a Cyclist	Number (%) as a Bus Rider
Daily	393 (87%)	69 (15%)	217 (48%)
Once or twice a week	45 (10%)	62 (14%)	102 (22%)
A few times a month	1 (<1%)	34 (7%)	42 (9%)
Less than once a month	3 (1%)	25 (6%)	33 (7%)
Almost never	12 (3%)	264 (58%)	60 (13%)
Total	*454 (100%)*	*454 (100%)*	*454 (100%)*

Turn Warning Systems

To gauge the extent of exposure of the respondents to the turn warning systems, the survey inquired about how often they had heard the turn warnings from the TriMet buses. Survey participants were asked to respond according to how they traveled as a pedestrian, cyclists, or bus rider. Respondents who reported traveling both as a pedestrian and as a cyclist reported their frequency of exposure to the turn warning system from both perspectives. The responses are presented in Table 7-5.

Table 7-5

Respondent Exposure to Turn Warning Systems

Frequency of Travel	Number (%) as a Pedestrian	Number (%) as a Cyclist	Number (%) as a Bus Rider
Never	25 (6%)	110 (66%)	138 (38%)
Only a few times	145 (36%)	26 (16%)	80 (22%)
A few times a month	55 (14%)	8 (5%)	30 (8%)
Once a week	37 (9%)	3 (2%)	25 (7%)
A few times a week	64 (16%)	13 (8%)	41 (11%)
Almost daily	70 (18%)	6 (4%)	39 (11%)
Not sure	4 (1%)	0 (0%)	8 (2%)
Subtotal	400 (100%)	166 (100%)	361 (100%)
N/A	5	239	44
Total	*405*	*405*	*405*

In total, 42% of respondents reported that they had either never heard the turn warnings or that they had heard them only a few times as a pedestrian. When considering that 85% of the respondents reported walking at least once or twice a week (70% daily), this non-exposure rate is quite high. Although the surveys were conducted at intersections along the test routes, the relatively small number of test buses on each route likely contributed to this high non-exposure rate. About 43% of respondents, however, reported that they had heard the turn warnings at least once a week as a pedestrian over the study period and could be considered to have sufficient exposure to the systems to make meaningful assessments of their effectiveness.

The results for bus riders are somewhat surprising, as 38% of respondents reported they had never heard the turn warnings as a bus rider, and another 22%

reported having heard the turn warnings only a few times. This suggests that these respondents were either infrequent riders or did not hear the warnings while on the bus or before/after riding the bus. About 29% of respondents reported hearing the turn warnings once a week or more as a bus rider.

The exposure rate was even lower for cyclists. Of the respondents who reported cycling, 66% had never heard the warnings, and another 16% heard the warnings only a few times. In fact, only 19% reported having heard the warnings at least a few times a month.

Respondents were asked to report what warnings they had heard. This question was posed to verify not only that the respondents had actually heard the warnings, but to determine if they could recall what they had heard. The responses are shown in Table 7-6. Some respondents included lengthy answers to this open-ended question. When individual responses included portions that could be considered separate thoughts, they may have been recorded in more than one category, resulting in a greater number of responses than respondents.

Table 7-6

Respondent Descriptions of Auditory Warning

Description of Warning	Count (%)
rning/bus turning	134 (27%)
Voice	107 (22%)
Beep	74 (15%)
Pedestrians, bus turning	28 (6%)
Caution, bus turning	26 (5%)
Left or right	26 (5%)
Warning, bus turning	12 (2%)
Caution	11 (2%)
Loud/annoying	8 (2%)
Robot	6 (1.2%)
Female/lady	4 (0.8%)
Sound/noise	3 (0.6%)
Attention	3 (0.6%)
Pedestrian something	2 (0.4%)
Warning	2 (0.4%)
Bus moving	2 (0.4%)
Warning use crosswalk	2 (0.4%)
Bus leaving stop/pulling away from curb	1 (0.2%)
Approaching	1 (0.2%)
Wait	1 (0.2%)
Pull out warning	2 (0.4%)
Other	27 (5%)
Don’t remember/not sure	13 (3%)
Total responses	*495* (100%)*

* 405 respondents. Some respondents provided multiple responses.

About 55% of the responses were accurate recollections of the actual warnings (i.e., "bus turning," "caution," "pedestrians," "beep"). About a quarter of the responses were more general, such as "voice," "female/lady," and "sound/noise." About 5% inaccurately recalled directional information (left/right) in the warnings, and 3% were not sure or could not remember. The "Other" category included responses that did not make sense or were irrelevant to this particular question.

System Effectiveness

Next, respondents were asked to rate the effectiveness of the turn warning systems in alerting pedestrians and in improving pedestrian safety when a bus is turning. Respondents rated effectiveness from the standpoint of a pedestrian, cyclist, and/or bus rider, and the questions varied depending on which perspective pertained. For example, only pedestrians were asked about the effectiveness of the systems at intersections, only bus riders were asked about the effectiveness of the systems at bus stops, and only cyclists were asked about the effectiveness at both intersections and bus stops. Responses from the pedestrian, cyclist, and bus rider perspectives are shown in Table 7-7, 7-8, and 7-9, respectively.

Table 7-7

Effectiveness of Turn Warning System – Perceptions as a Pedestrian

Based on your experience as a pedestrian, how effective do you think the turn warning systems are at …	Not At All Effective	Slightly Effective	Effective	Very Effective	Not Sure	Total
Alerting pedestrians that a bus is turning at an intersection	42 (11%)	88 (23%)	117 (31%)	116 (31%)	17 (4%)	380 100%)
Improving pedestrian safety when a bus is turning at an intersection	41 (11%)	77 (20%)	130 (34%)	112 (29%)	20 (5%)	380 100%)

Table 7-8

Effectiveness of Turn Warning System – Perceptions as a Cyclist

Based on your experience as a cyclist, how effective do you think the turn warning systems are at…	Not At All Effective	Slightly Effective	Effective	Very Effective	Not Sure	Total
Alerting cyclists that a bus is turning at an intersection	9 (15%)	16 (27%)	16 (27%)	16 (27%)	2 (3%)	59 (100%)
Alerting cyclists that a bus is pulling into a bus stop	12 (20%)	16 (27%)	14 (24%)	14 (24%)	3 (5%)	59 (100%)
Alerting cyclists that a bus is pulling away from a bus stop	8 (14%)	18 (31%)	15 (25%)	13 (22%)	5 (8%)	59 (100%)
At improving cyclist safety when a bus is turning at an intersection	8 (14%)	11 (19%)	21 (36%)	15 (25%)	4 (7%)	59 (100%)
At improving cyclist safety near bus stops	7 (12%)	13 (22%)	21 (36%)	14 (24%)	4 (7%)	59 (100%)

Table 7-9

Effectiveness of Turn Warning System – Perceptions as a Bus Rider

Based on your experience as a bus rider, how effective do you think the turn warning systems are at …	Not At All Effective	Slightly Effective	Effective	Very Effective	Not sure	Total
Alerting bus riders that a bus is pulling into a bus stop	48 (21%)	33 (15%)	62 (28%)	56 (25%)	25 (11%)	224 (100%)
Alerting bus riders that a bus is pulling away from a bus stop	48 (21%)	33 (15%)	65 (29%)	49 (22%)	29 (13%)	224 (100%)
Improving bus rider safety at bus stops	43 (19%)	34 (15%)	70 (31%)	59 (26%)	18 (8%)	224 (100%)

The pedestrian responses were very similar for the effectiveness of the systems at both alerting pedestrians and at improving safety during turns, with more than 62% of pedestrians reporting that the systems are effective or very effective. Only 11% of pedestrians reported that the systems were not at all effective in either circumstance.

The cyclist responses, shown in Table 7-8, were very similar for each of the five questions related to the effectiveness of the systems. With respect to alerting cyclists, about half agreed that the systems were effective or very effective (56% when a bus is turning at an intersection and 48% when a bus is pulling into or away from a bus stop). More than half the respondents (62%) felt that the systems improved cyclist safety when a bus was turning at an intersection as well as near bus stops.

The bus rider responses, shown in Table 7-9, were very similar for each of the three questions related to the effectiveness of the systems. Just over half—55% and 54%—reported that the systems were effective or very effective at alerting them when a bus was pulling into or away from a bus stop, respectively. A slightly higher share—59%—felt the warnings were effective or very effective at improving safety at bus stops.

Respondents also were asked if there had been a particular situation where they felt the turn warning systems helped them avoid a collision with a bus. Tables 7-10 and 7-11 show the responses and the circumstances (from a follow-up question) for those who indicated yes, respectively. About 12% of pedestrians indicated the warning system had helped them avoid a collision with a bus when crossing at an intersection (Table 7-10). Table 7-11 shows a breakdown of the circumstances described by those who had responded yes in Table 7-10. More than half indicated that the system alerted them, caught their attention, or the person was distracted. One-quarter indicated that the warning made them stop, slow down, or look.

Table 7-10

System Effectiveness in Avoiding a Collision – Pedestrians

Has there been a particular situation where you felt that the turn warnings helped you avoid a collision with a bus when crossing at an intersection?	Count (%)
No	333 (80%)
Yes	47 (12%)
Total	*380 (100%)*

Table 7-11

Description of Collision Avoidance Situations – Pedestrians

Responses	Count (%)
Alerted me/caught my attention/distracted	38 (55%)
Stopped moving or slowed down or made me look	17 (25%)
Phone	3 (4%)
Inebriated	2 (3%)
Thought had signal	2 (3%)
Other	7 (10%)
Total	*69* (100%)*

* 47 respondents. Some respondents provided multiple responses.

Tables 7-12 and 7-13 show the corresponding responses for cyclists. Only 10 of 59 cyclists, or 17%, indicated that the warning helped them avoid a collision with a bus. Of those who indicated "yes," 7 (58%) reported that the system alerted them, caught their attention, or that they were distracted. Two respondents (17%) said that the warning made them stop, slow down, or look.

Table 7-12

System Effectiveness in Avoiding a Collision – Cyclists

Has there been a particular situation where you felt that the turn warnings helped you avoid a collision with a bus while biking?	Count (%)
No	49 (83%)
Yes	10 (17%)
Total	*59 (100%)*

Table 7-13

Description of Collision Avoidance Situations – Cyclists

Responses	Count (%)
Alerted me / caught my attention / distracted	7 (58%)
Stopped moving or slowed down or made me look	2 (17%)
Other	3 (25%)
Total	*12* (100%)*

* 10 respondents. Some respondents provided multiple responses.

Tables 7-14 and 7-15 show the responses for bus riders. A total of 16 of the 224 bus riders, or 7%, indicated the warning system had helped them avoid a collision with a bus at a bus stop. Of those who indicated "yes," 11 (61%) reported that the system alerted them, caught their attention, or that they were distracted.

Table 7-14

System Effectiveness in Avoiding a Collision – Bus Riders

Has there been a particular situation where you felt that the turn warnings helped you avoid a collision with a bus at a bus stop?	Count (%)
No	208 (93%)
Yes	16 (7%)
Total	*224 (100%)*

Table 7-15

Description of Collision Avoidance Situations – Bus Riders

Responses	Count (%)
Alerted me/caught my attention/distracted	11 (61%)
Tailgate or squeeze you	2 (11%)
Phone	1 (6%)
Other	4 (22%)
Total	*18* (100%)*

* 16 respondents. Some respondents provided multiple responses.

System A Acceptance

To better understand respondents' level of acceptance of the turn warning systems, a series of questions was posed. The first two questions related to the perceived intrusiveness of the turn warning systems. The next two questions asked respondents to compare the potential benefits of the systems to the perceived drawbacks. The final two questions related to respondent support for more widespread deployment of the turn warning systems.

First, respondents were asked if they found the auditory turn warning systems to be intrusive to the environment. Then, those who responded affirmatively to this question were asked to rate the level of intrusiveness for the spoken warnings and the beeping warning separately. The responses to these questions are shown in Tables 7-16 and 7-17, respectively.

Table 7-16

Respondent Perceptions of Intrusiveness

Are the auditory warnings intrusive to the environment?	Count (%)
No	191 (65%)
Yes	101 (35%
Total	*292 (100%)*

Table 7-17

Respondent Perceptions of Intrusiveness by Warning Type

How intrusive do you find the …	Only Slightly Intrusive	Intrusive	Very Intrusive	Not Sure	Total
Spoken warnings	35 (35%)	35 (35%)	26 (26%)	5 (5%)	101 (100%)
Beeping warning	35 (35%)	20 (20%)	25 (25%)	21 (21%)	101 (100%)

Nearly two-thirds of the respondents (65%) reported that the turn warning systems were not intrusive to the environment. Among the 35% who did find the warnings to be intrusive, the reported level of intrusiveness for the spoken warnings was distributed fairly evenly, with a little more than one-third reporting them to be only slightly intrusive and another one-third reporting them to be intrusive. About one-quarter reported that the warnings were very intrusive. Intrusiveness ratings were distributed somewhat differently for the beeping warning, with a smaller share of respondents (20%) finding the beeping warning to be intrusive and a comparatively larger share (21%) reporting that they were not sure.

To determine if level of exposure to the systems impacted respondents' perceptions of intrusiveness, these factors were compared using a contingency analysis. The findings, which are shown in Table 7-18, were not significant, meaning perceived intrusiveness did not vary with the level of exposure to the systems.

Table 7-18

Respondent Perceptions of Intrusiveness by Level of Exposure

Do you find audible warnings to be intrusive to the environment?	Exposed Only a Few Times	Exposed a Few Times a Month	Exposed Once a Week	Exposed a Few Times a Week	Exposed Almost Daily	Total
No	55 (69%)	27 (64%)	16 (53%)	38 (72%)	51 (67%)	187 (67%)
Yes	25 (31%)	15 (36%)	14 (47%)	15 (28%)	25 (33%)	94 (33%)
Total	*80 (100%)*	*42 100%)*	*30 (100%)*	*53 (100%)*	*76 (100%)*	*281 (100%)*

Next, perceived intrusiveness by travel mode was compared using a contingency analysis. For this analysis, only those respondents that had reported hearing the warnings a few times a week or daily were included in the analysis. The findings are shown in Table 7-19, which shows that there was almost no difference in perceived intrusiveness between pedestrians and bus riders, with just under one-third finding the warnings intrusive to the environment. None of the cyclists found the warnings to be intrusive, although the number of cyclists exposed to the warnings weekly was quite low.

Table 7-19

Respondent Perceptions of Intrusiveness by Travel Mode

Do you find audible warnings to be intrusive to the environment?	Travel as a Pedestrian	Travel as a Cyclist	Travel as a Bus Rider
No	70 (68%)	11 (100%)	55 (69%)
Yes	33 (32%)	0 (0%)	25 (31%)
Total	*103 (100%)*	*11 (100%)*	*80 (100%)*

The second set of questions assessing the level of acceptance related to whether respondents perceived that the potential benefits of the turn warning systems outweighed any associated drawbacks. Respondents gave separate responses for the two types of warnings, as shown in Table 7-20. Again, the breakdown of ratings was very similar for the spoken and beeping warnings. A large majority of respondents strongly or somewhat agreed that the potential benefits of the turn warning systems outweighed any associated drawbacks (78% for the spoken warnings and 73% for the beeping warning). Very few respondents (less than 10%) disagreed or strongly disagreed.

Table 7-20

Respondent Perceptions Regarding Potential Benefits of Systems Compared to Drawbacks

To what extent do you agree or disagree with the following statements:	Strongly Disagree	Somewhat Disagree	Do Not Agree or Disagree	Somewhat Agree	Strongly Agree	Not Sure	N/A	Total
The potential benefits of the systems with the spoken warnings outweigh any associated drawbacks.	14 (4%)	20 (5%)	39 (10%)	120 (31%)	178 (47%)	10 (3%)	24	381 (100%)
The potential benefits of the systems with the beeping warning outweigh any associated drawbacks.	19 (6%)	19 (6%)	22 (7%)	102 (33%)	123 (40%)	21 (7%)	99	306 (100%)

The final two questions to assess level of acceptance concerned whether the respondents would like to see the turn warning systems installed on more buses. The findings are shown in Table 7-21. A majority of respondents agreed or strongly agreed with the idea of wider deployment (68% for the spoken warnings and 61% for the beeping warnings); however, this percentage was lower than the percentage that had previously agreed that the benefits of the systems outweighed the associated drawbacks.

Table 7-21

Respondent Perceptions Regarding Installation of More Systems

To what extent do you agree or disagree with the following statements:	Strongly Disagree	Somewhat Disagree	Do Not Agree or Disagree	Somewhat Agree	Strongly Agree	Not Sure	N/A	Total
I would like to see the systems with the spoken warnings installed on more TriMet buses.	39 (10%)	33 (9%)	33 (9%)	86 (23%)	175 (46%)	15 (4%)	24	381 (100%)
I would like to see the turn system with the beeping warning installed on more TriMet buses.	37 (12%)	40 (13%)	21 (7%)	82 (27%)	106 (35%)	20 (7%)	99	306 (100%)

To explore this further, a comparison was made between respondent perceptions regarding the potential benefits of the systems (survey questions 11a and 11b for the spoken warnings and beeping warning, respectively) and whether or not they would like to see more systems installed on TriMet buses (survey questions 11c and 11d for the spoken warnings and beeping warning, respectively). The findings for the spoken warnings are presented in Table 7-22, and the findings for the beeping warnings are presented in Table 7-23.

Table 7-22

Perceived Benefits vs. Installation of More Systems with Spoken Warnings

Question 11c): ***I would like to see the turn warning systems with the spoken message installed on more TriMet buses.***	Strongly Disagree	Somewhat Disagree	Do Not Agree or Disagree	Somewhat Agree	Strongly Agree	Not Sure	Total
Strongly disagree	86%	60%	13%	3%	2%	20%	39
Somewhat disagree	14%	30%	18%	10%	3%	10%	33
Do not agree or disagree	0%	0%	23%	15%	3%	0%	33
Somewhat agree	0%	10%	21%	40%	15%	20%	86
Strongly agree	0%	0%	18%	27%	76%	0%	175
Not sure	0%	0%	8%	5%	1%	50%	15
Total	*14*	*20*	*39*	*120*	*178*	*10*	*381*

*Q11a: The potential benefits of the turn warning systems with the spoken messages outweigh any associated drawbacks.

Table 7-23

Perceived Benefits vs. Installation of More Systems with the Beeping Warning

Question 11d): ***I would like to see the turn warning systems with the beeping warning installed on more TriMet buses.***	Strongly Disagree	Somewhat Disagree	Do Not Agree or Disagree	Somewhat Agree	Strongly Agree	Not Sure	Total
Strongly disagree	95%	16%	18%	4%	3%	19%	37
Somewhat disagree	5%	58%	27%	15%	3%	14%	40
Do not agree or disagree	0%	0%	23%	10%	4%	5%	21
Somewhat agree	0%	11%	32%	48%	19%	5%	82
Strongly agree	0%	5%	0%	19%	70%	0%	106
Not sure	0%	11%	0%	5%	1%	57%	20
Total	*19*	*19*	*22*	*102*	*123*	*21*	*306*

*Q11b: The potential benefits of the turn warning systems with the beeping warning outweigh any associated drawbacks.

If respondents agreed or strongly agreed that the systems offered benefits that outweighed the drawbacks, one would expect that they would also agree that more systems should be installed. Likewise, if respondents disagreed or strongly disagreed that the systems offered benefits that outweighed the drawbacks, it would be expected that these same respondents would also disagree that more systems should be installed.

A majority of responses did correspond with these expectations, as is shown in the shaded cells in the diagonals of both tables. On the negative end of the spectrum, the anticipated results held true for all respondents who strongly disagreed to benefits for both types of systems – in other words, when respondents strongly disagreed that there were benefits that outweighed the drawbacks, they also strongly disagreed that more systems should be installed. Ninety percent of the respondents that somewhat disagreed to benefits for the spoken warnings either disagreed or strongly disagreed to further deployment. For those that somewhat disagreed to benefits of the beeping warnings, however, there were as many that felt more systems should be installed as felt more systems should not be installed (16%).

On the positive end of the spectrum, there appears to be somewhat less conviction towards further deployment from those respondents who strongly agreed to system benefits; of the 178 people who strongly agreed to benefits of the systems with the spoken warnings, 15% only somewhat agreed to further deployment, and 5% disagreed (3% did not agree or disagree). The corresponding percentages for the system with the beeping warning were slightly higher (19% only somewhat agreed to further deployment, 6% disagreed, and 4% did not agree or disagree). For those who only somewhat agreed that the systems offered benefits that outweighed the drawbacks, only two-thirds supported further deployment of both types of system, while about 13% and 19% did not support further deployment of the spoken warnings and beeping warnings, respectively.

For both types of warnings, respondents who were neutral about the benefits were about evenly split when it came to whether they thought more systems should be installed, with a few more agreeing to further deployment of the spoken warnings and a few more disagreeing to further deployment of the beeping warnings. About half of the respondents that were unsure as to the benefits were also unsure about whether more systems should be installed.

These findings suggest that there is a small portion of the population that, while they may agree that the systems offer benefits that outweigh the associated drawbacks, do not agree that more systems should be installed. This may reflect a sentiment that the money that would be needed to make this investment could be better spent on other improvements.

BUS Blank-Out Sign

To assess pedestrian perceptions of the BUS blank-out sign, additional questions were included on the surveys that were administered at the intersection of SW 5th and Burnside. Respondents were asked how often they had seen the BUS blank-out sign, both as a pedestrian and as a cyclist. The findings are shown in Table 7-24. About half of the respondents reported that they had seen the sign only a few times or never. The remaining half reported that they saw the signs more frequently, with 22% having seen them almost daily. Fewer than 10% of the respondents had seen the sign as a cyclist.

Table 7-24

Respondent Exposure to BUS Blank-Out Signs

Over the past few months, how often have you seen the electronic BUS signs at this intersection in the following situations:	Never	Only a Few Times	Few Times a Month	Once a Week	Few Times a Week	Almost Daily	Not Sure	Total
As a pedestrian	5 (6%)	37 (42%)	9 (10%)	7 (8%)	10 (11%)	20 (22%)	1 (1%)	89 (100%)
As a cyclist	82 (92%)	2 (2%)	2 (2%)	2 (2%)	0 (0%)	1 (1%)	0 (0%)	89 (100%)

Similar to the question for auditory warnings, respondents were asked what warning they had seen. This question was posed to not only verify that the respondents had actually seen the blank-out sign, but to determine if they could recall what they had seen. The responses are shown in Table 7-25. Some respondents provided lengthy answers to this open-ended question; in some cases, portions of these responses were considered separate thoughts and were classified in more than one category, resulting in a larger number of responses than respondents.

Table 7-25

Participant Description of "BUS" Blank-Out Sign

Responses	Total (%)
"BUS"	56 (39%)
Flashing/linking	32 (23%)
Yellow	14 (10%)
Round/circle	7 (5%)
Gets attention/warns/effective	6 (4%)
Don't know/can't remember	5 (4%)
LED/light	5 (4%)
Orange	3 (2%)
Bright	2 (1%)
Symbol	2 (1%)
Turn/bus is turning	1 (1%)
Red	1 (1%)
White	1 (1%)
Need arrow	1 (1%)
Wonder where bus is	1 (1%)
Other	5 (4%)
Total responses	*142* (100%)*

* 89 respondents. Some respondents provided multiple responses.

About 39% of the responses were accurate recollections of the actual warning (i.e., BUS), and 33% were more general, indicating features of the sign such as "flashing," "blinking," and "yellow." One person correctly identified the intended meaning of the message as "bus turning." The "Other" category included responses that did not make sense or were irrelevant to this particular question.

