FTA Report No. 0234

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Research Report and Findings: Light Rail Technology Scan and Case Studies

PREPARED BY
Center for Urban Transportation Research

Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads

U.S. Department of Transportation
Federal Transit Administration

OCTOBER
2022

COVER PHOTO

Courtesy of istockphoto.com, mtcurado

DISCLAIMER

Research Report and Findings: Light Rail Technology Scan and Case Studies

OCTOBER 2022

FTA Report No. 0234

PREPARED BY
Lisa Staes, Jodi Godfrey, Rino Saliceto,
and Roberta Yegidis
Center for Urban Transportation Research
University of South Florida
4202 E. Fowler Avenue, CUT100
Tampa, FL 33620

Kane Sutton
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
55500 DOT Road
Pueblo, CO USA

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
https://www.transit.dot.gov/about/research-innovation

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	liters	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*

1. REPORT DATE October 2022	2. REPORT TYPE Final Report	3. DATES COVERED January 2018–October 2018
4. TITLE AND SUBTITLE Research Report and Findings: Light Rail Technology Scan and Case Studies		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Lisa Staes, Jodi Godfrey, Rino Saliceto, Roberta Yegidis, CUTR Kane Sutton, TTCI		5d. PROGRAM NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) Center for Urban Transportation Research University of South Florida 4202 E. Fowler Avenue, CUT 100, Tampa, FL 33620 Transportation Technology Center, Inc. (TTCI) A subsidiary of the Association of American Railroads 55500 DOT Road, Pueblo, CO 81001		8. PERFORMING ORGANIZATION REPORT NUMBER FTA Report No. 0234
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration Office of Research, Demonstration and Innovation 1200 New Jersey Avenue, SE, Washington, DC 20590		10. SPONSOR/MONITOR'S ACRONYM(S) FTA 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12 . DISTRIBUTION/AVAILABILITY STATEMENT Available from: National Technical Information Service (NTIS), Springfield, VA 22161; (703) 605-6000, Fax (703) 605-6900, email [orders@ntis.gov]; Distribution Code TRI-30		
13. SUPPLEMENTARY NOTES [www.transit.dot.gov/research-innovation/fta-reports-and-publications] [https://www.transit.dot.gov/about/research-innovation] [https://doi.org/10.21949/1527647] Suggested citation: Federal Transit Administration. Research Report and Findings: Light Rail Technology Scan and Case Studies. Washington, D.C.: United States Department of Transportation, 2022. https://doi.org/10.21949/1527647.		

14. ABSTRACT

Light rail and streetcar rail transit present transit safety risks, specifically pedestrian/bicyclist and motor vehicle collisions. Operation of these systems, often within shared corridors, presents high probabilities of these collision events. The research team performed extensive background research and reviewed relevant literature to identify effective measures that have been proven successful in improving the safety of light rail operations. Identified were systems reported as successful at reducing collision or other incidents or those being tested that show promise. Case studies identified onboard technologies that agencies had deployed that resulted in improved safety. In addition, innovative solutions such as left-turn gates, parking lot-style gates, pedestrian gates and channelized crossings, and quad gates at vehicular intersections were successful in reducing risk and improving system safety. Fencing placed along rail lines was described as effective in deterring unwanted pedestrian crossings.

15. SUBJECT TERMS
Safety, light rail, streetcar rail transit, shared-use corridors, collision reduction, onboard technologies

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unlimited	207	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Light rail and streetcar rail transit present transit safety risks, specifically pedestrian/bicyclist and motor vehicle collisions. Operation of these systems, often within shared corridors, presents high probabilities of these collision events. The research team performed extensive background research and reviewed relevant literature to identify effective measures that have been proven successful in improving the safety of light rail operations. Identified were systems reported as successful at reducing collision or other incidents or those being tested that show promise. Case studies identified onboard technologies that agencies had deployed that resulted in improved safety. In addition, innovative solutions such as left-turn gates, parking lot-style gates, pedestrian gates and channelized crossings, and quad gates at vehicular intersections were successful in reducing risk and improving system safety. Fencing placed along rail lines was described as effective in deterring unwanted pedestrian crossings.