Next, for those respondents who had seen the signs, the survey inquired about their perceived effectiveness in alerting pedestrians and improving pedestrian safety during turns. The findings are shown in Table 7-26. The distribution of responses is almost identical for both alerting pedestrians and improving pedestrian safety; just over half of respondents reported the signs to be effective or very effective. However, 29% reported the signs to be only slightly effective, and 13–14% reported the signs to be not at all effective.

Table 7-26

Effectiveness of BUS Blank-Out Signs

Based on your experience as a pedestrian, how effective do you think the BUS blank-out signs are at …	Not At All Effective	Slightly Effective	Effective	Very Effective	Not Sure	Total
Alerting pedestrians that a bus is turning	12 (14%)	24 (29%)	26 (31%)	21 (25%)	1 (1%)	84 (100%)
Improving pedestrian safety during turns	11 (13%)	24 (29%)	27 (32%)	20 (24%)	2 (2%)	84 (100%)

Next, respondents were asked if there was a particular situation or situations where they felt that the BUS blank-out signs helped them avoid a collision with a bus when using the treated crosswalk at SW 5th and Burnside. The responses are shown in Tables 7-27, showing that 23% of respondents reported that the signs had helped them avoid a collision with a bus. Conversely, none of the seven cyclists who responded to this question indicated that the blank-out sign had helped them avoid a collision while biking through this intersection.

Table 7-27

Avoiding a Collision – Pedestrians

Has there been a particular situation as a pedestrian where you felt that the electronic "BUS" warning signs help you avoid a collision with a bus when crossing at this intersection?	Count (%)
No	65 (77%)
Yes	19 (23%)
Total	*84 (100%)*

Respondents who indicated the BUS blank-out sign helped them avoid a collision with a bus were asked to describe the situation with an open-ended response. Table 7-28 shows a breakdown of the responses. A total of 30% of the responses described how the system alerted them, caught their attention, or that they were distracted, and 43% described how the blank-out sign made them stop, slow down, or look.

Respondents at SW 5th and Burnside were asked if they would like to see BUS blank-out signs installed at more intersections in Portland. The findings are shown in Table 7-29, with 73% either strongly or somewhat agreed that they would like to see the blank-out signs installed at more intersections, and only 11% strongly or somewhat disagreed with that statement.

Table 7-28

Description of Collision Avoidance Situations – Pedestrians

Responses	Count (%)
Alerted me/caught my attention/distracted	7 (30%)
Stopped moving/slowed down/made me look	10 (43%)
Crossing	3 (13%)
Phone	1 (4%)
Other	2 (9%)
Total	*23* (100%)*

* 19 respondents. Some respondents provided multiple responses

Two questions on the survey asked respondents to compare the effectiveness of the auditory warning systems to the effectiveness of the BUS blank-out signs. These questions were only posed to those who had been exposed to both the auditory warnings and the blank-out sign. Only four of the persons surveyed were exposed to both types of technologies, too few to allow a meaningful interpretation of their responses.

Table 7-29

Further Deployment of BUS Blank-Out Sign

Statement	Strongly Disagree	Somewhat Disagree	Do Not Agree or Disagree	Somewhat Agree	Strongly Agree	Not Sure	Total
I would like to see the systems with the spoken warnings installed on more TriMet buses.	4 (4%)	8 (8%)	10 (11%)	28 (31%)	37 (42%)	2 (2%)	89 (100%)

Summary/Conclusions

The overall sentiment from the results of this survey indicates a generally positive impression of the turn warning systems (including the BUS blank-out sign). A majority of respondents believed the systems were effective at alerting pedestrians about a turning bus as well as improving safety when a bus is turning at intersections. Additionally, most people did consider the systems to be intrusive. Those who did indicate that the systems were intrusive were distributed fairly evenly among the various levels of intrusiveness.

Most respondents also indicated that they agreed that the benefits of both the spoken and the beeping turn warning systems outweighed any drawbacks, although the spoken warnings were favored slightly. Additionally, a majority of respondents would like to see the systems installed on more TriMet buses, with more of the respondents expressing this sentiment for the systems with the spoken warning than for the system with the beeping warning. There was a high level of agreement among those who felt the benefits of the systems outweighed the drawbacks and the desire to have more of the systems installed on more buses. There was also a strong sentiment from the respondents about installation of more BUS blank-out signs. A majority of those exposed to the sign would like to see them installed at more intersections in Portland.

Pedestrian Focus Groups

As a follow-up to the pedestrian field intercept survey, three focus groups were conducted in September 2014 with a smaller set of pedestrians. Focus group participants were recruited during the field survey. In all, 27 people participated across the 3 focus groups.

At the start of each focus group, introductions were made, including number of years living in the Portland area, frequency of walking/biking, and overall exposure to the turn warning systems and BUS blank-out sign. Next, the focus group facilitator provided an overview of the project. Then, the goals of the focus group, which included developing a general sense of the participants' impressions about the systems and delving deeper into the issue of system effectiveness and the specifics associated with the warnings, were shared with the participants. Figure 7-3 is a photo taken during one of the pedestrian focus groups.

Figure 7-3

Pedestrian focus group

Auditory Warnings

Warning Type/Message

As previously discussed, three different warnings were used on the test buses:

- "Pedestrians, bus is turning."
- "Caution, bus is turning."
- Beeping warning

The pedestrian focus groups provided an opportunity to discuss the advantages and disadvantages of each warning. As such, in addition to the three warnings used on the test buses, four additional warnings were presented to and discussed with focus group participants. These warnings included:

- Turn indicator (clicking) noise.
- "Caution, bus moving left."
- "Caution, look both ways (with turn indicator noise)."
- "Caution, bus moving left. Pedestrians, look both ways."

These specific warnings were selected for a number of reasons. First, several are either in use or have been tested by other transit agencies. Second, they broaden the range of possible warnings, including noises verses spoken warnings (as well as a combination warning), short versus longer warnings, and warnings with a variety of detail in the message (e.g., action words, directional information).

Participants were shown short video clips of a bus making a left turn with each of seven auditory warnings (Figure 7-4). Participants were asked to observe each video clip and listen for the auditory warning. In order to better understand what qualities constitute a good warning, participants were asked to rate each warning on a number of factors.

Figure 7-4

Bus making left-turn with auditory warning

Following the rating exercise, participants were asked to select their top two or three warnings overall. The three warnings that received the most votes were:

- "Caution, bus is turning." (19 votes)
- "Caution, pedestrians; bus is approaching." (17 votes)
- "Pedestrians, bus is turning." (16 votes)

Next, participants were asked to indicate what it was that was "good" about their top warnings. Participants in all three groups noted that they selected warnings that were clear in meaning and easy to understand. Participants in groups two and three noted that their preferred warnings were concise, and participants in groups one and two selected warnings that indicated exactly what was happening. Most participants liked the word "caution," as it is direct and gets people's attention.

Qualities of a Good/Ideal Warning

- Clear meaning
- Concise
- Specific
- Direct
- Unique
- Loud enough to get attention
- Location/time specific

When asked what constitutes an "ideal" warning, participants reiterated that the warning needs to be clear, concise, and specific. In addition, ideal qualities of a warning reported by participants included "simple" and "direct." Participants in groups one and two indicated that the warning needs to be loud enough to get people's attention, while group three noted that the tone/quality of the warning should "stand out" and be audible over other noises. Participants also emphasized the importance of having a warning that is unique to buses (similar to the "bong-bong" of the Max light rail trains operated by TriMet). Other recommendations included a combination warning (spoken message along with some sort of noise) and/or a visual component to reinforce the warning (depending on the environment or ambient noise), one might be more noticeable. Participants in group two noted that the warning should start before the bus starts the motion of turning. They also advocated for "targeted," personalized warnings (similar to honking the horn to warn someone). They noted that the warnings (and volumes) should be relative to a particular place/location and that there should be an ability to program the systems to turn off when/where they are not needed. While some participants reported consistency as an important quality of a warning, others reported that changing the warnings would help keep the warnings from being tuned out.

To be Avoided in an Auditory Turn Warning

- Just another noise that blends into background
- Intrusive – "blaring" in every direction
- Directional information
- Too long/wordy
- Word "pedestrians" – too specific

Participants had a number of thoughts regarding what should be avoided in a warning. Although the warning needs to stand out and get people's attention, it should not be overly intrusive, "blaring in every direction," as one participant put it. In addition, an effective warning would be more than "just another noise," as there are already too many noises and beeps associated with other things. A warning/noise that lacks specificity or is not unique would be "useless." Most participants agreed that directional information (e.g., bus turning left/right) is confusing and possibly dangerous because it depends on the orientation of the pedestrian to the bus.

Most participants agreed that if a warning is too long or wordy, people would tune it out. In addition, there was concern that the bus would already be into the turn before the entire message was heard.

More specifically, the use of the word "pedestrians" and the warning "look both ways" were not popular amongst participants. Most participants agreed that the word "pedestrians" is too specific and should be avoided. Regarding "look both ways," participants noted that it is not specific enough and it does not give a reason for looking. Some participants reported that they look anyway, while a few others noted that it does not hurt to be reminded to do so. Finally, a few participants reported that the spoken messages were not good for non-English speakers.

Balancing Warning Volume and Intrusiveness

At the beginning of the demonstration test, there were a number of public complaints about the turn warning systems. Participants were asked if they thought these complaints were mostly about volume (as reported), or if they might have been about something else. Some thought the complaints were primarily about the initial volume levels. Participants in two of the groups reported that the volume of the spoken messages was acceptable once turned down, but that the beeping warning was still too loud. Participants reported that the complaints could also have been related to the frequency of the warnings. Several of the focus group participants reported that they lived or worked along one of the test routes, and that the warnings could be "noisy," "annoying," and "intrusive." One of the participants actually had called in a complaint to TriMet.

To more effectively balance the volume level between one that is perceptible and effective and one that is intrusive, participants offered a number of recommendations. Participants in groups one and two thought that operators should be allowed to adjust the volume as appropriate and/or be able to turn the system on/off as necessary. Participants in group two offered that the volumes should vary by time of day and/or the volumes should adjust automatically relative to the environment—loud enough to get above the ambient noise. Some participants reported that the warnings should only activate at turns (not bus stops), while others said that the warnings were not necessarily needed at every turn, rather only in specific "trouble" locations. One comment related to the directionality of the speakers in helping to channel the warning/noise in the right direction without impacting others all around.

BUS Warning Sign

As previously discussed, two BUS warning signs were installed at either end of one crosswalk at the intersection of SW 5th and Burnside in downtown Portland. While only one sign/message could be field-tested, the pedestrian focus group setting provided an opportunity to discuss the advantages and disadvantages associated with the test signs, as well as alternative sign designs. As such, three additional warning signs were presented and discussed with focus group participants. These warnings signs included:

- BUS TURNING
- LOOK BOTH WAYS
- Bus symbol sign

Participants were shown four photographs of the intersection of SW 5th and Burnside, which showed a bus in the left-turn lane and an active (blinking) warning side just above the pedestrian signal head (Figure 7-5). In each of the photographs a different depiction of the bus warning sign was demonstrated, as shown in Figure 7-6. Participants were asked to observe the warning sign in each photograph. In order to better understand what qualities constitute a good sign, participants were asked to rate each sign on a number of factors.

Figure 7-5

BUS blank-out sign at SW 5th and W Burnside

Figure 7-6

Alternative bus warning signs

Following the rating exercise, participants in the three groups were asked to select their top two signs overall. The BUS TURNING sign was greatly favored, with 23 votes, compared to only 14 votes for the LOOK FOR BUS sign (the BUS and symbol signs received only 8 and 4 votes, respectively).

Next, participants were asked to indicate what it was that was "good" about their top choices. Characteristics associated with all four signs, but that participants thought were good, included the location/position of the sign above the pedestrian signal head, that the signs were yellow and bright, and that they were flashing, which helps get pedestrians' attention.

In addition, participants selected signs that were clear, indicated what was happening, reinforced the DO NOT WALK, had an object and action, and that made sense in relation to where the pedestrian is standing. More specifically, BUS TURNING was noted as being more specific and indicating exactly what is happening.

When asked what constitutes an "ideal" sign, participants reiterated that the sign needs to be clear, specific, big, bright, and flashing. In addition, some participants thought that the sign should be used in conjunction with an audible warning, and some even reported that the audio should be customized ("branded") by TriMet. One specific recommendation was to put the message in a yellow triangle to indicate a warning.

Qualities of a Good/Ideal Bus Turning Warning Sign

- Clear meaning
- Specific
- Big
- Bright
- Flashing
- Location specific
- Used in conjunction with an audible warning

Some participants also noted concerns with the turning warning signs. They felt that some of the signs were not clear, as they were not sure for whom the sign was intended. While participants in all three focus groups liked the idea of a symbol sign because it is universal and gets around the language barrier, almost everyone agreed that this particular symbol needed improvement, such as showing the side view of a bus. One participant noted that he/she would not notice the symbol, another noted it was not clear for whom the sign was intended (pedestrians, bus, or both), while another noted it looked too much like the MAX train. Another suggestion for improvement was to add the word BUS or TURNING under an improved bus symbol.

Another concern was that the sign might be on all of the time at intersections where there are numerous turning buses, which might cause the sign to just "blend in" over time, and that if someone is going to ignore the DO NOT WALK, they will probably also ignore the bus warning sign. Finally, one participant noted that the three signs that did not specifically state that the bus was turning might indicate to bus riders that their bus was at a nearby stop, which might cause them to run. One participant thought that the LOOK FOR BUS sign was condescending.

Use with the Pedestrian Signal Head

As currently configured, the BUS warning sign is activated only during protected left turns from a bus-only lane. This movement occurs during the DO NOT WALK phase of the pedestrian signal in the affected crosswalk. Therefore, the BUS sign functions as a warning, providing additional information to pedestrians about why, particularly in this situation, it is not safe to cross against the DO NOT WALK signal. This sign functions in a similar capacity to the Manual on Uniform Traffic Control Devices (MUTCD) W10-7 light-rail activated blank-out symbol sign. When light rail transit (LRT) operates in a semi-exclusive right-of-way, light rail vehicles (LRV) interface with automobiles, bicycles, and/or pedestrians at at-grade crossings (i.e., signalized intersections). Initially, LRT was incorporated in semi-exclusive rights-of-way without any additional signals or warning devices for motorists; however, collisions between LRVs and turning automobiles led the industry to develop what is now the W10-7 light-rail activated blank-out symbol sign. The W10-7 is a blank-out sign that displays a flashing LRV symbol (Figure 7-7), which is activated during a red arrow for left- or right-turning vehicular traffic. Even though the traffic signal displays a red arrow to left- or right-turning motorists, the W10-7 functions as a warning, providing additional information to motorists about why, particularly in this situation, it is not safe to turn against the red traffic signal.

Figure 7-7

W10-7 light rail activated blank-out symbol sign

In addition, participants were asked if the BUS warning sign would provide conflicting information if it were displayed in conjunction with the WALK or flashing DON'T WALK. Ideally, in this situation, the sign would still function as a warning—a "heads up"—to pedestrians, rather than as a message to stop or yield to a turning bus. The response from focus group participants was somewhat divided. About half of the participants in the first focus group felt the message was conflicting, but that they would become accustomed to it over time. About three-quarters of the participants in the second focus group felt that the message was conflicting, noting that the blinking message indicates to pedestrians that they should stop. While almost all of the participants in the third focus group felt the warning was conflicting during the WALK signal, they did feel it was appropriate during the flashing DON'T WALK. For those that did not view the message as conflicting, they noted that if the pedestrian signal displays WALK, they are going to walk, and that the bus warning sign would be effective in reducing jaywalking. A few participants across the focus groups felt the message was unclear.

When asked if the warning was necessary during the pedestrian WALK phase, some reported that it did provide additional information. Others noted that it might cause people to stop and yield to a bus, and that buses should not be "pushing" pedestrians when they have the right of way.

Effectiveness of Technologies

After discussing the pros and cons of the auditory turn warnings and the bus turn warning signs, the issue of warning effectiveness was discussed. Effectiveness can have many dimensions: Is the warning effective at getting pedestrians' attention? Does it clearly convey what is happening and what the pedestrian should do, if anything? As previously noted, focus group participants rated each auditory turn warning and each bus warning sign on a number of different factors. The results are presented and discussed below.

Ratings of Effectiveness – Auditory Turn Warnings

To better understand what qualities constitute a good warning for the pedestrian turn warning systems, participants were asked to rate each auditory warning on three different factors:

- Ability to get pedestrians' attention – if you were walking down the street and heard this warning, would it get your attention?
- Clarity – how clear is the warning in indicating to pedestrians what is happening?
- Environmental intrusiveness – if you were walking down the street and heard this warning, how intrusive to the environment would you find it to be?

Participants rated each warning on each factor on a scale of 1 to 4, with 1 being "not at all," 2 being "possibly," 3 being "probably," and 4 being "definitely." An average rating among all 27 participants was calculated for each of the warnings on each factor. The averages are shown in Table 7-30.

Table 7-30

Average Ratings for Auditory Warnings on Three Factors

Warnings	Attention	Clarity	Intrusiveness
"Pedestrians, bus is turning"	3.4	3.3	2.4
"Caution, bus is turning"	3.4	3.4	2.3
Beeping	2.9	2.0	3.0
Turn indicator	1.7	1.7	1.6
"Caution, bus moving left"	2.9	2.6	2.2
"Caution, look both ways" (with turn indicator)	3.3	3.1	2.4
"Caution, bus moving left – pedestrians look both ways"	3.1	3.1	2.4
"Caution, pedestrians – bus is approaching"	3.4	3.2	3.2

"Pedestrians, bus is turning," "Caution, bus is turning," and "Caution, pedestrians. Bus is approaching" received the highest average rating (3.4) for ability to get pedestrians' attention. "Caution, look both ways" (with turn indicator noise) was close behind, with an average rating of 3.3. The turn indicator noise received the lowest average rating for ability to get pedestrians' attention (1.7).

For clarity, "Caution, bus is turning" received the highest average rating (3.4), with "Pedestrians, bus is turning" a close second (at 3.3). Again, the turn indicator noise received the lowest average rating (1.7). The beeping warning was the second overall lowest rated for clarity, with an average rating of 2.0.

For intrusiveness, the lower the rating, the less intrusive; thus, the turn indicator noise was rated as least intrusive, with an overall average rating of 1.6. "Caution, pedestrians. Bus is approaching" had the highest average rating for intrusiveness (3.4), while the beeping warning was second, with an average rating of 3.0. All other warnings were rated about the same for intrusiveness, with averages between 2.2 and 2.4.

Across all factors, the highest rated warning was "Caution, bus is turning." The second highest rated warning was "Caution, pedestrians. Bus is approaching." Although the clarity of this message was rated slightly lower than the clarity of the two spoken test warnings, the intrusiveness was rated slightly lower than both. The beeping and turn indicator warnings were by far the lowest rated overall.

Ratings of Effectiveness – Bus Warning Signs

As with the turn warning systems, to better understand what qualities constitute a good bus warning sign, participants were asked to rate each sign on four factors:

- Ability to get pedestrians' attention – if you were walking down the street and saw this sign, would it get your attention?
- Clarity – how clear is this sign in indicating to pedestrians what is happening?

- Effectiveness – how effective is this sign at indicating to pedestrians what they should do, if anything?
- Environmental intrusiveness – if you were walking down the street and saw this sign, how intrusive to the environment would you find it to be?

Participants rated each sign on each factor using a scale of 1 to 4, with 1 being "not at all," 2 being "possibly," 3 being "probably," and 4 being "definitely." An average rating for all 27 participants was calculated for each of the signs on each factor. These averages are shown in Table 7-31.

Table 7-31

Average Ratings for Bus Warning Signs on Four Factors

Warnings	Attention	Clarity	Effectiveness	Intrusiveness
BUS	2.6	2.4	2.1	1.3
BUS TURNING	3.3	3.5	3.3	1.3
LOOK FOR BUS	2.9	2.7	3.0	1.3
Bus symbol sign	2.4	2.2	2.0	1.2

The BUS TURNING sign received the highest average ratings across three of the four factors, including getting pedestrian attention, clarity, and effectiveness. The LOOK FOR BUS sign had the next highest average ratings across the same three factors. The BUS sign was the third highest rated across the same three factors, with the bus symbol sign being the lowest rated across the three factors. Al four signs were rated similarly on intrusiveness, with average ratings of 1.2 and 1.3.

Discussion of Effectiveness

Participants were asked if they felt the auditory warnings and bus warning signs were effective at reducing collisions between pedestrians and buses, including why or why not. The majority of participants felt that both the auditory warnings and the signs were effective in improving pedestrian safety. A few participants offered first-hand accounts. One said he/she was about to jaywalk but saw the sign and stopped. Another reported seeing a pedestrian on the phone who looked up, startled, when an auditory warning sounded during a right turn, and further noted that the pedestrian was "within seconds of being hit." For most participants, however, the sentiment that the warnings/signs offer improved safety came with caveats. Most felt like they would help in some cases and with some people, but certainly not in all situations, particularly when pedestrians are distracted or "tuned-out." Some felt that the systems may not be effective in the long run, as people become accustomed to hearing/seeing them and eventually tune them out. Some felt that this "desensitizing effect" might be overcome by changing/rotating the warnings/messages. One participant noted that the bus warning signs might make pedestrians think again before running across the street, trying to "cheat" the light. In the end, most participants felt that the systems were more effective than having nothing. Many said that while the systems were not going to be effective at warning all people in all situations, they felt having a warning would be better than having no warning at all.

Participants who did not feel that the systems were effective in reducing collisions between buses and pedestrians offered a number of reasons for their sentiment. Quite a few noted distraction as a real problem, especially from electronic devices, and one that is not likely to be addressed with the turn warning systems and/or bus warning signs. Some felt that there are too many people that jaywalk and/or do not obey signs/signals. In addition, there is a lot of ambient noise downtown that makes it difficult to hear or pay attention to the auditory warnings, which only add to the noise. One participant thought that the warning would train pedestrians that they do not have to be accountable for their own safety.

Although participants were not asked specifically to compare the auditory turn warning systems to the signs, several comparisons emerged during the discussions, with some participants preferring the signs to the auditory warnings for the following reasons: they were not as intrusive; they did not affect people for which they are not intended; and people with ear buds can still see the sign, but may not be able to hear the auditory warnings.

Participants also were asked in which locations/situations they felt the warnings (either auditory or visual) would be more or less effective. Locations/situations that were noted as potentially more effective included:

- Schools (or anywhere were there are a concentration of children)
- Bus stops
- Parks
- Malls/shopping centers
- Where people are known to jaywalk
- Multi-directional intersections
- Unsignalized intersections
- Minor streets crossing busy streets
- Locations with a history of pedestrian-bus conflicts/collisions
- Blind spots
- Tight spots
- High traffic times
- Poor visibility
- Special events such as marathons
- Nights and weekends
- Mornings and evenings (until 9:00 PM)

There were differences in opinion regarding the effectiveness of the auditory turn warnings in downtown versus residential areas and at transit centers. Although some participants reported the downtown area as one where the warnings would be more effective, others felt there were too many buses and bus stops and that the area is already too noisy. Likewise, some participants thought that the turn warnings would be more effective at transit centers, and others felt the warnings would create too much noise and confusion. Many thought that the warnings would prove to be less effective in residential areas.

Finally, focus group participants were asked if they thought that TriMet should invest in fleet-wide installation of the auditory turn warning systems, either as the systems are currently designed, or only after improvements. Most of the participants in the first focus group felt that TriMet should install the systems "as is" fleet-wide, and about two-thirds of those in the second focus group agreed. Participants in the third focus group, on the other hand, did not think that TriMet should install more systems as they currently are, that the money would be better spent elsewhere (e.g., increasing service frequency).

When considering their suggested improvement to the systems (e.g., targeted warnings, specific areas/situations), almost all of the focus group participants felt that fleet-wide installation of the turn warning systems would be worth the cost of purchase and installation. Only one or two participants did not agree and were concerned that the benefits would not outweigh the costs. This minority reported that there were higher priorities and that the most cost effective approach is to "honk the horn" (assuming the operator sees the pedestrian).

Summary/Conclusions

Seven different auditory warnings and four different visual messages were presented and discussed with the focus group participants. The two spoken warnings used in the field demonstration test were among the top three selected—in terms of the message itself and the effectiveness of the warning—by participants, along with the warning, "Caution, pedestrians. Bus is turning." The beeping warning was among the least liked warnings. In general, participants preferred warnings, both auditory and visual, that were clear, concise, and specific. Almost all participants agreed that what is needed is a unique and "friendly" tone, similar to that used for TriMet's Max trains as opposed to just another noise that blends into the background.

To more effectively balance the volume of the auditory warnings participants recommended improving the directionality of the speakers, allowing operators to adjust the volume as necessary, programming the volume to adjust by time of day and/or relative to the environment, and activating the warnings only during turns (not bus stops) and maybe not even every turn, rather specific "trouble" locations.

BUS TURNING was by far the most preferred message, in terms of both the message itself and the overall effectiveness of the warning, for the crosswalk blank-out sign.

The majority of participants felt that both the auditory warnings and the signs were effective in improving pedestrian safety, and a few participants offered first-hand accounts of improved safety situations. For most participants, however, the sentiment that the warnings/signs offer improved safety came with caveats, including the ability of the warnings to get the attention of distracted pedestrians and the long-term effectiveness of the warnings. These concerns were very similar to those of bus operators.

SECTION

8

Pedestrian and Cyclist Behaviors

This section presents the findings from the analysis of pedestrian/cyclists behaviors, which were video-recorded at four intersections in October 2014. Following data collection, the video data were downloaded onto DVDs for reduction and analysis. Video data reduction involved watching for interactions between a crossing pedestrian/cyclist and a turning bus. When pedestrian/cyclist interactions with turning buses were identified, the video was observed in more detail to document various reactions, as well as other characteristics of each turn event. Characteristics of each event included type of bus, type of turn, type of warning system, and pedestrian walk phase (when visible).

During the 80 hours of video coverage recorded across the 4 intersections, a total of 894 turning-bus events occurred (with and without turn warning systems). Of the total bus turns, 124 were test buses, and 109 of these were made when a pedestrian was present at the intersection at the time of the turn (pedestrian interaction with test bus). Of the 109 pedestrian interactions with a test bus, 13 cases (12%) were those in which the pedestrian visibly reacted in some way to the auditory warning.

Table 8-1 summarizes the number of turns, the number of pedestrian interactions with a test bus, and the number of pedestrians that reacted to the warnings by location and by turn warning system. For comparison purposes, the same numbers are provided for non-test bus turns, pedestrian interactions, and pedestrian reactions.

Table 8-1

Number of Turns, Pedestrians Interactions with Turning Buses, and Corresponding Reactions

Location/Events	System A	System B	System C	Test Buses	Non-Test Buses	Total
46th & Woodstock						
Bus turns	22	15	20	57	85	142
Pedestrian interactions	15	4	6	25	30	55
edestrian reactions	1	1	1	3	0	3
5th & Burnside						
Bus turns	0	1	10	11	285	296
Pedestrian interactions	0	0	13	13	166	179
Pedestrian reactions	0	0	2	2	1	3
5th & Madison						
Bus turns	9	12	17	38	133	171
Pedestrian interactions	16	5	15	36	137	173
Pedestrian reactions	0	1	3	4	0	4
6th & Everett						
Bus turns	0	9	9	18	267	285
Pedestrian interactions	0	13	22	35	330	365
Pedestrian reactions	0	2	2	4	0	4

What is surprising is the extremely low number of visible reactions of pedestrians to a turning bus. While the reactions to the auditory warnings were low, only one pedestrian was observed to have reacted in some way to the 663 non-test buses. It may be that these pedestrians did indeed see the bus, but no visible movements were made in reaction to its presence (or at least none that were visible on the video).

Table 8-2 and Figures 8-1, 8-2, and 8-3 provide a brief summary and examples of the types of behaviors that were observed during the pedestrian interactions with a test bus. These behaviors generally occurred concurrently with the warning from the turning bus. Most of the behaviors demonstrated by pedestrians during their interactions with a test bus were either head movements (up, around) or entire body movements (running). Of the three systems, System C had the greatest number of pedestrians who appeared to have reacted to the auditory warning. This result echoes the responses and feedback received from bus operators and pedestrians in their respective surveys and focus groups.

Table 8-2

Observed Behaviors during Turns with Warning System

Intersections	Pedestrian Reactions	System	Observations
5th & Madison	2	C	Two pedestrians broke into a run to cross while bus was yielding; two other pedestrians appeared to want to take advantage that bus was already yielding to other pedestrian and beat flashing DON'T WALK signal.
6th & Everett	2	C	Two crossing pedestrians ran into crosswalk while flashing DON'T WALK signal was active and as warning was sounding. Two pedestrians standing on corner but not crossing appeared to turn their heads towards bus as warning sounded.
5th & Burnside	2	C	Two crossing pedestrians looked up at bus, continued to walk as warning sounded.
5th & Madison	1	B	Crossing pedestrian turned and looked back at bus once reaching opposite corner.
5th & Madison	1	C	Crossing pedestrian turned and looked back at bus while crossing (Figure 8-1).
46th & Woodstock	1	B	While crossing, pedestrian appeared to turn and glance over shoulder after warning sounded (Figure 8-2).
46th & Woodstock	1	C	Pedestrian sped up and looked back at bus while warning sounded. Pedestrian then looked down at phone halfway through crossing.
46th & Woodstock	1	A	While crossing, pedestrian turned head and looked at bus after warning sounded.
6th & Everett	1	B	Pedestrian approaching on sidewalk waved at bus as bus was turning and after warning had played (Figure 8-3). Pedestrian then crossed.
6th & Everett	1	B	Warning sounded after one pedestrian crossed and did not appear to react. Another pedestrian at corner noticeably turned head and looked at bus as bus finishes turn. Pedestrian then crossed.

Figure 8-1
Observations at SW 5th & SW Madison (System C)

Figure 8-2
Observations at SE 46th & SE Woodstock (System B)

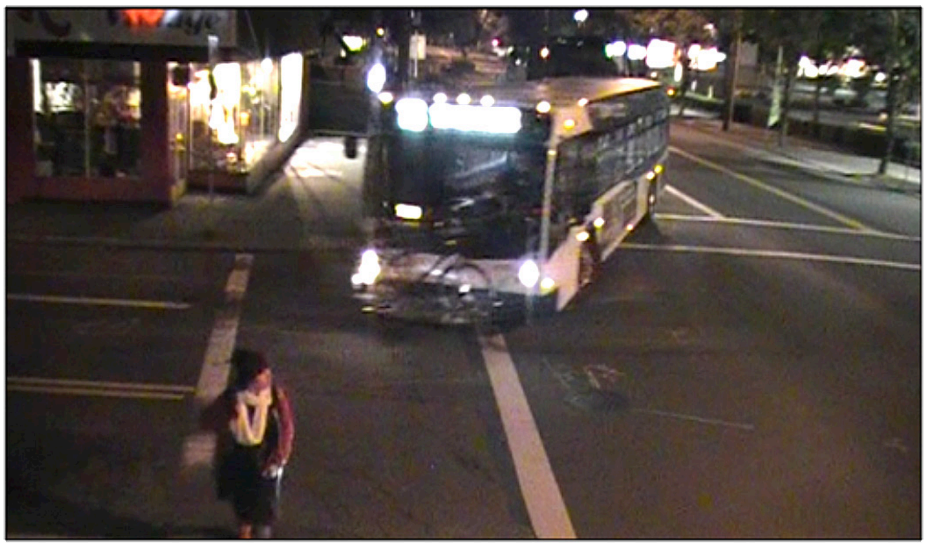


Figure 8-3
Observations at NW 6th & NW Everett (System A)

In addition to the pedestrian-bus interactions that occurred with test buses, a total of 159 buses turned left from the protected bus left turn lane on the eastbound approach to the intersection of 5th Avenue and Burnside Street, none of which were equipped with a turn warning system. However, these buses were the "test" buses that activated the BUS blank-out sign. Of the 159 total left turns at this intersection, 27 were made when a pedestrian was present and 2 were made when a cyclist was present. In all of these cases, the bus was waiting and/or already turning from the protected left-turn lane, the BUS blank-out sign was flashing, and the DON'T WALK pedestrian signal was visible to the pedestrian/cyclist. In this analysis, however, it was more difficult to determine if the pedestrian/cyclist was reacting to the sign.

In some of the cases (seven, including six pedestrians and one cyclist, or 26%), the pedestrians/cyclist waited on the curb until the pedestrian WALK signal (or until the bus turned), which would indicate that they acknowledged the sign and/or the pedestrian DON'T WALK and complied with the signal/sign. In most of the remaining cases, the pedestrians appeared to have ignored the BUS blank-out sign and the pedestrian DON'T WALK signal altogether. Some walked or ran across before the bus turned. Others began crossing, but then stopped and/or stepped back in the crosswalk or onto the curb to allow the bus to turn. In a couple of these cases, the bus operator even had to honk at the pedestrians as the bus was turning. And in each of these cases, the pedestrian crossed immediately after the bus had turned. In one particular case, the pedestrian appeared to acknowledge the sign/signal at first, stopping at the curb and looking to the right for oncoming traffic (the bus had not yet started to turn), and then began crossing against the sign/signal. It was not until the bus began to turn, and he saw the bus, that he acknowledged the bus, stopped, and waved the bus operator to continue to turn (Figure 8-4).

Figure 8-4

Observations at SW 5th & W Burnside (BUS blank-out sign)

Overall, when compared to the number of turning buses captured on the video, there were few situations where both a pedestrian/cyclist and a test bus were present at the same time, and there were even fewer situations where an interaction occurred that led to a visual reaction by the pedestrian.

The post hoc judgments of pedestrian reactions made during this analysis were subjective in nature. Furthermore, it is uncertain whether the observed reactions were a direct result of the turn warning systems. Nevertheless, the overall number of pedestrian reactions observed during interactions with test buses (12%) was significantly greater than the number of pedestrian reactions observed during interactions with non-test buses (0.2%). Therefore, these behaviors seem to indicate that there was some increased level of awareness attributable to the warning systems.

SECTION 9

TriMet Perceptions, Acceptance, and Institutional Issues Associated with Technologies

This section summarizes the results from the interviews with TriMet staff, which were conducted following the demonstration test in an effort to assess interviewee perceptions and acceptance of the technologies, as well as to identify any institutional issues surrounding the procurement, installation, and maintenance of the technologies.

Functions, Roles and Responsibilities of Interviewees

Seven individuals with varying roles and responsibilities within TriMet were interviewed as part of the assessment. All seven were involved in the demonstration test to some extent. Although there was some slight variability in the interview questions depending on the role of the individual, the questions were generally the same for those interviewed. The seven interviewees included:

- **TriMet Safety Executive** – led all aspects of the pedestrian collision warning demonstration project from TriMet's end and was responsible for purchase, installation, calibration, and maintenance of the turn warning systems; coordination and administration of the bus operator surveys; and coordination of the bus operator focus groups and interviews with the TriMet staff.
- **Assistant Manager of Transportation** – worked with the maintenance team to understand which buses were equipped with a test warning systems, which was important for situational awareness and to be able to better handle operator feedback. He also worked with the Safety Executive's team to ensure the daily bus operator survey questionnaires were included in the operator packs for each shift.
- **Maintenance Manager** – planned, arranged, and led the installation of Systems A and B and programming of System C.

- **Maintenance Trainer** – oversaw the installation of the turn warnings systems and helped with adjustments. He was the lead for the installation, programming, and adjustment of System B.
- **Assistant Supervisor, Maintenance** – installed, adjusted, and maintained the auditory turn warning systems and was the lead for the installation of System A, including training three other mechanics. He shadowed System B installations by the vendor to determine how the system worked and how to make the necessary adjustments[17] and also worked on the programming of System C to activate the auditory warning feature.
- **Manager of Operations Training** – provided input and feedback for the test based on his experience from TriMet's previous test of a turn warning system. He also helped with communications to the bus operators about the systems.
- **Public Information Officer (PIO)** – was responsible for pushing information about the demonstration test to the public through traditional and social media, handling media requests, and addressing feedback received from the public. He also organized a "media day" on which news organizations were able to observe one of the test buses at TriMet's Gateway Transit Center. Media were given the opportunity to ride the test bus around the block a few times to observe the system, talk to the bus operator, and ask the PIO questions. This event gave members of the media an opportunity to see and hear the turn warning systems in a controlled environment.

The findings from the interviews are summarized below.

Summary of Findings

Installation and Adjustment of Systems

According to the Maintenance Manager, System B was the most flexible of the three systems in terms of installation and adjustment. Comparing Systems A and B, System B, as purchased and installed for this test, offered more operational options (such as geofencing capabilities) that were included without additional costs. In addition, technical and customer support for System B was more readily available.[18] While already installed, the primary issue with System C was that it required the manufacturer to develop a program to activate the auditory warning feature (TriMet ordered the buses with only the directional LED headlights activated). This change required work on the part of the maintenance staff to program each of the buses.

The Maintenance Trainer indicated that overall the installations went well. The installation of System A was more labor-intensive than that of System B because it required the installation of hardware under the bus, which required two mechanics to work together. The Assistant Supervisor of Maintenance noted that System A took approximately 4 hours to install and System B took approximately

1.25 hours to install. The primary reasons for the difference were that System A required a significant amount of wiring and re-wiring of various parts such as the steering box, speakers, and the LED strobe lights (which were not a part of System B). He noted that for System A, the calibration involved adjusting the switches to come on at the desired angles. The trigger had to be adjusted on the pitman arm, which typically was a trial-and-error process. It was more difficult to make these adjustments because bolts had to be loosened under the bus and changes made to the switch to meet the pitman arm. Adjustments to the pitman arm typically took two people about 15–30 minutes.

The installation of System B, on the other hand, was much easier due to the lack of external parts (everything was done inside the bus), and only one person was needed to make any adjustments. In addition, changes could be made by connecting a computer to the system's ECU via its internal software. System B adjustments typically took only about 5 minutes. The Assistant Supervisory of Maintenance noted that the calibration of System B involved the adjustment of the checkerboard sticker on the steering column. TriMet used the default sticker pattern, and no adjustments were made to the steering angle. Had any adjustment been required, new stickers would have had to be printed by the vendor and sent to TriMet to install on the steering columns of all test buses.

Maintenance of Systems

Overall, the three systems required almost no maintenance during the seven-month test period. Generally, the systems functioned properly, as calibrated. One of the System A units was damaged from something under the bus and had to be replaced. After that unit was replaced, there were no further problems. In the long term, the only maintenance issue of concern for the Maintenance Manager was the pitman arm sensors associated with System A, which he felt may need readjusting over time. System A also had side flashing LED strobe lights that were installed by the maintenance staff. There were no reported problems with the lights.

In general, the Maintenance Trainer believed that the maintenance of any of the systems would be fairly minimal. In his opinion, based on the seven-month demonstration test, the failure rate of the systems was not more than any other part of a bus. In addition, he felt that the directional LED headlights were well recessed and protected and that they were only slightly more expensive than a regular headlight that would be standard on a new bus build. He suggested that it was important for maintenance staff to be heavily involved in the pre-installation and installation phases of any additional deployment of the turn warning systems.

Perceptions and Acceptance of the Technologies

Overall, perceptions and acceptance of the technologies among TriMet management and other personnel was neutral to positive.

The Safety Executive did not report strong feelings about the turn warning systems one way or the other and believed that the decision to procure more units would require more analysis, including the analyses that had yet to be done for this study at the time of the interview. Although he did see a potential role for these types of systems, his primary concern was when and where to turn them on (and off) so that there would be an overall safety benefit.

The Assistant Manager of Transportation received a great deal of feedback from the bus operators regarding the turn warning systems, echoing many of the issues that have already been discussed, such as the frequency of the beeping warning, the continuous playing of the System A warning if the wheels were not straightened when parked, the perception that the systems were going to only work for a certain percentage of the time, and that those on electronic devices and/or wearing headphones may not be able to hear the warnings. As such, he noted that most operators likely have a negative impression of the systems. He also noted that towards the end of the demonstration test the number of operator comments or questions about the systems had declined to almost none. His overall impression was that TriMet should install more of the systems but continue to study their effectiveness so a determination could be made as to the best system for the agency.

The Maintenance Trainer noted that the auditory feature on System C used the same sound as that of the ADA/ramp/kneeling features but with a different rate of beeping. This beeping rate was the only aspect of the warning that could be changed via programming. The volume of the noise was a manual setting external to the system, which he believed was not a good idea because bus operators potentially could make adjustments unbeknownst to maintenance personnel. In his opinion, the beeping was originally quite loud but was somewhat mitigated with the adjustments made by TriMet. Also, he noted that if the systems save one life, then they are worth the cost.

When comparing systems, in general the Assistant Supervisor of Maintenance preferred System B because it was easier to make adjustments such as the steering angle. In addition, the volume could be adjusted for certain times of the day and by location (using GPS coordinates). He noted that System A did not have a day/night volume adjustment feature like System B (although it did have an ambient noise adjustment capability). Additionally, to use the geofencing function of System A, stationary signals (through RF antennas) were required, which were very expensive. As is, he felt that System B probably fit TriMet's needs best as they had the software to modify the systems, whereas with System A, the vendor had to make programming changes. He received a lot of complaints about System C from bus operators because they did not like the high volume (not necessarily the beeping itself). He personally would have preferred System C if it had a spoken message (instead of the beeping) and no feature to allow the volume to be adjusted manually on the exterior of the bus. He indicated that if System B were actuated by the turn signal (instead of the turn of the steering wheel), he would also recommend System B. His ideal system would be System B actuated by the turn signal and including the LED strobe lights.

The opinion of the Manager of Operations Training was informed by feedback from three of his operator trainers. One trainer reported that the warnings grabbed his/her attention, which defines the importance of safety during turns. Another trainer had initial concerns about hearing the warning all day long, but eventually adapted to the noise. The third trainer felt the auditory warning gets lost in the noise of the streets and that pedestrians seem indifferent to the warnings.

Prior to the launch of the demonstration test, primarily negative feedback was obtained from the media. Once the demonstration began, the PIO and the customer service office began receiving phone calls and emails from the public complaining about the systems. The PIO had to emphasize that this was a demonstration project for FTA and that it was intended to help improve pedestrian safety. Most of the complaints were from non-habitual complainers. Many indicated that the warning was being actuated during curves (not full turns), and these complaints occurred mostly before adjustments were made to the steering angles. The PIO indicated that, to her knowledge, no positive feedback or compliments were ever received from the public regarding the turn warning systems. She did note that this was not necessarily unusual, as it is rare for TriMet to receive compliments from the public. Over time, there were fewer media inquiries and fewer public complaints, especially after the adjustments were made. Cyclists complained about the spoken messages when a bus was pulling away from a stop, because the bus was not turning. However, some operators provided feedback to the PIO that they liked the warnings at bus stops.

Implications of Technology Implementation

The biggest potential implication of further deployment of the turn warning systems relates to safety. The Assistant Manager of Transportation cautioned that the systems were not the "be all, end all" in addressing pedestrian safety. He emphasized that even though technology can play a role, operator training is still very important. In addition, training on the technology is important and should be a part of any future deployment of the turn warning systems. In addition, he reported that he wished that the auditory warnings had a visual component and that he had not heard any comments or complaints about the flashing strobe LED lights on System A or the directional LED turning headlights on System C.

Similarly, the Manager of Operators Training noted that training is ultimately a very important aspect of an operator's job. It is the bus operator's responsibility to scan and be aware of the surroundings when driving, and although the technology may help, operators cannot rely on it to do their job. One of his concerns regarding these technologies was that bus operators may become complacent or reliant on the technologies and that, consequently, safety will be compromised.

The Safety Executive discussed the role that the turn warning systems have in a broader context than just the demonstration test. He noted that these technologies are not a panacea; rather, they are just one tool in an array of strategies that transit agencies should consider. Approaches such as operator training, the examination of the physical aspects of a bus, and the evaluation of routes should be considered when trying to improve safety. In addition, technology is not a replacement for operator responsibility. Looking 5 to 10 years into the future, the Safety Executive believes that although turn warning system technologies will be used more readily by the transit industry, the systems will become more advanced and likely will include proximity sensors that provide feedback to the operator. He noted that the City of Portland has requested that the BUS blank-out signs remain operational at the intersection of 5th and Burnside, which is an indication of the effectiveness and/or level of acceptance of the signs from the City's perceptive.

Recommendations for Other Transit Agencies

TriMet management and other staff offered a number of recommendations and advice for other transit agencies considering the purchase of the turn warning systems. The Safety Executive noted that the agency needs to look at the locations at which the biggest safety issues exist in their operational coverage area. He also noted that sound levels need to be considered, and the agency needs to determine how loud is loud enough because it is likely to get complaints, at least with initial deployment. Also, adjustments likely will have to be made, but they will be location-specific. Portland may be different from other cities in terms of its tolerance for public noise levels. If he could repeat the demonstration, he would have included geo-fencing features for both systems from the beginning. In his opinion, at the time of procurement, System A did not include a reasonably-priced geofencing option. While the GPS-based geo-fencing feature on System B was used in the bus yard, expanding the use of this feature would likely be very helpful in mitigating concerns in certain areas of Portland in any future deployments.

The Maintenance Manager was not a strong proponent of any of the turn warning systems. His opinion was that the systems are an additional maintenance item and the units are an additional cost to the agency, and he was doubtful of the long-term return on investment. As a result, he did not believe TriMet should install any more units because the systems just provide more noise without any realized safety benefit. If he had to recommend one system, however, he would recommend System B, as he believed it was simple and effective at warning pedestrians. The programming is easy, and he would recommend that the vendor do the installation if possible.

The Maintenance Supervisor recommended that the maximum speed threshold be set to 15 mph, at most, because a bus typically is not going any faster during a turn or when pulling into or away from a bus stop. If TriMet were to install more turn warning systems, his recommendation would be System B on the basis of customer service and ease of installation and adjustment. Additionally, he had general concerns about the fact that System A had parts that were under the bus and possibly exposed to damage from road debris.

The Manager of Operations Training recommended that two additional external speakers be added to future installations. He noted that adding two speakers to the rear of the bus would help reduce the chance that the auditory warning would be masked by engine noise. Additionally, he believed that linking the auditory warning to the GPS would be important in controlling when, where, and how loud the warning is. His advice for other transit agencies was to incorporate the findings from this study and then purchase one system and thoroughly test it. In addition, it is very important to get buy-in from the bus operators and the public and to be open and honest about what the agency is trying to do.

SECTION

10

Analysis of Costs and Benefits

This section presents the findings from a benefit-cost analysis of the pedestrian warning systems. The analysis draws from avoided close-call information recovered during the field test phase of the project, cost information for the warning systems, and monetization and other relevant information from external sources.

An important feature of the benefit-cost analysis involves the imputation of bus-pedestrian incident outcomes of increasing severity from close-call information. The underlying logic for these imputations, based on Heinrich's safety pyramid concept, is explained below.

Benefits and costs were derived and are presented for a range of possible conditions. Issues associated with inferences that can be drawn from the benefit-cost findings are then discussed.

Safety Effect of Pedestrian Turn Warning Systems

At the outset, it should be emphasized that bus-pedestrian collisions resulting in injuries or fatalities are rare events. For example, the 2010 National Transit Database (NTD) reports 27 such fatalities and 283 injuries requiring transport in association with the delivery of nearly 1.6 billion miles of revenue service. This translates to about 1.7 fatalities and 17.7 injuries per 100 million revenue service miles. To put these rates in context, TriMet's entire bus system logs approximately 20 million revenue service miles per year. Thus, a research design predicated on documenting changes in fatalities and injuries on this study's six routes over a seven-month period likely would find no "treatment effect" attributable to pedestrian turn warning systems. In fact, no fatalities or injuries occurred on the study routes during the test period in association with either the warning system-equipped or the non-equipped "control" buses.

Alternatively, close calls involving buses and pedestrians occur with much greater frequency than actual collisions. Given a defined hierarchy of safety risks and outcomes, it is possible to impute the expected incidence of pedestrian fatalities and injuries in relation to the frequency of close calls. Such an exercise draws on the concept originally developed by Heinrich (Figure 10-1).[19] With respect to its application in the present study, the base of the Heinrich pyramid primarily consists of acts by pedestrians that elevate their safety risk exposure in the bus operating environment. Such acts might include jaywalking or crossing against the light at intersections, running to catch a bus, or, as is becoming increasingly common, simply being distracted from one's surroundings by the use of personal digital devises.[20] In turn, such unsafe acts elevate the risks of close-call incidents and, beyond this, other outcomes with more serious consequences.

Figure 10-1

Heinrich's Safety Pyramid

Heinrich operationalized his safety pyramid by documenting the relative frequencies of close calls, minor injuries, and major injury/fatality incidents in an industrial setting. He found that 300 close calls corresponded with 29 minor injury incidents and one major injury/fatality incident. Nearly 40 years later, Bird[21] used information collected from 1.75 million accidents involving workers from 297 companies to update and extend Heinrich's original findings. Bird's resulting relative frequencies were 600 close calls, 10 minor injury incidents, and one major injury/fatality incident.

Safety analysts have commonly observed that the relative frequencies of the Heinrich and Bird pyramids are sensitive to context-specific circumstances, with differing outcomes likely to be obtained across industries or settings. In the urban transit industry, for example, buses typically operate at fairly low speeds, and operator training strongly emphasizes incident anticipation and prevention, whereas the origins of unsafe behaviors occur primarily outside the operator's direct control. The combined effects of these factors likely would yield a much larger number of close calls per injury or fatality incident than is defined by the Heinrich or Bird safety pyramids. Thus, to operationalize the safety pyramid for the present study, relative frequency data specific to close calls and collisions involving buses and pedestrians must be employed.

The NTD can provide some of the relative frequency data needed to construct an operational bus-pedestrian safety pyramid. The NTD reports the number of bus-involved pedestrian fatalities, as well as injuries to pedestrians requiring transport. Given the rareness of such events, the main advantage of the NTD's industry-level data is that they are is considerably less volatile over time compared to like data at the transit property level. However, the NTD does not report incidents involving minor or no apparent injury to pedestrians, nor does it report the frequency of close calls. These data must be recovered at the transit property level. Thus, constructing a bus-pedestrian safety pyramid requires a hybrid approach drawing on industry and transit property-level data. In the present case, TriMet's safety information system serves as the source of minor/no injury and close-call data.

The 2010 NTD's reported 27 fatalities and 283 injuries requiring transport serve to define the top two tiers of the pedestrian safety pyramid, with each fatality thus associated with 10.5 injuries requiring transport. Data for the remainder of the pyramid were taken from TriMet's safety information system. This system was initiated in December 2010 and maintains a comprehensive and consistent record of all safety incidents. A system data query yielded 27 bus-pedestrian collisions over 46 months through October 2014, with 7 pedestrians requiring transport and the remaining 20 sustaining minor or no injury. On an annualized basis, this translates to 1.83 transport and 5.22 minor and no injury incidents, respectively.

TriMet's annual average frequency of minor and no injury incidents must be scaled up to be consistent with the NTD relative frequencies of fatalities and injuries requiring transport. In this case, the scale factor is constructed from the data on injuries requiring transport, which are common to both NTD and TriMet. The scale factor is obtained as follows:

Scale Factor = NTD 2010 relative frequency/TriMet annual frequency
= 10.5/1.83
= 5.74

Applying this scale factor to TriMet's annualized minor/no injury incident rate yields the following:

5.74 x 5.22 = 30.0

The relative frequency of close calls represents the final data requirement of the pedestrian safety pyramid. TriMet has maintained close-call event records in its safety information system since the spring of 2013, following the deployment of an upgraded bus dispatching system. Close-call event records are generated by operators pressing particular buttons on a control head in the cabin, with each button corresponding to the specific subject of the close call (e.g., pedestrian, vehicle, etc.). A query of close-call event records for the May 2013–May 2014 period, however, revealed that relatively few operators (22%) had reported such events involving pedestrians, suggesting that they may have either perceived potential negative consequences or saw no benefit in reporting close calls. Whatever the case, it was apparent that close calls were being under-reported.

Another source of close-call information is provided by a confidential survey of safety risk perceptions that was completed by TriMet bus operators in 2012.[22] Among other things, this survey asked operators how often they experienced close calls. Their mean response was that such events occurred once per week. Applying this rate across the bus operator population, whose number averaged 1,062 between December 2010 and November 2014, yields an average of 55,224 close calls per year at the system level during this period.

This annual estimate covers close calls of all types. One means of imputing pedestrian-related close calls is provided by the safety information system's records for evasive action/hard stop incidents. These records are also operator-keyed and are generated when the operator believes that the action taken may have resulted in an on-board injury. The records then serve as a time reference in retaining and reviewing files from on-board cameras in the event of a customer claim.

One of the data fields in evasive action/hard stop event records identifies the principal contributing factor to the event, among which pedestrians are included. A query of the event records revealed that of the 390 evasive action/hard stop events that occurred between December 2010 and November 2014, a total of 46 (11.9%) were incidents in which a pedestrian was the principal contributing factor. Applying this percentage to the annual close-call total yields an imputed estimate of 6,572 pedestrian related close calls per year on TriMet's bus system. When factored up to be compatible with the other relative frequencies in the safety pyramid, the close-call value expands to 37,723.

The resulting relative frequencies for the bus-pedestrian safety pyramid are presented in Table 10-1. Compared to the Heinrich and Bird pyramids, the most noteworthy distinction in the bus-pedestrian safety pyramid is the substantially greater relative frequency of close-calls. In the bus-pedestrian pyramid, for example, the number of close calls per fatality is more than 60 times greater than its corresponding value in the Bird pyramid. As previously mentioned, this may be a reflection of the greater density of pedestrian risk exposure in the bus operating environment, in which stops often are located at busy intersections with higher pedestrian crossing volumes. Another possibility is that operators are reporting a mixture of unsafe behaviors by pedestrians and actual close calls. In the context of the present study, this potentially would be beneficial, considering that the purpose of the pedestrian warning system "announcements" is to interrupt unsafe behaviors and thereby reduce close calls and collisions.

The bus-pedestrian safety pyramid in Table 10-1 provides an operational tool for imputing avoided pedestrian fatalities and injuries from warning system related reductions in close calls. The daily operator survey provides the basis for estimating the reduction in close calls attributable to the pedestrian warning systems. In that survey, 5.6% of the operators indicated that the warning system on their bus helped to avoid a close call during their assigned run on the survey day. Analysis also found no significant differential in this response across the types of warning systems, nor did it find evidence of directional trending over the three-month survey period. Thus, a direct inference of total avoided close calls can be made from survey period assigned run information for the 45 test buses. A query of TriMet's scheduling database indicated that the 45 test buses completed 6,307 runs during the survey period, which results in an inferred reduction of 353 close calls attributable to the warning systems. On an annualized basis, the reduction in close calls increases to 1,413.

Table 10-1

Bus-Pedestrian Safety Pyramid

Incidents	Frequency
Fatality	1.0
Injury (transport)	10.5
Minor or no injury	30.0
Close calls	37,723

The close-call relative frequency information from Table 10-1 can be reconfigured to determine the imputed number of incidents of varying severity that would be avoided as a consequence of a reduction of 1,413 close calls. The results are shown in Table 10-2. The imputed annual number of fatalities avoided (i.e., 1,413/37,723), for example, is quite small. Another way of interpreting this value is that it would require about 27 years of warning-system-attributed-avoided close calls to realize one avoided fatality. The corresponding time spans for realizing avoided injuries requiring transport and minor or no injury incidents are considerably shorter, at about 2.5 years and 11 months, respectively.

Table 10-2

Annual Avoided Incidents Attributable to Avoided Close Calls

Incident Types	Close Calls per Incident	Annual Avoided Incidents
Fatality	37,723	0.037
Injury (transport)	3,593	0.393
Minor or no injury	1,257	1.124

Benefit-Cost Analysis

The benefit-cost framework employed to evaluate the pedestrian warning systems drew from two principal sources of guidance: information on discounting and the treatment of uncertainty from *OMB Circular A-94*,[23] and monetary valuation information from the U.S. Department of Transportation.[24] Values provided by these sources, along with other information relevant to the analysis, are presented in Table 10-3. The time frame for the benefit-cost analysis was set at 12 years, consistent with the FTA's minimum service life policy for full size buses (see FTA Circular 9030.1B). Consistent with Circular A-94, the discount rate for the analysis was set at 7%.

The remaining values shown in Table 10-3 are subject to varying degrees of uncertainty. The benefit-cost analysis accounts for uncertainty by employing a range of values for each key parameter. In some instances (e.g., the valuation of fatalities and injuries), the range was defined by published guidance. In other cases (e.g., avoided incidents), the range was based on supporting evidence. Finally, for several parameters (installed cost and maintenance cost), the range was based on the researchers' judgment.

The baseline value for the installed cost of the warning systems represents the actual acquisition and installation expenditures in this study for two of the warning systems. The third warning system (System C) was a standard feature on new buses purchased by TriMet. As information on its unit cost was unavailable, it was assumed to be equivalent to that of the other two systems. The baseline value in Table 10-3 covers the 45 units employed in the study. It should be noted that warning system unit costs have been declining and that the cost per unit for fleet-wide acquisition likely would be lower. The upper and lower bound (+/- 25%) unit cost values employed in the analysis reflect the authors' assessment of the extent of uncertainty. For information purposes only, current market cost estimates were developed based on information provided by the manufacturers in December 2014. This information is presented in Appendix A.

The deployment of turn warning systems in the transit industry has been both recent and limited in extent to date. Thus, there is almost no information from which to draw in setting expected maintenance costs, which would include system failure rates. In the present study, there were two instances where particular warning system components had to be replaced, and interviews with agencies that have deployed the systems found intentions to periodically clean selected system components. On the basis of this limited information, baseline maintenance costs were set at $86.25 per unit ($3,880 for all units), based on the assumption of 2 hours of annual maintenance per unit at $43.13 per hour (i.e., TriMet's rate at the time of this study). Given the uncertainty of this cost a fairly wide range (+/- 75%) was applied in setting upper and lower bound values.

Baseline values for annual avoided fatalities and injuries were adopted from the previous analysis of avoided close calls in this section. Upper and lower bound values (+/- 60%) also were considered to account for uncertainty. This range corresponds to +/- 1 standard deviation in the operator-reported frequency of close calls in the safety risk perception survey by Strathman et al.[25]

Table 10-3

Values Employed in Benefit-Cost Analysis

Elements	Value Employed
Time frame	12 yrs
Discount rate	7%
Turn warning systems (45 units) installed cost – baseline	$77,850
Turn warning systems (45 units) installed cost – upper bound	$97,200
Turn warning systems (45 units) installed cost – lower bound	$58,500
Annual maintenance cost – baseline	$3,880
Annual maintenance cost – upper bound	$6,790
Annual maintenance cost – lower bound	$970
Avoided fatality incidents per year – baseline	0.037
Avoided fatality incidents per year -upper bound	0.059
Avoided fatality incidents per year – lower bound	0.015
Injuries (transport) – baseline	0.393
Injuries (transport) – upper bound	0.629
Injuries (transport) – lower bound	0.157
Minor or no injuries – baseline	1.124
Minor or no injuries – upper bound	1.798
Minor or no injuries – lower bound	0.674
Safety benefit per avoided fatality incident – baseline	$6,200,000
Safety benefit per avoided fatality incident – upper bound	$8,990,000
Safety benefit per avoided fatality incident – lower bound	$3,400,000
Injury (transport) – baseline	$291,400
Injury (transport) – upper bound	$422,500
Injury (transport) – lower bound	$160,300
Minor or no injury – baseline	$18,600
Minor or no injury – upper bound	$27,000
Minor or no injury – lower bound	$10,200

Finally, the baseline monetary values associated with avoided fatalities and injuries were taken from the USDOT guidance addressing the valuation of a statistical life. For fatalities, the guidance values were derived from academic research on public willingness to pay to avoid or reduce safety risk. Injuries are scaled by severity according to a metric representing quality-adjusted life years forgone and then grouped by abbreviated injury scale (AIS) categories. In the present analysis, minor injuries are represented as AIS I severity, while transport injuries are represented as AIS II severity. The baseline fatality and injury values in Table 10-3 correspond to the point estimates recommended in the USDOT guidance. The upper and lower bound fatality-injury values reflect the range of uncertainty recommended in the USDOT guidance.

Having set the values of the key parameters, three scenarios were considered in the benefit-cost analysis. The first, a baseline scenario, employs the baseline cost and benefit component values presented in Table 10-3. The second, a maximum scenario, employs the combination of cost and benefit values from Table 10-3 that yield the largest achievable net benefit outcome. For this scenario, that combination would include lower bound installation and maintenance costs, upper bound values for avoided fatalities and injuries, and upper bound values for the valuation of avoided fatalities and injuries. In contrast, the minimum scenario employs component values that produce the smallest net benefit. Thus, the three scenarios cover the maximal range of outcomes obtainable from the information in Table 10-3.

Benefit-cost analysis findings for the three scenarios are presented in Table 10-4. The baseline scenario yields net present value benefits approaching $3 million, or about $65,300 per bus/warning system. The associated internal rate of return on the warning systems investment (i.e., the discount rate that would equate the cost and benefit streams) for this scenario exceeds 34%, which is fairly substantial. All three scenarios result in net positive benefits, covering a fairly considerable range. For example, net present benefits from the maximum scenario are more than 12 times those from the minimum scenario.

Table 10-4

Benefit-Cost Results

Categories	Baseline	Maximum	Minimum
A. Installed Cost	$77,850	$58,500	$97,200
B1. Annual Maintenance Cost	$3,880	$970	$6,790
B2. Present Value Maintenance Cost	$30,819	$7,705	$53,934
C1. Annual Avoided Fatality Benefits Cost	$229,400	$530,410	$51,000
C2. Present Value Avoided Fatality Benefits	$1,916,014	$4,430,136	$425,967
D1. Annual Avoided Injury (transport) Benefit	$114,520	$265,752	$25,167
D2. Present Value Avoided Injury (transport) Benefit	$956,504	$2,219,637	$210,202
E1. Annual Avoided Minor or No Injury Benefit	$20,906	$48,546	$6,875
E2. Present Value Avoided Minor or No Injury Benefit	$174,613	$405,470	$57,422
F. Present Value Benefits (C2+D2+E2)	$3,047,131	$7,055,243	$693,591
G. Present Value Costs (A+B2)	$108,669	$66,205	$151,134
H. Net Present Value (F-G)	$2,938,462	$6,989,038	$561,807
I. Ratio of Benefits to Costs (F/G)	28.0:1	106.6:1	4.6:1
J. Internal Rate of Return	34.5%	51.4%	16.5%

The monetization of avoided fatalities clearly represents the largest source of benefits, despite the relatively small underlying incidence of such outcomes. More generally, it can be said that the benefits of avoided bus-pedestrian collisions grow exponentially with the severity of outcomes. This finding corresponds with the analysis of bus-pedestrian collision incidents reported in the 2010 National Transit Database conducted by Schneeberger et al., who found that while such incidents accounted for 13.9% of all bus collisions, their consequences amounted to 54.1% of the total resulting economic cost.[26]

While the benefit-cost analysis accounts for various sources of uncertainty, there are several additional factors that should be considered in interpreting the results at the system level for TriMet or, more broadly, for other transit properties. First, although the radial and crosstown routes selected for the study are representative of TriMet's overall network typology, they do contain features that can affect inferences drawn from the findings. For example, the study routes are somewhat longer, contain relatively more turns, and serve more riders than average.

Second, the pedestrian warning systems were installed on recently-purchased buses. Typical of industry practice, TriMet assigns new buses to base service runs, while dedicating its older vehicles to peak service. As a result, the daily revenue mileage of new buses exceeds that of older buses, which elevates their relative risk exposure.

Third, the avoided fatality-injury benefits obtained from the benefit-cost analysis should not be interpreted as avoided financial liabilities from warning system-related reductions in fatalities and injuries. For instance, not all incidents result in claims. Also, state law commonly establishes limits on liability for state and local public bodies. In TriMet's case, for example, ORS 30.272 presently defines a maximum liability of $666,700 for individual death and personal injury claims. At the extreme (i.e., for a fatality claim), this statute-limited amount represents just 11% of the baseline monetary value of a statistical life employed in the benefit-cost analysis. Thus it is important to distinguish the social monetary benefits associated with the benefit-cost analysis from the actual monetary savings that would be realized by a transit agency.

From a safety performance evaluation standpoint, the analysis in this section provides an illustration of the use of close-call information in the assessment of safety hazards and countermeasures in the transit operating environment, as envisioned by Ahmed's[27] safety management framework. In this instance, the reliance on close-call information has been necessitated by the rarity of bus-pedestrian incidents. As the benefit-cost findings show, however, even a marginal reduction in small safety risks can still produce a substantial benefit to society.

SECTION 11

Summary Discussion

Three turn warning systems and an infrastructure-based turn warning sign were tested in a field demonstration project and subsequently evaluated for their effectiveness. The results presented in this report show a range of perceptions, levels of acceptance, and recommendations for improving the technologies. The purpose of this section is to bring together the findings of the demonstration, information gained from other agencies' experiences with turn warning systems, and a scan of the potential offered by emerging technologies. Together, the integration of knowledge gained from these sources should assist the reader in understanding the full spectrum of implications associated with the implementation of the technologies.

This summary discussion is organized around the following topics:

- Common themes emerging from the research
- Technology effectiveness
- Acceptance of technologies
- Recommendations for improving technologies
- Other approaches for improving pedestrian safety around transit buses

Common Themes Emerging from the Research

A number of common themes emerged from the surveys and focus groups involving operators, pedestrians, and cyclists, as well as from early complaints from the general public. These themes were:

- Finding an appropriate volume level for the warnings
- Finding the right sensitivity setting for warning activation (for those activated via the steering wheel)
- Selecting the right warning type/content
- Determining when and where the warnings should activate

Each of these issues is discussed below in terms of the entirety of the research findings.

Warning Volume – Finding an Appropriate Volume Level

Getting the volume settings of the warnings right was an issue throughout the duration of the demonstration test. The volume levels were initially established (mid-80 decibels) based on factory settings and vendor experiences with other transit agencies; however, after early complaints by operators, passengers, and residents along the routes, the volumes were adjusted. TriMet used the City of Portland's Noise Control Program assessment process to measure and establish the new volume levels. For System B, the daytime volume levels were adjusted to approximately 70 decibels, and the "nighttime mode" was activated and programmed to 60 decibels between 9:00 AM and 7:00 PM. System A did not have a feature to change the volume levels by time of day; therefore, the volume was adjusted to 60 decibels so as to not be too loud at night. Following these adjustments, noise complaints declined, but a growing number of operators also reported in the daily surveys that the volumes had become too low to be effective. In fact, analysis of the daily survey showed that responses indicating the volumes being "too loud" trended downward over the test, while responses indicating the volume being "too soft" trended upward. In the end, responses on the operator comprehensive survey showed, by a significant margin, that the warning volumes were too loud rather than too soft.

Considered together, the responses recovered from the daily and comprehensive surveys seem to reveal a confounding perception among operators of the volume necessary for the systems to be effective with an attitude that any volume above a fairly low threshold is annoying. Regarding the individual systems, operator responses showed that the "too loud" margin was significantly greater for systems with the spoken warning message than for the system with the beeping sound.

From the perspective of the public, a majority of the pedestrians surveyed did not find the warnings to be intrusive to the environment. Of those that did, more found the spoken warnings to be intrusive than the beeping warning. Participants in the public focus disagreed somewhat, reporting that the volumes of the spoken messages were acceptable once they were adjusted, but that the beeping warning was still too loud. At any rate, the study found a lack of consensus about what the "appropriate" warning volume level should be.

Considering the experiences of other transit agencies, the volume issue is not unique to TriMet's test. At the time the interviews were conducted for this project, Metro Transit (Madison, Wisconsin) was still looking for ways to address the noise issues, including balancing the volume setting and the location of the speakers. Similarly, GCRTA (Cleveland, Ohio) reported that the ambient volume adjustment for its system did not seem to work well. In addition, GCRTA reported that installing a speaker on the front of the bus (in additional to the ones it had on the left and right sides of the bus) would have improved the coverage, as well as the ability to better hear and understand the message, when the bus was turning. WMATA (Washington, DC) had also requested improvement to the ambient noise setting of its system.

It should be noted that volume alone may have not been the only issue contributing to the noise complaints. In the focus groups, both operators and the public reported that the repetition and/or the frequency of the warnings may have also been an issue. Those most impacted by the repetition/frequency of the warnings were operators, passengers (when the warnings could be heard from inside the bus), and, to some extent, residents along the route (particularly routes with frequent bus service and/or early morning or late night service). Several participants in the public focus groups reported that they lived or worked along one of the test routes and that the warnings could be "noisy," "annoying," and "intrusive." Operators tended to sit firmly on one side or the other of the repetition issue. Some recommended that the warning (whatever it is) needs to sound at least two times to get people's attention, while others were more adamant that the warning sound only once to reduce the sheer number of times they had to hear it.

To mitigate some of the volume issues, feedback from the focus groups was that the warnings (and the volumes) should be relative to a particular location and that there should be an ability for the operators to manually adjust the volume or to program the systems to automatically turn off when and where they are not needed. Both System A and System B did have automated noise adjustment capabilities; however, as previously discussed, this feature for System A was disabled as a result of the way it was installed. While the nighttime mode of System B was used, the time needed to program the warnings based on spatial inputs was too extensive for this demonstration test. Further, it was not possible to program the system to adjust the volumes by geography, only whether the warning was on or off. TriMet noted that the former would be a desirable feature. In addition, improved speaker locations was recommended by TriMet operators in the focus groups.

Sensitivity of Warning Activation – Finding the Right Sensitivity Setting

Another issue that proved challenging throughout the test was finding the right sensitivity setting to activate the warnings. This issue was specific to the two systems that were activated by rotating the steering wheel (Systems A and B). For two primary reasons, the activation angles for both systems were initially set to provide early warnings.[28,29] One reason stemmed from the findings of an earlier, more limited, test of one turn warning system conducted by TriMet. In that test, TriMet found a tendency for the warnings to activate too late in the turn to be effective at providing sufficient advance warning to pedestrians. A second motivation for early activation was the desire to test the effectiveness of the turn warning systems at bus stop locations (when pulling into a stop and when pulling away from a stop). Although the systems were not specifically designed for this purpose, the objective was to select turn angles that were sensitive enough to activate the warnings at locations that required operators to pull the bus out of the main travel lane in order to service the stop.

The initial turn angles produced false activations of the warnings in certain situations. More specifically, operators reported that both systems would sometimes activate when navigating sharp roadway curves or during lane changes. These complaints were more common for System A in the daily surveys. In addition, the warning for System A would continue to play after parking with curbed wheels. These problems were mitigated somewhat via system adjustments (but only to System A), which was evidenced by a downward trend in the reporting of false activations in the operator daily survey. Despite the adjustments and the downward trending in complaints, a majority of operators later indicated in the comprehensive survey that the systems activated too early, and a substantial majority reported the systems activated in roadway curves. These findings indicate that to some extent the problems continued and/or the operators were still resentful about the early issues. Indeed, operators participating in the focus groups confirmed that the problems with false activations were mitigated somewhat via system adjustments, but that they continued in some cases. To the contrary, a few operators noted that the systems would not always activate early enough in a turn to be effective.

From a maintenance perspective, TriMet noted that the calibration of System B was less complicated than System A. For System A, the trigger had to be adjusted on the pitman arm, which was typically a trial and error process that took two people under the bus about 15–30 minutes to complete. Adjustment of System B, on the other hand, was much easier. Everything was done inside the bus by connecting a computer to the system's ECU via its internal software, which took one person about five minutes. Adjusting the activation angles for System B involved changing the checkerboard sticker on the steering column, which were printed by the vendor and sent to the agency for replacement.

It should be noted that at least part of the false activation issue may have been related to the maximum speed threshold selected for warning deactivation. For both systems, a maximum speed threshold of 25 mph was selected prior to the test. Although lowering the speed threshold was discussed once the test was underway, doing so would have resulted in a disruption to the test as both systems required an update to each individual unit via an external connection. System A would have required the use of a portable programming device to connect to each unit; therefore, TriMet would have had to obtain one of the devices from the manufacturer, which would have interrupted the test bus operations. System B required the use of a USB drive to connect to each unit. While TriMet did have access to one of these devices, the decision was made not to change the speed on any units to be consistent across the systems.

Therefore, the decision was made to keep the maximum speed thresholds at 25 mph and to adjust the activation angles instead. In effect, adjusting both may have done more to mitigate the false activation problem. Given that turns, as well as bus stop arrivals and departures, are made at relatively slow speeds (5–10 mph at most), setting the maximum speed threshold closer to 15 mph would eliminate at least some of the false activations.

As with the volume, TriMet's issues with warning activation have occurred at other agencies. GCRTA reported similar issues associated with warning activation for System A. Initially the agency wanted to make sure the warnings came on before the bus entered the crosswalk, but when the trigger angles were set too tight, the warnings were reportedly "going off all the time." In addition, GCRTA noted that improper turns (e.g., "rainbow turn," "banana turn") tended to trigger the warnings too early or multiple times. As a result, the agency had to stress to operators the need to make proper 90-degree turns.

Warning – Selecting the Right Type/Content

Warning type and content can play a critical role in the ultimate success of the turn warning systems, particularly in terms of acceptance. Selecting a warning that is too harsh, not specific enough, confusing, not long enough, or too long could turn operators and/or the public against the system, despite its ability to get pedestrians' attention and improve safety. The warnings for Systems A and B were configurable and any message or sound could have been programmed to promote system acceptance; but there was no clear answer to the question of what warning was the best warning to use for the test.

A survey of peer practices produced a range of possible warnings. WMATA initially used a spoken warning, then changed to a clicking/turn signal warning, and eventually went back to a spoken warning, as the clicking was not effective at generating a response from pedestrians. GRTC selected a short message and chose to use the word "approaching" in lieu of the word "turning," as the warnings are sometimes activated at bus stops. After much discussion, GCRTA decided on an eight-second spoken message that repeats at least part of the phrase and broadcasts during the entire turn. Metro Transit was using a beeping warning, but was interested in the affordability/availability of a spoken warning.

Based on these practices and discussions with TriMet staff, two different types of auditory warnings were used in the demonstration test—spoken warnings and a beeping warning—and the content of the two spoken warnings differed slightly. In addition to the auditory turn warnings, only one visual warning/sign could be tested. Therefore, to supplement what could be learned about these warnings from the field test, a variety of auditory and visual warnings were presented to and discussed with participants in the pedestrian focus groups. The results showed some consensus and some disagreement as to what constitutes the best auditory and visual warnings.

Regarding warning type, operators were most divided over the beeping warning. Some operators liked the beeping warning because it was a "universal," recognizable sound, and/or they felt it was more effective than the spoken warnings at getting people's attention. Other operators did not like it because they thought it was too loud, harsh, irritating, and potentially distracting. Other complaints were that the meaning of the beeping warning was not obvious for people with sight impairments and that the particular beeping used was too similar to other noises (e.g., kneeling bus, ramp or lift deployment, backing truck), in which case the warning might blend in or get ignored.

Pedestrian perceptions of warning type were less divided, as survey responses showed no significant difference in the perceptions/ratings of the two types of warnings regarding intrusiveness, associated benefits, and more widespread deployment. Focus group participants, however, tended to prefer the spoken warnings over the beeping warning.

Regarding warning content, there was strong consensus amongst operators and pedestrians that "Caution, bus is turning" is a better warning than "Pedestrians, bus is turning." Almost everyone liked the word "caution," and there were numerous complaints about the word "pedestrians." In fact, in the pedestrian focus groups, "Caution, bus is turning" was rated above all other warnings and was favored by most. Interestingly, despite dislike of the word "pedestrians" in a warning, "Pedestrians, bus is turning" was rated a close second, and "Caution, pedestrians. Bus is turning" was a close third (although there was something about the voice/tone of this warning that made it more intrusive to participants). Noises such as the beeping and clicking were less desirable, and directional information (left/right) was not viewed as helpful, rather confusing. One recommendation that came from both operators and pedestrians was to have a combined warning that incorporated both a spoken warning and a sound/tone, which might also help to address the repetition conundrum.

Feedback from the pedestrian focus groups was that, overall, the warning should be concise, clear in meaning, specific, direct, and long and loud enough to get the attention of pedestrians at particular locations/times of the day. Beyond that, pedestrians stressed that the warning be easily-recognized and unique to TriMet buses, as well as "friendly." In fact, both pedestrians and operators recommended something similar to the "bong-bong" of TriMet's MAX light rail vehicles. At any rate, the warning should not be intrusive or "just another noise" that blends into the background. Additional operator feedback was that, rather than focus on one message, they should be varied to keep attention and to make it fun for the public.

With respect to the visual warning/sign, an ideal sign would be clear in meaning, specific, big, bright, flashing, and used in conjunction with an auditory warning. The BUS TURNING sign was highly favored over the other signs presented and discussed. While many liked the idea of a bus symbol, the particular symbol presented in the focus groups was not well received. Alternatively, participants recommended adding the word BUS or TURNING under an improved bus symbol sign.

Application of the Turn Warnings – Determining When and Where the Warnings Should be Used

Although not specifically designed for activating at bus stops, both System A and System B initially were set to be sensitive enough to activate at some bus stops, depending on the nature of the stop (e.g., when pulling out of the travel lane versus stopping in travel lane). Due to false activations early in the demonstration, the steering angles were adjusted on one of the two systems, which may have affected the frequency with which these systems activated at bus stops. Assuming operators used their turn signals at stops, System C would have activated both pulling into and away from bus stops.

Operators overwhelmingly felt that the application of the turn warnings at bus stops was as important, if not more important, than at intersections. Pedestrians tended to agree. Slightly more operators reported that the warnings were more necessary when making right turns than left turns and when pulling into a stop than pulling away from a stop.

However, two recurring issues suggest that it may be prudent to consider selective versus ubiquitous application of the turn warnings. The first issue was the complaints received early on by some Portland residents. While these complaints were generally mitigated by adjusting the volumes, giving more thought to where the warnings should activate (and also at what times of the day) could help to avoid these types of complaints. Second, bus operators and pedestrians reported concern regarding the long-term efficacy of the turn warnings; both groups believed that the warnings would eventually blend into the background noise and/or be tuned out. This belief was driven at least somewhat by the perceived ubiquity of the warnings, particularly if they were activated both at intersections and at bus stops during all service hours.

Instead, both operators and pedestrians strongly recommended that the volumes vary by location and/or time of day or that the volumes adjust automatically relative to the environment. Alternatively (or additionally), participants recommended that the warnings activate only on routes and/or at specific "trouble" locations and/or intersections/locations where there is a history of pedestrian-bus conflicts/collisions.

Outside of temporal variations and known "trouble" spots, there were differences in opinions regarding where the turn warnings might meet with greater success. For example, study participants did not agree on the application of the turn warnings in the downtown area versus residential areas, or at transit centers. Whereas some reported downtown as an area where the warnings would be more effective, others felt there are too many buses and bus stops and that the area is already too noisy. Likewise, some thought that the turn warnings would be more effective at transit centers, while others felt the warnings would create too much noise and confusion. Many, but not all, thought that the warnings would prove to be less effective in residential areas. Specific locations suggested for application of the turn warnings included: schools, parks, malls, unsignalized intersections, minor streets crossing busy streets, and locations where people are known to jaywalk. Times suggested for using the turn warnings included: peak travel periods, nights, and weekends. Situations suggested for using the turn warnings included: during periods of poor visibility and special events.

The flip side of this issue, however, relates to liability—what happens if a pedestrian is struck at a location or time of the day when the warnings are inactive? Here again is a trade-off in the application of the turn warning systems in terms of how much is too much versus too little. This is likely a decision that needs to be carefully considered and weighed by each individual transit agency given the seriousness of the problem, culture of its community, and potential legal implications. At the least, a transit agency will need to define a process involving the community for determining where and when its turn warning system will be inactive.

Technology Effectiveness

Beyond demonstrating the technologies, a major objective of this project was to determine the effectiveness of the technologies by assessing the perceptions of bus operators, the general public, and TriMet management, as well as the ability of the technologies to impact behaviors and reduce close-calls between buses and pedestrians. Additionally, an objective of this project was to develop benefit-cost estimates associated with the turn warning systems to assist other agencies considering the implementation of similar technologies. Subjective assessments of system effectiveness were recovered via the operator and pedestrian surveys and focus groups, interviews with TriMet management and other personnel, and an analysis of pedestrian behaviors. A more objective analysis was conducted to estimate the benefits and costs associated with the turn warning systems.

Overall, bus operators were generally less favorably impressed with the effectiveness of the systems than the general public. From the daily surveys, less than half of operators thought the systems were effective at alerting pedestrians at intersections and bus stops, and less than one third thought the systems were effective at reducing close-calls. Of the three systems, significantly more operators perceived System B as being effective; however, this was still generally less than half of the operators. Operator responses on the comprehensive survey were slightly more positive than those on the daily survey. The majority of operators reported that the systems got pedestrian attention, with somewhat more reporting this effectiveness during right turns versus left turns, and when pulling into a stop versus when pulling away from a stop. Likewise, overall, a little more than one third of operators reported the systems to be effective at reducing close calls, with greater reported effectiveness in reducing close calls during right turns and when pulling into a stop. A substantial majority of operators found the directional LED headlights to be effective.

Focus group discussions with operators echoed the survey findings. Additionally, two caveats surfaced with respect to system effectiveness—one related to the impact of pedestrian distraction on effectiveness, and the other related to the sustainability of the effectiveness of the warnings. According to most operators, many pedestrians do not pay attention and/or are engaged with electronic devices, including headphones and ear buds. According to operators, these behaviors render the systems completely ineffective. One operator commented that the beeping alert, so loud to the point of being borderline distracting to drivers, still did not get the attention of people with ear buds. Further, while the systems may be effective in some cases, many of the operators felt that this may only be temporary; operators felt that eventually the warnings will blend into the background and/or people will "tune them out." Finally, there was concern that some operators may begin to rely on the system and become less vigilant, in which case safety might be compromised rather than improved.

Regarding the effectiveness of the systems in affecting pedestrian behaviors, overall, operators reported that they observed some changes, but probably not as much as hoped, which was verified through the limited observations of pedestrian-bus interactions via the field behavioral analysis. In addition, most operators agreed that the turn warning systems had far less of an effect on cyclist behaviors than on pedestrian behaviors.

About 6% of operators reported in the daily survey that the system had helped them avoid a close-call or collision with a pedestrian that day. On the comprehensive survey, an even greater share (about 11%) reported that the systems had helped them avoid an actual collision with a pedestrian or bicyclist during the demonstration test. There were no significant differences across the three systems in reported avoided close-calls/collisions in either the daily or comprehensive surveys. In the comprehensive survey, virtually all of the responses to the open-ended follow up to the close-call question provided either generalized statements addressing the effectiveness of the warning systems in reducing hazardous behaviors among pedestrians and cyclists or, to a lesser extent, descriptions of specific hazardous encounters that would seem to be better characterized as an avoided close call rather than an avoided collision (e.g., pedestrian reacting to the warning by stepping back to the curb at an intersection while the bus was turning or a patron stepping back from the edge/over the edge of the stop platform as the bus was pulling in). Whereas some operators felt that improvements to the volume, added operator controls, and additional training might help, others felt like the systems are as effective as they are going to be. This sentiment seemed to be associated with the level of pedestrian distraction witnessed daily by operators, and that the systems cannot make up for pedestrian distraction/use of headphones/earbuds.

In the daily operator survey, conducted prior to the focus groups, operators consistently reported that they preferred System B over the others. While this sentiment was echoed in the operator focus groups, these differences did not show up in the comprehensive survey. Where the sentiment did resurface was in the rankings of the systems for overall system performance. In this question, using the mean rankings, System B was ranked highest, followed by System C and then System A. However, the distribution of operators' rankings for each of the systems presented a more complicated picture. In fact, some 42% of rankings "cast" for System C were for first place, which was notably greater than the first place rankings received by either of the other two systems. At the same time, System C's favorability at the top was slightly more than offset by its percentage of third-place rankings.

These results suggest that operators' assessments of the systems were driven by multiple, confounding, and (in some cases) controllable factors. In other words, as this was not a controlled test where all combinations of factors could be tested, at least some of the decisions made at the beginning of the demonstration test likely influenced the outcome described above. For example, operators preferred the System B warning over that of System A, but these warnings can be changed. In addition, operators tended to prefer (although not unanimously) that the warning be spoken only once (as with System B), as opposed to the repetition of the System A warning, which, again, can be modified if desired. Bigger issues may have been those associated more directly with the individual systems, such as warning activation and an automatic volume adjustment feature; however, these issues emerged more as a result of the focus group discussions, as there were no significant differences between the systems based on operator responses to the effectiveness questions on the comprehensive survey. Interestingly, System C took some operators out of the System A vs. System B debate because they preferred it primarily due to its turn signal activation.

On the contrary, analysis of responses on the pedestrian survey showed that a fair majority of pedestrian respondents felt that the systems were effective at both alerting pedestrians and improving pedestrian safety. About half of the cyclist and bus rider respondents thought the systems were effective at alerting them at intersections and bus stops, respectively. In total, 12% of pedestrians, 17% of cyclists, and 7% of bus riders reported the systems played a role in avoiding a collision with a bus.

Regarding the BUS blank-out sign, a little over half of the respondents found the sign to be effective at alerting pedestrians that a bus is turning and at improving pedestrian safety, and a surprising 23% reported that the sign had helped them avoid a collision with a bus. Pedestrian focus group participants cautioned, however, that if the sign is frequently on at an intersection where there are numerous turning buses, it may begin to "blend in" over time, reducing its efficacy. Furthermore, participants felt that if someone is going to ignore the DO NOT WALK signal, they will also probably ignore the bus warning sign.

While subjective assessments can provide some insight into the effectiveness of the systems, and are certainly important for understanding the nuances of the systems, estimations of the benefits and the costs of the systems can help to interpret effectiveness in more objective terms. The benefits and costs of a generic warning system (not specific to any one system tested, but based on actual costs and overall imputed benefits) were developed for three scenarios: a baseline scenario, a minimum scenario, and a maximum scenario. The baseline scenario employed the estimated baseline cost and benefit component values. The maximum scenario employed the combination of cost and benefit values that yielded the largest potentially achievable net benefit outcome (including lower bound installation and maintenance costs, upper bound values for avoided fatalities and injuries, and upper bound values for the valuation of avoided fatalities and injuries). The minimum scenario employed component values that produced the smallest potential net benefit. Thus, the three scenarios covered the maximal range of outcomes that could be reasonably expected for the warning systems based on information recovered during the test and otherwise available at the time.

The results showed that the baseline scenario yielded net present value benefits approaching $3 million overall for the 45 warning systems in the demonstration test, or about $65,300 per bus/warning system. The associated internal rate of return on the warning systems investment for this scenario exceeded 34%, which is fairly substantial. All three scenarios yielded net positive benefits, covering a fairly considerable range, with net present benefits from the maximum scenario more than 12 times greater than those from the minimum scenario.

Acceptance of Technologies

As previously discussed, even if the technologies prove effective at increasing awareness and improving safety, their ultimate success hinges on whether they are accepted by bus operators, the general public, and transit agency personnel. If bus operators are not accepting, they could find ways of getting around the system or even tampering with its functionality. If the general public is not accepting, complaints could cause the transit agency to discontinue its use. If transit agency personnel are not accepting, there may not be long-term support for keeping the systems properly maintained or up to date, impacting the overall return on investment. As an example, although many operators agreed that the turn warning systems were as, if not more, effective at bus stops as compared to intersections, a few operators disagreed on the premise that the warnings would sound too frequently if also used when pulling into and out of every stop.

In general, acceptance of the technologies was assessed through survey questions and focus group discussions that addressed whether operators and pedestrians believed that the benefits of the systems outweighed any drawbacks, whether the systems had a negative impact on the quality of life (work life for operators, environmental intrusiveness for the public), and whether they supported wider deployment of the systems.

As in other areas, the findings were mixed. Nearly half of the operators surveyed agreed that the potential safety benefits outweighed the drawbacks of the warning systems (with more than half of junior operators agreeing); however, overall, only about one-third agreed with the prospect of wider deployment, while nearly half disagreed. System B gained substantially greater favor among operators over the other two systems; in fact, it was the only system that did not encounter majority opposition to the prospect of wider deployment. In contrast, a large majority of pedestrian respondents agreed that the potential benefits of the systems outweighed any associated drawbacks for both types of warnings.

Regarding quality of life, the median response among operators indicated that the systems had no impact on daily work life quality, with more reporting an improvement in daily work life quality than those reporting a decline. Male operators and senior operators were more likely to indicate that the systems reduced the quality of their daily work life. From the public's perspective, overall, 65% did not find the warnings to be intrusive to the environment. Of those that did, more found the spoken warnings to be intrusive than the beeping warning, for which more were unsure (this was counter to what was heard in the pedestrian focus groups). Neither travel mode nor level of exposure appears to have affected respondents' perceptions of intrusiveness except, perhaps, among cyclists; however, the sample size of cyclists was likely too small to produce meaningful results.

The general sentiment among the 27 operator focus group participants regarding further deployment of the turn warning systems can be described as ranging from apathetic to skeptical. Most seemed to have adapted to the presence of the warnings, but did not strongly support nor completely reject the idea of their continued or expanded use. When considering the prospect of system improvements, only some of the operators became more supportive of the idea. Several of the operators were strongly opposed to the continued use of the systems, particularly the system with the beeping warning. One group thought that many operators would be supportive of an improved system; however, they also felt that, no matter what, a small number of operators would not be supportive, including more senior/experienced operators that are "stuck in their ways" and are unwilling to accept new technologies (a sentiment that reinforces the findings from the comprehensive survey).

In contrast, a majority of pedestrian survey respondents agreed that more systems should be installed. It appears, however, that there is a small portion of the population that may agree that the systems offer benefits, but does not agree that more systems should be installed. This sentiment may be because these people feel that the money that would be needed to make this investment could be better spent on other improvements. This sentiment was actually expressed in at least one of the pedestrian focus groups, and is evident in the divided findings from these three groups with respect to TriMet's further investment in the turn warning systems. Whereas almost all of the participants in the first focus group agreed that more systems should be installed "as-is," no one in the third focus group agreed, as they felt the money could be better spent elsewhere. Most from this latter group did agree, however, that if improvements were made to the systems they would buy-in to further deployment, but only in certain areas/ situations. Participants in the second focus group were divided; slightly more than half thought that TriMet should invest in more systems "as-is," and about three-quarters would be on board if improvements were made to the systems.

More than 100 operators provided open-ended responses on the comprehensive survey about their overall experience with the systems that were tested, of which about a quarter offered an endorsement of a specific system (most often the directional LED headlights). Another one-third of the respondents expressed general opposition to all of the warning systems, most frequently pointing to the systems' ineffectiveness, distractions, or annoyances.

In contrast, other transit agencies that have implemented turn warning systems have had greater acceptance on the part of their operators. GCRTA equipped its entire fleet, starting more than four years ago, and continues to procure buses with turn warning systems. Similarly, GRTC (Richmond, Virginia) and New Jersey Transit have installed turn warning systems fleet wide. Pace Bus (Chicago area) reported that it was ordering about 90 new buses per year equipped with turn warning systems. GCRTA reported that only a small minority of its operators was not accepting of their systems, and this was primarily due to the internal message directed at operators (which was not part of this demonstration test). In the case of GCRTA, there is a speaker mounted right behind the operator's head, and some operators do not like the repetitiveness of message. WMATA and New Jersey Transit had similar experiences with high overall acceptance of the systems, but also had a few "hold outs" due to the internal speaker. These experiences are a primary reason why TriMet opted not to include the internal speaker. New Jersey Transit noted that its operators were generally happy with the additional safety afforded by the system. GRTC and Metro Transit noted that some operators initially complained about the volume, but that after making adjustments, the operators were more supportive of the systems. Metro Transit conducted an operator survey to get feedback, but only received about 30 responses, indicating that operators may have been indifferent about the system.

With respect to the public, GCRTA reported that they may have received some complaints at night or in residential areas, but overall the public did not have much to say about the systems. Initially, GCRTA did get some unflattering press from the local radio stations, but it "stuck to its guns" and it went away. GRTC reportedly received positive customer feedback and favorable media coverage after implementing the turn warnings systems. New Jersey Transit received some public complaints about the volumes from residential areas late at night, but has received no complaints from transit customers. Similarly, WMATA received a good deal of public complaints about the noise, particularly "after hours," as well as complaints that it was not spending money wisely. At one point the turn warning systems were turned off, but were later turned back on.

Finally, both operators and pedestrians were supportive of further deployment of the BUS blank out signs.

Recommendations for Improving the Technologies

A number of recommendations for improving the technologies emerged over the course of the test. These recommendations are discussed here with consideration of the fact that not all of the options and components associated with the turn warning systems were tested, and also with the recognition that the technologies have evolved and continue to do so. In other words, some of the recommendations may have actually been possible at the time of this demonstration test, but not attainable within the associated timeframe and budget. Likewise, some of the recommendations may now currently be available as options for one or more of the systems.

Most of the operators who participated in the focus groups agreed that the manufacturers still needed to "tweak" the systems and "get the bugs out." Recommendations for improvements were extracted from the discussions where operators were asked to create their own "ideal" system. Much of these discussions centered on two key themes: operator control and linking the turn warning systems to the GPS/AVL system on the buses.

Almost everyone agreed that total operator control over the system was not a good idea. The majority of operators felt that the automated nature of the systems ensured consistency in when the warnings were activated, and many expressed concerns that operators would not use the system correctly and/or they may take advantage of or abuse the system or turn it off altogether. On the other hand, some operators advocated for some level of control over the system, particularly with regard to when the warning could be sounded and the warning volume. For example, operators noted that they know when people are not paying attention, and/or when they are displaying risky behaviors (e.g., hanging off the edge of the curb); therefore, being able to hit a button to send a targeted warning from the bus prior to when the automated warning would be activated (if at all) would be an improved feature of the system. In addition, many thought they should be able to adjust the volume to a more appropriate level depending on the existing conditions.

During the discussions, a majority of operators agreed that an improved system would involve tying the system to the turn signal (as opposed to the rotation of the steering wheel), selecting a lower speed threshold for warning activation (to reduce or eliminate activation of the warnings in sharp curves and during lane changes), and activating the system only when the wheels are moving. The only counter concern expressed was that some operators may not use their turn signal to avoid hearing the warning.

To further these discussions, several operators offered more detailed recommendations for a system that is even smarter and more "programmable" via integration with the buses' GPS/AVL system. Due to the frequency of activations that would occur if the warnings activated at every turn and every bus stop, a primary concern for operators was that the warnings would either begin to blend into the background noise and/or that pedestrians would eventually tune them out altogether. Operators felt that this potential outcome might be avoided by programming the system to activate only when/where necessary. Examples included programming the volumes to be louder in certain areas and during certain times of the day and activating the warnings only on routes and/or at intersections/locations with previous safety issues or pedestrian activity that might be problematic. In the end, one operator noted that if the system was integrated with the CAD/AVL system and properly programmed, then no operator control features would be necessary.

Beyond the issues of operator control and a smarter system, there were a few recommendations regarding the warning itself. Although most operators liked the word "caution" and, consequently, the warning "Caution, bus is turning," many felt that improvements to the warning could increase the systems' effectiveness. In an attempt to overcome an already noisy environment and/or distracted pedestrians, operators recommended that the tone, voices, and/or messages be changed day-to-day. Operators felt that this change would help to capture people's attention and prevent them from tuning out the warnings. Another recommendation was to repeat the warning a second time, with the first time being louder, and the second time being softer, or starting with a chime/sound followed by a spoken warning. Additionally operators recommended that the warnings sound only in the direction of the turn (rather than on both sides of the bus).

To avoid overuse of the warnings, the pedestrian focus group participants agreed that operators should be able to adjust the volume as appropriate and/or be able to turn the system on/off as necessary. In addition, some pedestrian participants offered that the volumes should vary by time of day and/or the volumes should adjust automatically relative to the environment. Some participants reported that the warnings should only activate at turns (not bus stops), while others reported that the warnings were not necessarily needed at every turn, rather only in specific "trouble" locations. Finally, there was a recommendation to improve the directionality of the speakers to channel the warning in the right direction without impacting everyone around.

Other Approaches for Improving Pedestrian Safety around Transit Buses

Beyond the technologies tested and evaluated in this demonstration project, other approaches to improving pedestrian and cyclist safety were discussed with both bus operators and pedestrians in the focus groups. A wide range of approaches, including both alternative technology and non-technology approaches were discussed.

Technology Approaches

It was primarily the operators who suggested alternative technology approaches to improving pedestrian safety around transit buses. One recommendation was to install more of the BUS blank-out signs, make them big, and possibly add an auditory component. Another recommendation was to use sensors that detect movements or body temperature to trigger the warnings. Finally, more than one operator suggested sending instant messages to distracted pedestrians and cyclists through their smart phones/electronic devices/earphones.

A corresponding literature search for related technologies indeed revealed a number of emerging technologies and systems along the lines of those suggested by bus operators. These technologies, both for transit buses and motor vehicles, show promise for improving pedestrian and cyclist safety around buses. USDOT recently completed a test of a Pedestrian in Signalized Crosswalk Warning (PCW) application, which uses Vehicle-to-Infrastructure (V2I) technology to warn a bus driver when pedestrians are in the intended path of the bus when making a right or left turn. In addition, both General Motors and Honda have developed and/or demonstrated wireless communications technologies to detect and alert pedestrians of potentially dangerous, imminent situations via a smartphone. Other technologies identified included a light rail transit pedestrian crossing warning system (similar to the BUS blank-out sign) and automotive collisions avoidance systems using a variety of vehicle sensors (e.g., wide-angle radar, thermal cameras). Some of these technologies are further along in development that others, with some in need of further development and testing, others in place in some motor vehicles, and others in use within the transit industry. These technologies are further described in Appendix F.

Non-Technology Approaches

It was acknowledged in the focus groups that the systems being tested represent a technology approach to reducing pedestrian-bus collisions, but that other approaches exist and may be as, if not more, effective, particularly when combined. Both operator and pedestrian participants were asked what other approaches they thought might be effective at reducing the number of collisions with pedestrians, and a variety of options surfaced from these discussions. Approaches recommended by operators ranged from public education to strategies focused on operator well-being, and are summarized below:

- Increase the education/awareness of pedestrians:
  - Initiate public awareness campaigns (e.g., using billboards, TV advertisements, signs in bus shelters, video screens on buses) to education pedestrians about how to ride buses and how to be more alert, particularly when crossing the street and around bus stops.
  - Educate school-age children (e.g., take a bus to different schools to educate them on riding buses, how to form lines at bus stops, how to cross after getting off the bus).
  - Require customers to watch a 5-minute video before they can obtain a monthly pass.
  - Have operators work with the public to improve safety (e.g., use the PA system to educate/inform them of safety issues as they arise).
- Hold the public more accountable for their safety as well by enforcing against jaywalking, walking against traffic signals, and illegal/dangerous cyclist behaviors.
- Implement safety improvements/strategies in areas where there are a lot of children.
- Scan—scanning is the number one key strategy.
- Slow down.
- Reduce blind spots on the new buses/improve visibility.
- Cultivate better operators (e.g., reduce operator stress); well-rested, well-nourished operators are safer drivers.
- Reduce the interior glare/reflection on the buses.
- Set realistic schedules; allow for more flexibility/slack in schedule.
- Move bus lanes to the left side of the one-way streets.
- Install bike stop signs on the buses.

Approaches recommended by pedestrians paralleled those offered by operators and included:

- Use public service announcements (PSAs) to increase awareness.
- Use TVs at stops and on buses with safety messages.
- Improve communication between operators and riders (via use of the internal and external PA system)
- Reinforce positive behaviors through education.
- Have buses slow down on the approach to a bus stop.
- Once the auditory turn warnings/bus warning signs have been finalized, use them in educational activities, commercials, and PSAs.

With respect to the specific issue of pedestrian distraction, focus group participants offered the following suggestions:

- Continue outreach/education and public service PSAs and target at-risk populations.
- Look to what other cities with higher density are doing about the problem.
- Enforcement targeting distracted behaviors.
- Put signs and/or bumps on the ground to remind people to look up.
- Install sidewalk gates.
- Increase the development and use of pedestrian malls.

One specific and potentially critical activity mentioned was outreach to schools, specifically to address the transition for children from school bus travel to transit bus travel. On school buses, children have enhanced protections (e.g., all traffic comes to a halt for access/egress and boarding/alighting), but they need to become more aware of risks as they transition to traveling by transit bus. Thus, an effective outreach program in the schools would not only reduce their risks for transit bus travel, it would potentially spill over to reduce risks elsewhere. This type of outreach could represent one key facet of a "safe routes to schools" program.

Closing Thoughts

In the larger traffic safety context, the problem of pedestrian-bus collisions is comparatively small, amounting to less than 1% of all pedestrian fatalities and injuries. Thus, the efforts and investments in training and designing better vehicles and infrastructure are apparently working. In many cases, however, it is a catastrophic event that drives a transit agency to look for additional solutions. Both GCRTA and GRTC developed and implemented turn warning systems following fatal pedestrian-bus collisions. In the opinion of one GCRTA representative, relying solely on trained operators to follow procedures (and to always get everything right) is one of the least reliable ways to control for safety. The technology places a level of control above and beyond that of the operator and therefore increases dependability. And whereas the technology has met with success in Cleveland, GCRTA recognizes that the technology alone will not eliminate incidents.

In fact, transit agencies are being met with new challenges, such as a growing number of distracted pedestrians and cyclists. TriMet bus operators in particular seemed to be highly sensitized to the safety risks associated with pedestrians and cyclists, describing unsafe behaviors and distractions as being something that they regularly experienced during their shifts. Maybe as a result, operators were more likely to conclude that the turn warning systems were not a sufficient "intervention" that would have a meaningful impact on these perceived, pervasive, unsafe behaviors.

Approaching zero deaths will take commitments on multiple fronts. The reduction in collisions GCRTA has realized since deploying the turn warning systems was not simply a result of the technology; it was 100% the whole program. GCRTA's existing procedures (e.g., two-second rule turn procedure from red light, rocking-and-rolling to see around mirrors and A-pillars, posters) are all still in place, and the technology has just enhanced the effectiveness of what they already do. Through its experience with this demonstration test, TriMet agrees that these technologies are not a panacea; rather, they are just one tool in an array of strategies that transit agencies should consider when working to improve safety. In addition, it is important that technologies be employed properly and updated periodically to meet the challenges in the environment, including maintaining buy-in from and collaboration with the community and operators. Perhaps the collective message and take-away is that, while the findings from this study indicate that the warning technologies can make a meaningful and cost-effective contribution, there is still more to be done to deal effectively with this problem.

ENDNOTES

[1]National Highway Traffic Safety Administration, U.S. Department of Transportation, "Quick Facts 2013: Early Release," undated.

[2]For this test, the angles were initially set at 180 degrees for both left and right turns. After initial testing, the angles were modified to 170 degrees to increase the sensitivity of warning activation. After complaints from operators about false activations, the angle for the left turn was adjusted to 240 degrees, and the angle for the right turn was adjusted to 120 degrees.

[3]Per the manufacturer's recommendation, the speed threshold was set to 25 mph for the test.

[4]TriMet connected the system to two existing speakers, one located on each side of the bus behind the front wheels.

[5]The side-mounted LED strobe lights are an option and were included in the demonstration test of System A.

[6]For this test, the trigger angles for System B were set at approximately 90 degrees for right and left turns. No adjustments were made to these angles during the test. It should also be noted that due to the differences in the ways that Systems A and B are activated, the angles cannot be directly compared.

[7]TriMet connected the system to two existing speakers, one located on each side of the bus behind the front wheels.

[8]TriMet added temporal inputs shortly after the demonstration test began to decrease the warning volume between the hours of 9:00 PM and 7:00 AM. No spatial zone inputs to adjust the volume were used in the test.

[9]The automatic ambient noise adjustment feature uses the roadside speaker to sample the ambient noise prior to the warning and adjusts the volume accordingly. This feature was not used, as TriMet chose to make use of the existing speakers used for the Americans with Disabilities Act (ADA) and stop alert systems. By doing this, the manufacturer was required to install a relay to switch on the speaker during audio playback of the turn warning and then to release the speaker for the ADA and stop announcements. The installation of the switch disabled the ability of the system to sample the ambient noise.

[10]While not used in operating service, the geo-fencing feature was used to disable the auditory warning in the bus yard.

[11]Public complaints are discussed in more detail in Section 7.

[12]This feature was deactivated on the 45 buses equipped with the three pedestrian warning systems so as not to confound its effects with the perceived effects of the warning systems.

[13]Responses on the turn warning systems' stop-related effectiveness were screened by a leading question that asked whether the warning announcements activated when the bus pulled into and away from stops. More than 80% of the respondents reported that the systems did activate in these circumstances, and regression analysis indicated that positive responses to this question trended upward over the survey period.

[14]Some of the new buses equipped with System C served as statistical controls during the field test period, and the turn warning component was disabled. In addition, the directional LED headlights on the buses equipped with System A and System B were turned off during the test period. Thus, the operator responses on the failure to activate for these two systems may have been affected.

[15]For the directional LED headlights, operators were asked to assess their effectiveness at night.

[16]This was largely due to the nature of how cyclists travel as compared to pedestrians. Although an effort was made to include cyclists in the survey sample, unless a cyclist was walking his/her bicycle through the intersection, they were difficult to engage for the survey. The original hypothesis was that with the large number of pedestrians and cyclists in the Portland area, the survey sample would include respondents who were both pedestrians and cyclists; however, this ultimately was not the case.

[17]System 2 units were purchased as part of the FTA demonstration test. System 1 units were given to TriMet by the vendor as an in-kind contribution to the project.

[18]System 2 units were purchased as part of the FTA demonstration test. System 1 units were provided to TriMet as an in-kind contribution by the vendor.

[19]Heinrich, H.W., 1931, *Industrial Accident Prevention: A Scientific Approach*, New York: McGraw Hill Publishers.

[20]Schwebel, D.C., D. Stavrinos, K.W. Byington, T. Davis, E.E. O'Neal, E.E., and D. de Jong. 2012, "Distraction and Pedestrian Safety: How Talking on the Phone, Texting, and Listening to Music Impact Crossing the Street," *Accident Analysis and Prevention*, 45, 266-271.

[21]As described in Geller, E.S., 2001, *The Psychology of Safety Handbook*, 2nd Edition, Boca Raton: Lewis Publishers.

[22]Strathman, J., Kwon, S., and S. Callas 2013. "Bus Operator Perceptions of Safety Risks," paper presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, DC, January.

[23]White House Office of Management and Budget, 1992, *Circular A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* Washington, DC.

[24]U.S. Department of Transportation, 2011, *Treatment of the Economic Value of a Statistical Life in Departmental Analysis* (2008 Revised Guidance and 2011 Update), Washington, DC: Office of the Secretary.

[25]*Ibid.*

[26]Schneeberger, J., G. Torng, D. Hardesty, and A. Jacobi, 2013, "Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research: Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions," Washington, DC: U.S. Department of Transportation, Research and Innovative Technology Administration.

[27]Ahmed, S.A., 2011, *Transit Safety Management and Performance Measurement, Volume I: Guidebook*. Washington, DC: U.S. Department of Transportation, Federal Transit Administration, Office of Safety and Security.

[28]Initially, the settings for System A were 180 degrees for both left and right turns. After initial testing, the angles were modified to 170 degrees to increase the sensitivity of warning activation. After complaints from operators about false activations, the angle for the left turn was adjusted to 240 degrees and the angle for the right turn was adjusted to 120 degrees.

[29]The trigger angle settings for System B were set at about 90 degrees for both left and right turns. No adjustments were made.

APPENDIX

A

Current Market Cost Estimates

Current Market Cost Estimates

The benefit-cost analysis presented in Section 10 was based on the costs of the turn warning systems at the time they were tested. Additionally, one of the systems has been modified since the demonstration test began. Therefore, to provide more updated cost information, a hypothetical current market cost estimate was developed. Current market cost estimates were developed from information provided by the system manufacturers in December 2014. These estimates are shown in Table A-1.

The cost information presented in Table A-1 is based on a hypothetical purchase order. This hypothetical purchase order assumes a fleet of 50 buses from a public transit agency in the United States. The manufacturers were asked to provide unit costs for a retro-fit of 50 buses. Although all three of the systems could be purchased as part of a new bus build, that situation might be priced very differently. Further, this option was not explored for this report because many agencies may want to install these systems but may not be able to purchase new buses.

The hypothetical transit agency's fleet already had third-party on-board computers, CAD/AVL, and two external speakers, but no LED strobe lights. These were some basic specifications that many agencies typically already have on their buses. Other existing features could have been included but may not be as widely available on transit fleets, especially those from smaller agencies. It should also be noted that the cost information in Table A-1 includes additional features that were not available at the time the systems were procured for the demonstration test in early 2014 (e.g., an object detection feature was added to System A, as was a noise adjustment feature that uses spatial and temporal inputs).

Table A-1: Current Market Cost Estimates (as of December 2014)
Based on Hypothetical Purchase Order

Features	Unit Cost of System A	Unit Cost of System B	Unit Cost of System D (Assessed but Not Tested)
Base ECU	$869	$2,871	$1,500
GPS (geo-fencing)	$225	Included	Not available
RF (geo-fencing)	$253*	Included	Not available
Strobe lights	$175	$155	Not available
Speed sensing technology	Included	Included	Included
Ambient volume adjustment	Included	Included	Not available
Installation and training	Included	$505	Included
Object detection	Included (less sensors)	Not available	Not available
Warranty	2 yr (Included)	1 yr (Included)	1 yr (Included)
Total cost	$1,522	$3,531	$1,500

* To use System A's RF geo-fencing feature, RF receivers must be purchased for each location for which an agency wants to create a geo-fence. This cost is not associated with the per-unit cost of the turn warning system. Each RF receiver costs approximately $1,000.

It should be noted that this is presented *for informational* purposes only to assist transit agencies and others interested in learning about the potential cost of purchasing these systems. The real costs likely will differ based on market conditions and other factors such as agency-specific requirements.

APPENDIX

B

Bus Operator Surveys

Bus Operator Surveys

Turn Warning System Survey

Dear Operator,

TriMet has been testing three pedestrian collision warning systems since March on Routes 4, 8, 15, 33, and 75. This test is part of a Federal Transit Administration-sponsored study conducted by TriMet, AEM Corporation, and Portland State University.

The bus that you drove today is equipped with one of the warning systems. We would like to know what you think about how this system performed. We are interested in knowing if the system worked as intended (Did it activate when it was supposed to?), and whether it had any effect (Did pedestrians or cyclists react to the warnings?).

This survey that follows will take about 5 minutes to complete. Your responses to the survey questions will be treated as confidential information, and your identity will not be known. Our plan is to summarize survey information from many operators to determine whether these systems can improve safety. Your participation in the survey is completely voluntary. You can choose not to take the survey. If you do take the survey, you can choose to stop at any time. Your entitled rights or benefits will not be affected by any choice that you make.

If you have any questions about the project or your participation in this survey, you can contact Professor Jim Strathman, Portland State University, who is responsible for administering the survey. He can be reached at strathmanj@pdx.edu or (503) 725-4069. You can also contact PSU's Office of Research Integrity, which oversees research involving human subjects. They can be reached at (503) 725-2227.

Thank you for contributing to improving safety at TriMet and in the transit industry.

Bus Operator Turn Warning System Survey

Today you operated a bus with a pedestrian turn warning system. Please let us know about your experience TODAY ONLY.

1. Did you experience any PROBLEMS with the turn warning system today?

□ No (skip to Question 2)
□ Yes

Please mark all that apply:
□ Warning did not activate during one or more LEFT turns.
□ Warning did not activate during one or more RIGHT turns.
□ Warning activated TOO LATE during one or more LEFT turns (after bus entered crosswalk during turn).
□ Warning activated TOO LATE during one or more RIGHT turns (after bus entered crosswalk during turn).
□ Warning falsely activated –> please describe: ________________________________
□ Volume of warning was TOO LOUD.
□ Volume of warning was TOO SOFT.
□ Warning was garbled.
□ Patron complained about the warning –> describe complaint: ____________________
□ Other –> please describe problem: _______________________________________

2. Was there a particular situation where you think the turn warning system helped AVOID a close-call or collision with a pedestrian?

- □ No (skip to Question 3)
- □ Yes –> please describe what happened: ______________________________________

3. In your opinion, how SUCESSFUL was the turn warning system at the following:	**Not at all successful 1**	**2**	**3**	**Very successful 4**	**Not sure**
Alerting pedestrians that the bus was TURNING.	□	□	□	□	□
Reducing close calls between pedestrians and buses DURING TURNS.	□	□	□	□	□

4. Did the turn warning system activate when you were pulling into or out of one or more bus stops?

- □ No (skip to Question 5)
- □ Yes

5. In your opinion, how SUCESSFUL was the turn warning system at the following:	**Not at all successful 1**	**2**	**3**	**Very successful 4**	**Not sure**
Alerting pedestrians that a bus was PULLING INTO or OUT OF A BUS STOP.	□	□	□	□	□
Reducing close calls between pedestrians and buses AT BUS STOPS.	□	□	□	□	□

6. To what extent do you AGREE or DISAGREE with the following statement. (Use a scale of *1* to 5, with 1 being *strongly disagree* and 5 being *strongly agree*.)

I would like to see this turn warning system installed on more or all TriMet buses.

Strongly disagree 1	**Somewhat disagree 2**	**Do not agree nor disagree 3**	**Somewhat agree 4**	**Strongly agree 5**	**Not sure**
□	□	□	□	□	□

THANK YOU!
PLEASE RETURN THE COMPLETED SURVEY TO STATION AGENT.

Bus Operator Comprehensive Survey

Over the past several months, TriMet has been testing four different systems aimed at improving pedestrian safety around buses: three audible turn warning systems and an LED cornering headlight system, meant to better illuminate the crosswalks during turns.

Please indicate which of the 4 systems you have operated at least once. (Check all that apply.)

☐ Turn warning system with the *beeping alert*. (Q1-7)

☐Turn warning system with the spoken alert: "*Caution, bus is turning*." (Q8-14)

☐ Turn warning system with the spoken alert: "*Pedestrians, bus is turning*." (Q15-21)

☐ LED cornering headlights. (Q22-28)

This survey contains questions about your OVERALL experience with and perceptions of EACH system separately. Please answer the questions as honestly as possible and to the best of your ability.

Questions for Turn Warning System with Beeping Warning

1. The beeping alert for this system was designed to activate with the turn signal. At any point while operating buses with this turn warning system, did you experience PROBLEMS with the system not working properly?

☐ NO, this turn warning system always worked properly. (Skip to Question 3.)

☐ YES, I experienced one or more problems with the system not working properly.

FIRST, check the problem(s) you experienced. THEN, rate HOW OFTEN each problem occurred.	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
☐ The beeping alert did not activate when I used the turn signal.	☐	☐	☐	☐	☐	☐
☐ The beeping alert activated when I did not used the turn signal.	☐	☐	☐	☐	☐	☐
☐ The beeping alert was not loud enough for pedestrians to hear.	☐	☐	☐	☐	☐	☐
☐ The beeping alert was too loud.	☐	☐	☐	☐	☐	☐
☐ Other ___________________	☐	☐	☐	☐	☐	☐

2. Overall, HOW OFTEN did you observe that the beeping alert got the attention of pedestrians when you were:	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
… turning LEFT at an intersection.	☐	☐	☐	☐	☐	☐
… turning RIGHT at an intersection.	☐	☐	☐	☐	☐	☐
… PULLING INTO a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐
… PULLING AWAY from a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐

3. In your opinion, HOW EFFECTIVE is this turn warning system at reducing close-calls between buses and pedestrians:	**Not at all effective**	**Slightly effective**	**Effective**	**Very effective**	**Not sure**
… during LEFT TURNS at an intersection.	☐	☐	☐	☐	☐
… during RIGHT TURNS at an intersection.	☐	☐	☐	☐	☐
… when PULLING INTO a service stop (when the alert is active).	☐	☐	☐	☐	☐
… when PULLING AWAY from a service stop (when the alert is active).	☐	☐	☐	☐	☐

4. Were there any situations where you believe that this turn warning system helped to avoid an actual collision with a pedestrian or cyclist?

☐ NO

☐ YES Please describe the situation(s): ____

5. Using the scale below, please rate how this turn warning system affects the QUALITY of your day to day work-life.

Greatly Decreases Quality					No Effect on Quality					Greatly Increases Quality
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

6. To what extent do you AGREE or DISAGREE with the following statements regarding the turn warning system with the *beeping alert*:	**Strongly disagree**	**Somewhat disagree**	**Do not agree or disagree**	**Somewhat agree**	**Strongly agree**	**Not sure**
The potential benefits of this turn warning system outweigh any associated drawbacks.	☐	☐	☐	☐	☐	☐
I would like to see this turn warning system installed on more TriMet buses.	☐	☐	☐	☐	☐	☐

Questions for the Turn Warning System with the Spoken Alert: "Caution, bus is turning."

7. The spoken alert for this system was designed to activate in advance of left and right turns at intersections. At any point while operating buses with this turn warning system, did you experience PROBLEMS with the system not working properly?

☐ NO, this turn warning system always worked properly. (Skip to Question 10.)

☐ YES, I experienced one or more problems with the system not working properly.

8. FIRST, check the problem(s) you experienced. THEN, rate HOW OFTEN each problem occurred.	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
☐ The spoken alert activated too early.	☐	☐	☐	☐	☐	☐
☐ The spoken alert activated too late.	☐	☐	☐	☐	☐	☐
☐ The spoken alert did not activate at all.	☐	☐	☐	☐	☐	☐
☐ The spoken alert activated in roadway curves.	☐	☐	☐	☐	☐	☐
☐ The spoken alert was not loud enough for pedestrians to hear.	☐	☐	☐	☐	☐	☐
☐ The spoken alert was too loud.	☐	☐	☐	☐	☐	☐
☐ Other ______________________	☐	☐	☐	☐	☐	☐

9. Overall, HOW OFTEN did you observe that the spoken alert got the attention of pedestrians when you were:	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
… turning LEFT at an intersection.	☐	☐	☐	☐	☐	☐
… turning RIGHT at an intersection.	☐	☐	☐	☐	☐	☐
… PULLING INTO a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐
… PULLING AWAY from a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐

10. In your opinion, HOW EFFECTIVE is this turn warning system at reducing close-calls between buses and pedestrians:	**Not at all effective**	**Slightly effective**	**Effective**	**Very effective**	**Not sure**
… during LEFT TURNS at an intersection.	☐	☐	☐	☐	☐
… during RIGHT TURNS at an intersection.	☐	☐	☐	☐	☐
… when PULLING INTO a service stop (when the alert is active).	☐	☐	☐	☐	☐
… when PULLING AWAY from a service stop (when the alert is active).	☐	☐	☐	☐	☐

11. Were there any situations where you believe that this turn warning system helped to <u>avoid an actual</u> collision with a pedestrian or cyclist?

☐ NO

☐ YES Please describe the situation(s): ______________________________

12. Using the scale below, please rate how this turn warning system affects the QUALITY of your day-to-day work life.

Greatly Decreases Quality					No Effect on Quality					Greatly Increases Quality
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

13. To what extent do you AGREE or DISAGREE with the following statements regarding the turn warning system with the spoken alert, "*Caution, bus is turning*":	**Strongly disagree**	**Somewhat disagree**	**Do not agree or disagree**	**Somewhat agree**	**Strongly agree**	**Not sure**
The potential benefits of this turn warning system outweigh any associated drawbacks.	☐	☐	☐	☐	☐	☐
I would like to see this turn warning system installed on more TriMet buses.	☐	☐	☐	☐	☐	☐

Questions for Turn Warning System with Spoken Alert: "Pedestrians, bus is turning."

14. The spoken alert for this system was designed to activate in advance of left and right turns at intersections. At any point while operating buses with this turn warning system, did you experience PROBLEMS with the system not working properly?

☐ NO, this turn warning system always worked properly. (Skip to Question 17.)

☐ YES, I experienced one or more problems with the system not working properly.

15. FIRST, check the problem(s) you experienced. THEN, rate HOW OFTEN each problem occurred.	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
☐ The spoken alert activated too early.	☐	☐	☐	☐	☐	☐
☐ The spoken alert activated too late.	☐	☐	☐	☐	☐	☐
☐ The spoken alert did not activate at all.	☐	☐	☐	☐	☐	☐
☐ The spoken alert activated in roadway curves.	☐	☐	☐	☐	☐	☐
☐ The spoken alert was not loud enough for pedestrians to hear.	☐	☐	☐	☐	☐	☐
☐ The spoken alert was too loud.	☐	☐	☐	☐	☐	☐
☐ Other ______________________________	☐	☐	☐	☐	☐	☐

16. Overall, HOW OFTEN did you observe that the spoken alert got the attention of pedestrians when you were:	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
… turning LEFT at an intersection.	☐	☐	☐	☐	☐	☐
… turning RIGHT at an intersection.	☐	☐	☐	☐	☐	☐
… PULLING INTO a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐
… PULLING AWAY from a service stop (when the alert was active).	☐	☐	☐	☐	☐	☐

17. Were there any situations where you believe that this turn warning system helped to avoid an actual collision with a pedestrian or cyclist?

☐ NO

☐ YES Please describe the situation(s): ____

18. In your opinion, HOW EFFECTIVE is this turn warning system at reducing close-calls between buses and pedestrians:	**Not at all effective**	**Slightly effective**	**Effective**	**Very effective**	**Not sure**
… during LEFT TURNS at an intersection.	☐	☐	☐	☐	☐
… during RIGHT TURNS at an intersection.	☐	☐	☐	☐	☐
… when PULLING INTO a service stop (when the alert is active).	☐	☐	☐	☐	☐
… when PULLING AWAY from a service stop (when the alert is active).	☐	☐	☐	☐	☐

19. Using the scale below, please rate how this turn warning system affects the QUALITY of your day-to-day work life.

Greatly Decreases Quality					No Effect on Quality					Greatly Increases Quality
-5	-4	-3	-2	-1	0	1	2	3	4	5
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

20. To what extent do you AGREE or DISAGREE with the following statements regarding the turn warning system with the spoken alert, "Pedestrians, bus is turning":	**Strongly disagree**	**Disagree**	**Do not agree or disagree**	**Agree**	**Strongly agree**	**Not sure**
The potential benefits of this turn warning system outweigh any associated drawbacks.	☐	☐	☐	☐	☐	☐
I would like to see this turn warning system installed on more TriMet buses.	☐	☐	☐	☐	☐	☐

Questions for Direction LED Headlights

21. The direction LED headlights were designed to <u>activate with the turn signal</u>. The headlights illuminate the area to the right/left during right/left turns and when pulling into/out of bus stops. At any point while operating buses with this system, did you experience PROBLEMS with the system not working properly?

☐ NO, this turn warning system always worked properly. (Skip to Question 24.)

☐ YES, I experienced one or more problems with the system not working properly.

22. First, check the problem(s) you experienced. Then, rate HOW OFTEN each problem occurred.	**Almost never**	**Rarely**	**Sometimes**	**Frequently**	**Almost always**	**Not sure**
☐ Headlights did not activate when I used the turn signal.	☐	☐	☐	☐	☐	☐
☐ Headlights activated when I did not use the turn signal.	☐	☐	☐	☐	☐	☐
☐ Other ______________________________	☐	☐	☐	☐	☐	☐

23. Overall, HOW EFFECTIVE do you think the directional LED headlights are at illuminating pedestrians while:	**Not at all effective**	**Slightly effective**	**Effective**	**Very effective**	**Not sure**
… CROSSING AT INTERSECTIONS at night.	☐	☐	☐	☐	☐
… WAITING AT SERVICE STOPS at night.	☐	☐	☐	☐	☐

24. Overall, HOW EFFECTIVE do you think the directional LED headlights are at reducing close-calls between buses and pedestrians:	**Not at all effective**	**Slightly effective**	**Effective**	**Very effective**	**Not sure**
… during LEFT TURNS at night.	☐	☐	☐	☐	☐
… during RIGHT TURNS at night.	☐	☐	☐	☐	☐
… pulling into SERVICE STOPS at night.	☐	☐	☐	☐	☐
… pulling away from SERVICE STOPS at night.	☐	☐	☐	☐	☐

25. Were there any situations where you believe that the directional LED headlights helped to avoid an actual collision with a pedestrian at an intersection or at a service stop AT NIGHT?

☐ NO

☐ YES Please describe the situation(s): ____

26. To what extent do you AGREE or DISAGREE with the following statement: I would like to see the directional LED headlights installed on more TriMet buses.

Strongly Disagree	**Somewhat disagree**	**Do not agree or disagree**	**Somewhat agree**	**Strongly agree**	**Not sure**
☐	☐	☐	☐	☐	☐

27. Considering everything and your overall experience, please RANK the performance of the three turn warning systems in the table below. Assign "1" to the best system, "2" for second system, and "3" for the worst system for OVERALL PERFORMANCE.

Turn Warning System	RANK for OVERALL System Performance
"Pedestrians, bus is turning"	
"Caution, bus is turning"	
Beeping warning	

Is there anything else you'd like to say about any of the systems or your experience with them? ____

END OF SURVEY – THANK YOU FOR YOUR PARTICIPATION!

APPENDIX

C

Bus Operator Focus Group Guide

Bus Operator Focus Group Guide

Introduction (*10 minutes*)

- Introductions
- Housekeeping
- Background to project – We are here as part of a study that is being sponsored by the Federal Transit Administration. Generally, the purpose of this study is to assess whether there are safety benefits of the turn warning systems that could justify the cost of implementing the systems. The warning systems we're testing didn't exist 10 years ago, and now they're being used in about 15 bus systems across the US. FTA selected TriMet for a controlled study. Evidence of safety benefits will be drawn from this study via surveys of bus operators and pedestrians, analysis of events recorded in TriMet's "close-call" database, and insights from operator and pedestrian focus groups.
- Goals for focus group – the operator surveys gave us a good general sense of the operators' impressions about the systems we're testing; but there are some issues that we need more direct first-hand feedback on. Today we will be discussing these issues with you.

Effectiveness (*35 minutes*)

The transit industry has an excellent safety record, with very low fatality rates compared to other travel modes. But pedestrians now account for 40% of all bus-involved fatalities, compared to just 10% for auto-involved fatalities. Therefore it's natural that efforts to improve bus safety performance would focus here. The turn warning systems offer a technology approach to reducing pedestrian fatalities.

- In general, do you think this type of technology offers potential to improve pedestrian safety (i.e., reduce the number of collisions with pedestrians)? Why or why not?
- From your experience, what are the advantages of these systems (e.g., get pedestrians'/bicyclists' attention, reduce close-calls)?
- The turn warning systems that TriMet is testing are "infant technologies" with a lot of bugs. Based on your experience, what are the biggest problems with these systems? If these problems were corrected, would it make the systems more effective? (Step through each problem one by one and get a feel for level of consensus.)
- Developing lists of both the pros and cons (in the words of the operators) and then have them choose their top 3 in each list to see which ones rise to the top.
- If you could start from scratch, what would your ideal turn warning system look like? What features would it have? Do you think some kind of operator control should be designed into the system? How would that work?
- Are there other/different approaches that you think would be more effective at reducing the number of collisions with pedestrians? Why do you think these approaches would be more effective?

Break (*10 minutes*)

Warning Specifics (*35 minutes*)

Getting the warning volume settings right has been a problem. After early complaints by operators, passengers, and residents along the routes, the volumes were turned down. Noise complaints then declined, but a growing number of operators also reported in the daily surveys that the volume was then too low to be effective. Do you think it the higher volume that people were complaining about or was it something else? Is there a better kind of warning that would be effective in alerting pedestrians, but still draw fewer complaints?

In the earlier survey, operators consistently preferred the system with the warning "Caution, bus is turning" over the system with the beeping noise or the one with the warning "Pedestrians, bus is turning." Can you think of some reasons why operators preferred the first system and had more problems with the other two (e.g., presence/repetition of the message, type/length/volume of the message, pitch/tone of the beeping)? Is there any message that you could live with?

When the warnings were active pulling into/out of bus stops, did you feel they were necessary and/or effective?

Do you feel the warnings had any effect (positive or negative) on bicyclists?

Observationally, did you witness pedestrians/bicyclists that changed/modified their behavior during/after the warning (compared to your experience before the test - i.e., do you feel the warning made a difference in an actual situation you encountered)?

When making a protected left turn (the bus has a green arrow and pedestrian has DO NOT WALK), do you feel the warning has helped to reduce jaywalking/walking against the signal?

Closing

APPENDIX

D

Pedestrian Field Intercept Survey

Pedestrian Field Intercept Survey

Pedestrian/Cyclist Survey on TriMet "Talking Buses"

SURVEYOR – Check the appropriate box before beginning survey:

☐ Pedestrian was crossing during active SPOKEN warning from bus (*go to Q1a*).

☐ Pedestrian was crossing during active BEEPING warning from bus (*go to Q1a*).

☐ Pedestrian was crossing with turning bus present, but no active turn warning (*go to Q1b*).

☐ Pedestrian was crossing with no turning bus present (*go to Q1b*).

We are conducting a survey of pedestrians and cyclists to obtain public feedback on the "talking buses" currently being tested by TriMet. The survey will take about 5 minutes of your time, and your input is greatly appreciated.

1a. When you were JUST crossing the street, did you hear a turn warning coming from the bus?

☐ No (*go to Q1b*)

☐ Yes. What was the warning you heard?_______________________________ (*go to Q2*)

1b. Have you ever seen/heard an audible turn warning coming from any of the TriMet buses anywhere?

☐ No (*end survey*)

☐ Yes   What are the warnings you have heard?___________________________(go to Q2)

2. Over the past few months, how OFTEN have you seen/heard turn warnings from any of the TriMet buses in the following situations?	**Never**	**Only a few times**	**A few times a month**	**Once a week**	**A few times a week**	**Almost daily**	**Not sure**
As a pedestrian (while walking/crossing the street)	☐ (skip Q3 & Q6)	☐	☐	☐	☐	☐	☐
As a cyclist (while biking)	☐ (skip Q4 &Q7)	☐	☐	☐	☐	☐	☐
As a bus rider (at a bus stop)	☐ (skip Q5 & Q8)	☐	☐	☐	☐	☐	☐

3. FOR PEDESTRIANS: Based on your experience as a pedestrian, how EFFECTIVE do you think the turn warning systems are at the following:	**Not at all effective**	**Slightly Effective**	**Effective**	**Very effective**	**Not sure**
a) … alerting pedestrians that a bus is TURNING at an intersection.	☐	☐	☐	☐	☐
b) … improving pedestrian safety when a bus is TURNING at an intersection.	☐	☐	☐	☐	☐

4. **FOR CYCLISTS: Based on your experience as a cyclist, how EFFECTIVE do you think the turn warning systems are at the following**:	**Not at all effective**	**Slightly Effective**	**Effective**	**Very effective**	**Not sure**
a) … alerting cyclists that a bus is TURNING at an intersection.	☐	☐	☐	☐	☐
b) … alerting cyclists that a bus is PULLING INTO a bus stop.	☐	☐	☐	☐	☐
c) … alerting cyclists that a bus is PULLING AWAY FROM a bus stop.	☐	☐	☐	☐	☐
d) … improving cyclist safety when a bus is TURNING at an intersection.	☐	☐	☐	☐	☐
e) … improving cyclist safety near BUS STOPS.	☐	☐	☐	☐	☐

5. FOR TRIMET BUS RIDERS: Based on your experience as a bus rider, how EFFECTIVE do you think the turn warning systems are at the following:	**Not at all effective**	**Slightly Effective**	**Effective**	**Very effective**	**Not sure**
a) … alerting bus riders that a bus is PULLING INTO a bus stop.	☐	☐	☐	☐	☐
b) … alerting bus riders that a bus is PULLING AWAY FROM a bus stop.	☐	☐	☐	☐	☐
c) … improving bus rider safety at BUS STOPS.	☐	☐	☐	☐	☐

6. **FOR PEDESTRIANS: Has there been a particular situation as a pedestrian where you felt that the turn warnings helped you avoid a collision with a bus when CROSSING AT AN INTERSECTION?**
   - ☐ No (go to Question 7 if cyclist, 80 if TriMet bus rider, or 9 if neither)
   - ☐ Yes Please describe the situation(s):____

7. **FOR CYCLISTS: Has there been a particular situation where you felt that the turn warnings helped you avoid a collision with a bus WHILE BIKING?**
   - ☐ No (go to Question 8 if TriMet bus rider, 9 if not)
   - ☐ Yes Please describe the situation(s):____

8. **FOR TRIMET BUS RIDERS: Has there been a particular situation as a bus rider where you felt that the turn warnings helped you avoid a collision with a bus AT A BUS STOP?**
   - ☐ No (*go to Question 9*)
   - ☐ Yes Please describe the situation(s):____

9. **Do you find the audible warnings to be intrusive to the environment?**
   - ☐ No (*go to Question 11*)
   - ☐ Yes

10. How INTRUSIVE do you find the audible:	**Only slightly intrusive**	**Intrusive**	**Very intrusive**	**Not sure**
a) …warnings with a spoken message (e.g., Caution, bus is turning)	☐	☐	☐	☐
b) …beeping warning	☐	☐	☐	☐

11. To what extent do you AGREE or DISAGREE with the following statements:	**Strongly Disagree**	**Somewhat disagree**	**Do not agree or disagree**	**Somewhat agree**	**Strongly agree**	**Not sure**	**N/A**
a. The potential benefits of the turn warning systems with the spoken messages outweigh any associated drawbacks.	☐	☐	☐	☐	☐	☐	☐
b. The potential benefits of the turn warning systems with the beeping warning outweigh any associated drawbacks.	☐	☐	☐	☐	☐	☐	☐
c. I would like to see the turn warning systems with the spoken message installed on more TriMet buses.	☐	☐	☐	☐	☐	☐	☐
d. I would like to see the turn warning systems with the beeping warning installed on more TriMet buses.	☐	☐	☐	☐	☐	☐	☐

12. **How OFTEN do you walk in Portland?**
    - ☐ Daily
    - ☐ Once or twice a week
    - ☐ A few times a month
    - ☐ Less than once a month
    - ☐ Almost never

13. **How OFTEN do you bike in Portland?**
    - ☐ Daily
    - ☐ Once or twice a week
    - ☐ A few times a month
    - ☐ Less than once a month
    - ☐ Almost never

14. How OFTEN do you ride TriMet buses?

☐ Daily

☐ Once or twice a week

☐ A few times a month

☐ Less than once a month

☐ Almost never

15. What is your age?

☐ Under 25

☐ 25 - 34

☐ 35 - 44

☐ 45 - 55

☐ 56 - 64

☐ 65 or older

16. Gender

☐ Female

☐ Male

APPENDIX

E

Pedestrian Focus Group Guide and Rating Sheets

Pedestrian Focus Group Guide and Rating Sheets

Pedestrian Focus Group Guide

Introduction (10–15 minutes)

- Introductions
- Housekeeping (restrooms, refreshments)
- Background
  - We are here as part of a study that is being sponsored by the Federal Transit Administration. The FTA is part of the U.S. DOT. Generally, the purpose of this study is to assess whether there are safety benefits of a variety of different pedestrian warning systems that could justify the cost of implementing the systems. The warning systems we're testing didn't exist 10 years ago, and now they're being used in about 15 bus systems across the US. But there's almost no hard evidence on whether these systems have been effective at improving pedestrian safety, which is why FTA selected TriMet for a controlled study. Evidence of safety benefits will be drawn from this study via surveys of bus operators and pedestrians, analysis of events recorded in TriMet's "close-call" database, and insights from operator and pedestrian focus groups.
- Goals for focus group
  - View and discuss the warning systems being tested in Portland, as well as a number of alternative warnings.
  - Discuss ways of increasing pedestrian safety around transit buses.
- Dos and Don'ts
  - Do – share your subjective and candid thoughts and opinions.
  - Do – keep your comments as concise as possible so that everyone has an opportunity to speak. Time is short.
  - Don't – be afraid to speak up. There are no right or wrong responses!

Auditory Warnings (25 minutes)

Demonstration and rating of auditory warnings (10 minutes):

- Introduction/instructions:
  - You will see 8 short video clips, each with a different auditory warning. Observe each video and listen to the warning.
  - If you would like to see any of the videos again, please raise your hand and I will replay them.
  - Then, use your response to sheet to rate each warning on 3 different factors (review the rating questions and response scales with the participants). I will give the line number of the table for each response. Please verify that you are recording your response on the correct line of each table.
- Thinking about all of the warnings together, which are your top 3 warnings (please circle)?

Discussion (15 minutes):

Top 3 warnings selected by participants.

- What is it about these warnings that is good?
- What about the other warnings make them less desirable?
- What are the characteristics of the ideal warning (more/fewer words, noises, combination messages, visual warning)?

- How loud do the warnings need to be to get the pedestrians' attention? How do you balance this and intrusiveness to the environment?
- There were numerous complaints, particularly from one neighborhood along one of the bus routes (give them some of the complaints)
  - What are your thoughts/opinions about these complaints?
  - Did you experience this yourselves?

Visual Warnings (25 minutes)

Demonstration and rating of various signs (10 minutes):

- Introduction/instructions:
  - You will see 4 short video clips, each with a different visual warning. Observe each video and the visual warning.
  - If you would like to see any of the videos again, please raise your hand and I will replay them.
  - Then, use your response to sheet to rate each warning on 4 different factors (review the rating questions and response scales with the participants). As with the auditory warnings, I will give the line number of the table for each response. Please verify that you are recording your response on the correct line of each table.
- Thinking about all of the warnings together, which are your top 2 warnings (please circle)?
- Show the video of the actual sign with a turning bus.

Discussion (15 minutes):

Top 2 signs selected by participants.

- What is it about these signs that is good?
- What about the other signs make them less desirable?
- What are the characteristics of the ideal sign (different/more words, symbol, combination, audible warning)?
- Does the BUS sign bolster/reinforce the DNW signal or is it independent or irrelevant?
- What if there was a Walk signal? Does the BUS sign contradict the Walk signal or is it perceived as simply a warning?

Break (10 minutes)

Effectiveness of Turn Warning Systems and Signs in Increasing Pedestrian Safety (30 minutes)

- Do you think the turn warning systems and signs are an effective approach to increasing pedestrian safety around transit buses?
- Are there certain locations/situations where you think these systems/signs are more likely to increase pedestrian safety than others (urban vs. suburban, specific types of intersections/bus stops, pedestrian distraction/inattention, crossing against the light)?
- In what locations/situations do you think these systems/signs are <u>not</u> likely to increase safety?
- How could the systems/signs be improved to be more effective in these situations?
- Are there better ways of increasing pedestrian safety around buses?
- Do you think TriMet/City of Portland should install more of these turn warning systems/signs? Is cost an issue? In your opinion, how much is "too much" for this type of system/sign?

Pedestrian distraction (10 minutes)

- While operators are extensively trained to always be on the alert for these kinds of circumstances, the warning systems/signs are intended to supplement this responsibility – do these systems help? If not, what do they recommend for dealing with this growing problem?)

Closing

- Take any remaining comments/questions.

Focus Group Rating Sheet – Bus Turn Warning Systems

Message Ability to Get Pedestrians' Attention – If you were walking down the street and heard this message, would it get your attention?

Message	Not at all 1	Possibly 2	Probably 3	Definitely 4
1 "Caution, bus is turning."				
2 "Pedestrians, bus is turning."				
3 "Caution, bus moving left."				
4 Beeping				
5 Turn indicator				
6 "Caution, pedestrians. Bus is approaching."				
7 "Caution, look both ways" (with turn indicator)				
8 "Caution, bus moving left. Pedestrians look both ways."				

Message Clarity – How CLEAR is each message in indicating to pedestrians what is happening?

Message	Not at all Clear 1	Somewhat Clear 2	Clear 3	Very Clear 4
1 "Caution, bus is turning."				
2 "Pedestrians, bus is turning."				
3 "Caution, bus moving left."				
4 Beeping				
5 Turn indicator				
6 "Caution, pedestrians. Bus is approaching."				
7 "Caution, look both ways" (with turn indicator)				
8 "Caution, bus moving left. Pedestrians look both ways."				

Message Environmental Intrusiveness – If you were walking down the street and heard this message, how intrusive to the environment would you find it to be?

Message	Not at all intrusive 1	Possibly intrusive 2	Probably intrusive 3	Definitely intrusive 4
1 "Caution, bus is turning."				
2 "Pedestrians, bus is turning."				
3 "Caution, bus moving left."				
4 Beeping				
5 Turn indicator				
6 "Caution, pedestrians. Bus is approaching."				
7 "Caution, look both ways" (with turn indicator)				
8 "Caution, bus moving left. Pedestrians look both ways."				

Focus Group Rating Sheet – Crosswalk Warning Sign

Message Ability to Get Pedestrians' Attention – If you were walking down the street and saw this sign, would it get your attention?

Sign	Not at all 1	Possibly 2	Probably 3	Definitely 4
1 BUS				
2 BUS TURNING				
3 LOOK FOR BUS				
4 Symbol sign				

Sign Clarity – How CLEAR is each sign in indicating to pedestrians what is happening?

Sign	Not at all Clear 1	Somewhat Clear 2	Clear 3	Very Clear 4
1 BUS				
2 BUS TURNING				
3 LOOK FOR BUS				
4 Symbol sign				

Sign Effectiveness – How EFFECTIVE is each sign at indicating to pedestrians what they should do, if anything?

Sign	Not at all Effective 1	Somewhat Effective 2	Effective 3	Very Effective 4
1 BUS				
2 BUS TURNING				
3 LOOK FOR BUS				
4 Symbol sign				

Message Environmental Intrusiveness – If you were walking down the street and heard this message, how intrusive to the environment would you find it to be?

Sign	Not at all intrusive 1	Possibly intrusive 2	Probably intrusive 3	Definitely intrusive 4
1 BUS				
2 BUS TURNING				
3 LOOK FOR BUS				
4 Symbol sign				

APPENDIX

F

Overview and Assessment of Emerging Technologies

Overview and Assessment of Emerging Technologies

The information in this appendix presents an overview and assessment of some of the emerging pedestrian/cyclist collision warning technologies. The overview synthesizes the findings from a review of the literature and other information available throughout the duration of the demonstration test. Emerging pedestrian/cyclist collision warning technologies explored were not limited to transit buses and included technologies that are appearing in the automotive industry. A limited literature review was performed to identify any published or otherwise documented information regarding the application, maturity, effectiveness, and costs of these technologies. In addition, where results are not already available, a high-level assessment of the various technologies is included. This assessment is based primarily on the maturity of the technologies, their potential applicability to a transit bus (if not already), and cost (when possible).

Emerging Transit Bus-Related Technologies

Connected Vehicle Pedestrian Detection Technology

The U.S. Department of Transportation (US DOT) recently completed the testing of five collision avoidance applications on three University of Michigan transit buses. This system, called the Transit Safety Retrofit Package (TRP), was part of the US DOT's Safety Pilot Model Deployment, a large-scale field demonstration of the potential benefits of 5.9GHz Dedicated Short-Range Communications (DSRC) wireless technology. It was of interest to determine if DSRC technologies could be combined with on-board safety applications to provide bus operators real-time alerting of potential and imminent crashes. [1]

One of the five applications was the Pedestrian in Signalized Crosswalk Warning (PCW). This application uses Vehicle-to-Infrastructure (V2I) technology to warn a bus driver if pedestrians are in the intended path of the bus when making a right or left turn. This application incorporates two methods of detecting pedestrians—activation of the crosswalk button by a pedestrian and a microwave motion sensor that detects the presence of pedestrians in the crosswalk. The application provides two levels of alerts to the driver—an informational/cautionary indicator if the crosswalk button is activated and an imminent warning if a pedestrian is actually detected in the crosswalk. Figure F-1 depicts the application of the Connected Vehicle V2I pedestrian warning system. The PCW was deployed at one intersection in Ann Arbor, Michigan.

The study team's major conclusions and lessons learned included the following:

- The TRP on-bus software was effective at providing alerts to transit drivers.
- The bus operators expressed acceptance of the TRP concept.
- There was a high rate of false alerts for the PCW application due primarily to a combination of GPS limitations and pedestrian detector limitations.
- Wide Area Augmentation (WAAS)-enabled GPS accuracy is insufficient for the PCW application. A more precise technology, such as Differential GPS, should be employed on future systems to achieve desired performance levels.

[1] Battelle, "Transit Safety Retrofit Package (TRP): Leveraging DSRC for Transit Safety—Fielding Results and Lessons Learned," November 2014.

- The Doppler microwave-based crosswalk detectors are insufficient for the PCW application. A more discerning technology, such as high-speed imaging, should be employed on future systems to achieve desired performance levels.
- DSRC radio technology performed well – there were no TRP problems traced to DSRC radio communications.
- Short-term system refinements yielded expected performance improvements.

Figure F-1 Connected Vehicle V2I pedestrian warning system

The US DOT Volpe Center is conducting an independent evaluation of the safety impact of each of the TRP safety applications, as well as an assessment of driver acceptance and overall system performance. Information from this evaluation should be available in early 2015.

According to the project's researchers, at the time of the study, commercially-available collision warning systems that were aimed at highway applications were not appropriate for the more complex urban and suburban operating environments. This ICWS project made advancements in the available technology at the time, and the project addressed some of the short-comings of the COTS systems. The researchers noted that in the controlled testing environment, the FCWS functioned adequately for longitudinal measurements but needed improvement in the quality of the lateral distance to objects in front of the bus. Additionally, no false negatives or missed warnings were observed from the SCWS in the controlled test environment. However, there was an issue of too many false positives for "under-the-bus" and "contact" incidents; consequently, the sensors for those types of collisions were not activated for the field tests.

At the time, the researchers' concluded that the system was not ready for commercial use in the near future. Although turning scenarios were tested and the controlled scenarios were somewhat successful, the field test results did not indicate a high confidence with performance. Additionally, the SCWA portion generated a significant number of false positives, which could potentially cause problems for the bus operators when pulling into and away from bus stops, given the presence of various non-hazardous objects in the vicinity of a bus stop.

Even though there were apparent shortcomings, it should be noted that the collision warning technologies were tested on a transit bus and within a typical bus operating environment. The research was conducted more than eight years ago, and there may now be significant advancements in the technologies used in this study. Depending on the maturity of the technologies, this type of system could be closer to commercial use than originally assessed. With continued development of algorithms and improved sensing and signaling technologies, there is potential for this to be developed further in the future.

University of Kansas IDEA Proposal

In 2013, the University of Kansas (KU) submitted a research proposal to the Transportation Research Board's (TRB) IDEA Transit Program describing a dynamic pedestrian warning system. KU's proposed pedestrian warning system consisted of 12 LED side markers mounted on the front, back, and both sides of a bus and integrated with a dual-technology passive infrared (PIR) plus ultrasonic, microwave (radar), or light detection and ranging (LIDAR) (laser) motion sensor. This combination of technologies provides a three-foot "safety-zone" around the bus. When a pedestrian or cyclist is detected within the safety zone while the bus is in motion (and within a pre-selected speed threshold) the system activates a warning to the bus operator via an onboard speaker. In addition, the pedestrian or cyclist is warned through the activation of the flashing red LED markers. Additionally, KU's proposed system provides stable and uniform lighting within the safety zone during boarding and alighting. The LED markers illuminate the safety zone to help increase visibility of pedestrians and cyclists, especially during nighttime conditions. These lights would activate only when a bus door is opened. Figure F-2 shows the proposed placement of the sensing detectors and LED markers and the intended coverage around the bus.

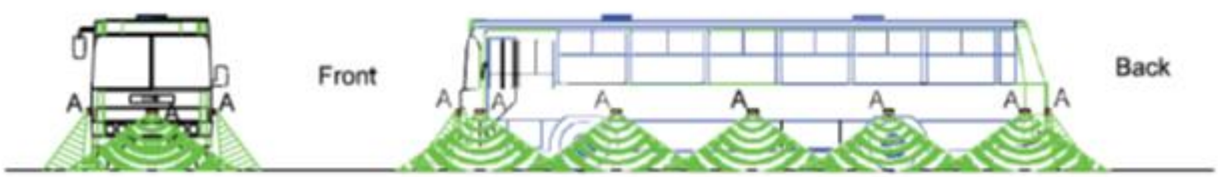


Figure F-2 University of Kansas proposed pedestrian warning system

While the project was not selected by TRB, the proposed description appears to offer a viable approach to improving pedestrian safety around transit buses that warrants testing and evaluation. The budgeted cost to equip one bus was approximately $2,000, which is not much more than the cost of the commercially available turn warning systems tested as part of this demonstration project.

Transit Integrated Collision Warning System (ICWS)

Another transit-based technology was developed and tested by the University of California Berkeley's (UCB) Partners for Advanced Transit and Highways (PATH) program and Carnegie Mellon University's

Robotics Institute in 2007. The Integrated Collision Warning System (ICWS) program was a continuation of previous research on individual frontal and side collision warning systems for buses.[2] The goals of the research effort were to improve the algorithms from the Frontal Collision Warning System (FCWS) and Side Collision Warning System (SCWS) projects and to test improvements of an integrated system in both controlled and operational environments. Figure F-3 shows the ICWS equipment installed on the front bumper of a transit bus. The ICWS utilized several technologies, including radar/LIDAR, video cameras, object sensors, host-bus sensors, and complex object detection and collision warning algorithms as part of an integrated system to detect front and side collisions.

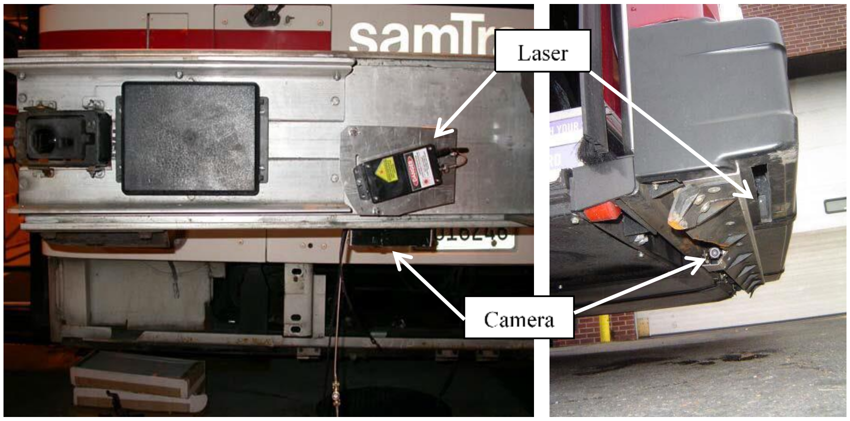


Figure F-3 UCB PATH's ICWS Collision Warning System

An evaluation of these systems found that the forward collision warning sensors worked reasonably well, with some modification needed, in the typical urban transit operating environment tested. Similarly, the side obstacle sensors and algorithms also worked reasonably well, but had some issues with appropriate threat detection. Further development of the software algorithms would be required. Conversely, the under-the-bus detection functions did not work well enough in the configuration tested to be enabled for revenue service. Advancements in technology would be required for this function to be effective. Bus operator feedback was also obtained. Driver reaction to the system in revenue service was generally positive.

The estimated costs of the entire prototype system were not described; however, it was noted that the cost of the most expensive components were the LIDARs (side laser scanner), which were over $15,000. The cost for the entire system would likely be upwards of $20,000 per bus.

Other Emerging Collision Warning Technologies

Wireless Pedestrian Detection Technologies

One related technology from the automotive industry is the General Motors (GM) wireless pedestrian detection system. This technology, which was under development in 2013, makes use of the Wi-Fi Direct peer-to-peer wireless standard. The Wi-Fi Direct wireless technology allows for direct communication from one device to another.[3] GM took the technology and expanded its potential by

---

[2] California PATH and Carnegie Mellon University, "Transit Integrated Collision Warning System," Vols. 1 and 2, Research Reports UCB-ITS-PRR-2007-19 and UCB-ITS-PRR-2007-19, November 2007.

[3] "GM developing wireless pedestrian detection technology," http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2012/Jul/0726_pedestrian.html, July 26, 2012, accessed August 20, 2013.

developing a system that detects pedestrians via a smartphone. This detection system would allow for vehicles to detect pedestrians or bicyclists with Wi-Fi Direct enabled devices (smartphones, tablets) at a much faster speed than typical wireless systems, which can take 7–8 seconds to connect. Using the Wi-Fi Direct peer-to-peer technology, connections of approximately 1 second would allow for quicker vehicle detection and could help reduce pedestrian/bicyclist collisions.

Using this direct wireless communications technology to connect to pedestrian smartphones offers a reasonable potential for reducing pedestrian-vehicle collisions. If fully developed, initially this system would be integrated into GM's passenger vehicle fleets.

Similarly, Honda and Qualcomm have demonstrated a system that uses DSRC communications on a smartphone to alert a pedestrian of a potentially-dangerous, imminent situation. Using a smartphone's internal GPS, a basic safety message (BSM) can be sent to alert the pedestrian and the driver. The range of this system is around 250 m (820 ft) and is capable of detecting potential collisions in situations such as when a pedestrian is in plain view, walking from behind a vehicle's blind spot, or if the smartphone is inside a person's bag. The alert provided to the driver when a collision is imminent is the word "BRAKE," and the pedestrian receives a beep and a flash from the smartphone. The vehicle system is able to detect whether the pedestrian was potentially distracted by music, games, or texting by showing an image of a person wearing headphones. Similarly, the system is potentially able to communicate to the pedestrian that the vehicle driver is multitasking.

While these technologies could be ready for real-world testing (if not already done), one issue of concern is the vehicle's ability to differentiate between a real threat, such as a pedestrian hidden from the driver's view about to cross the street, and a non-threat, such as a pedestrian in a nearby store. Wi-Fi Direct devices may be able to be detected up to 650 feet, and Honda's system can detect up to 820 feet, so there could be issues with false positive warnings being made to the driver.

Automotive Collision Avoidance Systems

Volvo has developed City Safety, a low-speed collision avoidance system that has been standard equipment on 2010 and newer Volvo XC60 midsize luxury SUVs and 2011 and newer S60 midsize luxury cars.[4] This system was developed to reduce low speed front-to-rear crashes by detecting objects in front of the vehicle and assisting in braking if there is a possibility of a collision. The system uses a computer that receives information from a wide-angle radar system that detects objects and monitors their speed and distance from the car. Working in conjunction with a camera fitted near the rear view mirror, the computer uses this information to identify objects, such as other vehicles or pedestrians and determines if they are on a collision path. While active at speeds of 31 mph or less, the City Safety system will automatically brake if a collision risk is detected and the driver does not react in time. The braking will only avoid a collision if the speed differential is 9 mph or less; however, collision severity could be reduced for speed differentials between 9 and 19 mph.

In 2012, the Highway Loss Data Institute (HLDI) conducted research to assess the effects of the City Safety system on insurance losses.[5] HLDI, an affiliate of the Insurance Institute for Highway Safety (IIHS), determined that there was a lower rate of property damage liability claims for Volvos equipped with the City Safety system when compared to other vehicles in the same class. Additionally, collision frequency, collision claim severity, and bodily injury liability frequency were lower for both City Safety system equipped vehicles (XC60 and S60) when compared to other vehicles in their respective classes.

[4] "Volvo City Safety System," http://www.volvocars.com/us/top/yourvolvo/volvoownersinstructionalvideos/pages/volvo-citysafety.aspx, accessed August 16, 2013.
[5] Highway Loss Data Institute (HLDI), "Volvo City Safety Loss Experience—An Update," Bulletin Vol. 29, No. 23, December 2012.

More recently, Volvo has improved the technology to also detect and react to cyclists.[6] According to Volvo, all vehicles outfitted with the vehicle and pedestrian detection system will have the cyclist detecting technology as well. It is now configured to alert drivers and apply full brake power when cyclists swerve in front of a vehicle heading in the same direction. To further improve the system's ability to detect pedestrians during low light conditions. In 2014, Volvo added a feature to detect pedestrians in the dark. This feature extends the system's ability to detect pedestrians to all times of the day, including nighttime. The previous version of the system worked well during the day and moderately well at dawn and dusk periods.

Similarly, Mazda has incorporated its i-ACTIVSENSE technologies into the all-new Mazda 6.[7] The i-ACTIVSENSE system is part of a series of Mazda's advanced safety technologies designed to aid the driver in recognizing hazards, avoiding collisions, and reducing the severity of accidents when they cannot be avoided. One of the advanced safety technologies most directly related to pedestrian safety is the City Brake system. This system automatically stops or reduces the speed of the vehicle when there is a risk of collision with a vehicle in front while travelling at speeds between 2 and 18 mph. It is not capable of detecting pedestrians at this time.

These automotive technologies have been commercially available for a few years on several different models, thus they are very mature. Although Volvo's system appears to have helped reduce insurance claims for forward collisions, there is no straightforward way to assess whether it would be effective in turning movements. No publicly-available research has been conducted regarding Mazda's system. The technologies used by Volvo and Mazda might be adapted for transit bus use fairly easily, but it would require additional improvements to address situations such as turning at intersections and pulling into and away from bus stops.

Infra-Red Warning System

Researchers from the University of Madrid in Spain have developed a system that can detect pedestrians up to 40 meters (131 ft) away via 2 thermal cameras. Because the contours of objects in infrared images have congruent phase features that do not vary with temperature and contrasting, the researchers developed specialized algorithms to analyze certain silhouette features to detect pedestrians. Pedestrians can be detected even when external illumination is not present. Once a pedestrian is detected in the path of the car, the system alerts the driver; however, the researchers continue to investigate how to alert the driver about the presence of a pedestrian without creating a dangerous distraction.

Based on a review of the summary of the research, the device appears to be mature enough to be installed on commercial vehicles that have visible-light cameras.

Light-Rail Transit Pedestrian Crossing Warning System (PCWS)

Protran Technologies developed a pedestrian crossing warning system (PCWS) for light-rail applications.[8] The PCWS is an infrastructure-based system intended for installation at locations where pedestrians cross at-grade, light rail trackways. The infrastructure-based portion of the system, as shown in Figure F-4, features a wireless antenna that receives a signal from an approaching train's on-board transmitter. The signal from the on-coming train initiates both an audible and visual warning to pedestrians/bicyclists near the crossing. The device flashes multiple LED lights and can emit either an auditory voice announcement or noise (similar to those heard at airport baggage claim carousels). Approximately 45 of the PCWS devices have been installed by Los Angeles County Metro (LAC Metro) and the Maryland Transit Authority (MTA) are currently in operation. The cost of a single purchase and installation is between $8,000 and $10,000.

---

[6] http://www.engadget.com/2013/03/06/volvo-cyclsist-detection-automatic-breaking-system, accessed January 2015.
[7] http://www.mazda.com/publicity/release/2012/201209/120921a.html?link_id=nre, accessed January 2015.
[8] Protran, "Pedestrian Crossing Warning System—PCWS," technical drawing, 12/5/2012.

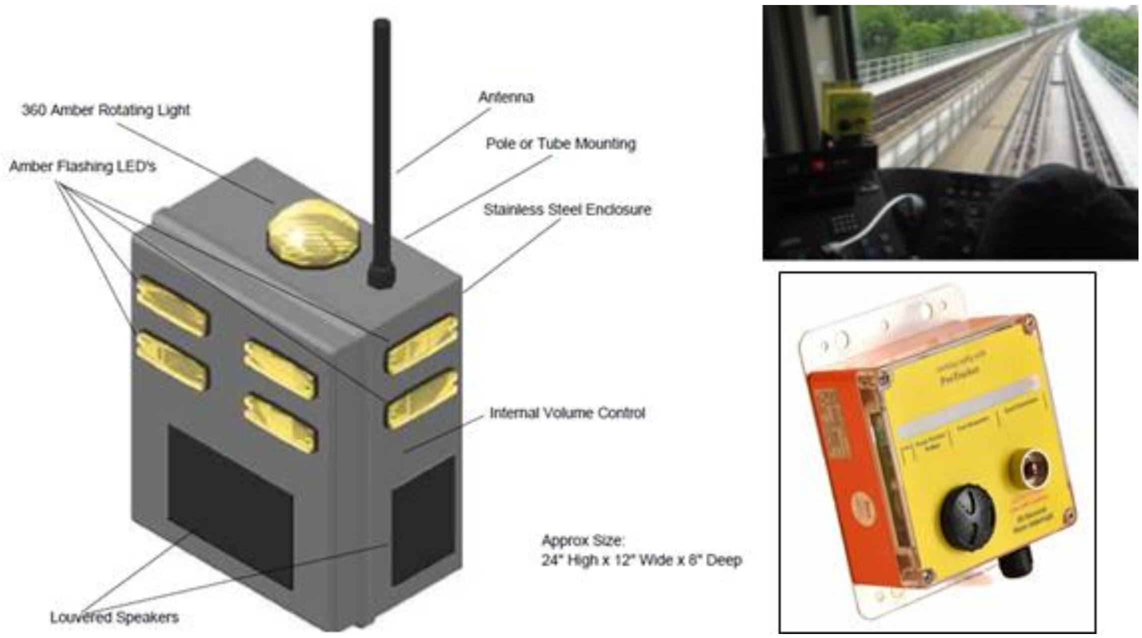


Figure F-4 Features of Protran pedestrian crossing warning system (*left*) and installation in field (*right*)

Based on the specifications and application of this technology, it is likely that it could be effectively applied at intersections where buses turn across a crosswalk. The Protran equipment that is installed on the light-rail vehicles in Los Angeles could be installed on transit buses. The same is also true about the infrastructure component shown in Figure F-4. The device is easily installed on any existing pole (square or round) and could be used at crosswalks where transit buses make turns. Although the application of the device at intersections likely would be very effective at warning pedestrians of turning buses, the equipment costs, coupled with the sheer number of intersections and bus stops, may prohibit the application of the device at all locations. This device may be more appropriate at high crash risk locations and where a higher benefit-cost may be realized.

Summary

This appendix has described selected technologies emerging both within and outside the transit industry that could be useful or applicable in a bus turn situation. Some of these technologies are more mature than others, which impacts cost. In addition, some are likely to be more adaptable to the bus-pedestrian collision scenario than others.

The Connected Vehicle, GM Wi-Fi Direct, and Honda/Qualcomm technologies are very advanced but still appear to be many years away from implementation due to regulation and policy issues, as well as the ability to extend the broader use of the sensing technology in locations other than intelligent intersections or situations only where pedestrians/cyclists have smartphones. The technologies such as the Protran infrastructure-based PCWS and the BUS blank out warning sign could be implemented immediately in the transit/bus environment. Other technologies, such as the Volvo's City Safety System and Mazda's City Brake, are fairly mature within the operating environment for which they were developed; however, based on a limited literature-based assessment, it is uncertain how easy or complex it would be to integrate these technologies into a bus turn warning system. While this application seems to have potential, more advanced analyses and assessment beyond the scope of this project is needed.

U.S. Department of Transportation

Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
http://www.fta.dot.gov/research