Executive Summary

Light rail and streetcar rail transit present transit safety risks, specifically pedestrian/bicyclist and motor vehicle collisions. Operation of these systems, often within shared corridors, presents high probabilities for collision events. Public transportation systems providing Light Rail Transit (LRT) services reported the following injury and fatality data to the National Transit Database (NTD):

- Injuries
  - From 2008–2014, for streetcar and light rail, the injury rates of occupants of other vehicles, in terms of both vehicle revenue miles (VRM) and passenger miles traveled (PMT), far exceeded all other transit modes.
  - When presented as a rate per 100 million VRM, light rail had the highest injury rate, at 79.1 injuries per 100 million VRM, to people waiting/leaving.
  - Injuries to pedestrians not in crosswalks were higher in light rail than any other transit mode.
  - Injuries occurring at pedestrian or street crossings accounted for 83.2% of total light rail injuries, the highest among all transit modes.
  - For injuries occurring to pedestrians walking along tracks, light rail accounted for 65.2% of total injuries reported from 2008 to 2014.
- Fatalities
  - Fatalities in light rail were third highest of all transit modes.
  - Most light rail transit fatalities are associated with person collisions (86.6%).
  - Light rail fatalities to pedestrians not in a crosswalk and those in crosswalks were the second highest of all transit modes, following transit bus.
  - For all transit modes, light rail reported the second highest number of fatalities to pedestrians/bicyclists.
  - Light rail had the highest number of fatalities to pedestrians crossing the tracks (74.5% of all fatalities in this category) and had the highest rate of increase (600%).
  - The increase in light rail collision fatalities was greater than all other rail modes combined.

In response to this identified area of safety risk, research was conducted under the leadership and direction of FTA's Research, Demonstration and Innovation and Transit Safety Oversight offices and stakeholder input was received from CUTR's FTA Transit Standards Working Group.

Project objectives included the following and are reflected in this report:

- Background research/literature review and analysis on mitigation measures that have proven effective in improving light rail safety as reflected in research studies and in case study locations.
- Scan of existing and emerging technology applications that have proven/may provide improved transit safety.
- Case study research on existing light rail systems to include collection of safety data for injuries and fatalities associated with light rail collisions and examination of operating conditions, trends, challenges, and successes.
- Recommendations related to technologies that may be demonstrated to establish their efficacy to improve transit safety, including the reduction of injuries and fatalities.

Summary and Findings

Light rail and streetcar rail transit present transit safety risks, specifically transit collisions with pedestrians/bicyclists and motor vehicles. Operation of these systems, often within shared corridors, establish a high probability of vehicle and/or pedestrian bicycle collision events.

An extensive background research and relevant literature review were conducted to identify effective measures proven successful in improving the safety of light rail operations. Systems reported as successful at reducing collision or other incidents or those being tested that show promise were identified. Innovative collision avoidance technologies are being tested or piloted at agencies, including Protran's Blind Spot Awareness System©, Mobileye Shield+ Collision Avoidance System©, and TCT's Train Intelligent Detection System (TIDS). The literature review identified products and systems being testing in Europe that show potential, including SIL4, Bombardier's DAS with 3D Stereovision, Bombardier's BodyGuard, Alstom's Pegasus 101, Bosch's Tram Forward Collision Warning System, and the multilayer laser scanner collision avoidance system applied to Durmazlar Machine's Silkworm tram.

Case studies identified onboard technologies that agencies have deployed that resulted in improved safety. In addition, innovative solutions such as left-turn gates, parking lot-style gates, pedestrian gates and channelized crossings, and quad gates at vehicular intersections were successful in reducing risk and improving system safety. Fencing placed along rail lines were described as effective in deterring unwanted pedestrian crossings. Successful modifications to operational practices and public outreach campaigns that improved safety on light rail systems are also reflected in the case study summaries.

Section 1

Introduction

The Federal Transit Administration (FTA) entered into a Cooperative Agreement with the University of South Florida and its Center for Urban Transportation Research (CUTR) to develop a Safety Standards Strategic Plan to identify areas of transit safety risk within the industry, inventory existing transit safety standards (or those within other transportation industries that could be modified to address transit safety-related risks), and establish focus areas for further research to support FTA's Standards Development Program (SDP). Through the SDP, research and background studies are being performed on safety-critical emphasis areas to collect information necessary to support the identification and potential adoption of relevant voluntary standards in cooperation and coordination with standard development organizations and to provide guidance or recommended practices to the industry on measures and processes that may be instituted to improve public transit safety.

Background

Light rail and streetcar rail transit present transit safety risks, specifically pedestrian/bicyclist and motor vehicle collisions. The operation of these systems, often within shared corridors, presents high probabilities for collision events. Public transportation systems providing Light Rail Transit (LRT) services reported the following injury and fatality data to the National Transit Database (NTD):

- Injuries
  - From 2008–2014, for streetcar and light rail, the injury rates of occupants of other vehicles, both in terms of vehicle revenue miles (VRM) and passenger miles traveled (PMT), far exceeded all other transit modes. Streetcar and light rail reported 686.6 injuries per 100 million VRM to occupants of other vehicle, followed by cable car, with 252.5 injuries per 100 million PMT.
  - When presented as a rate per 100 million VRM, light rail had the highest injury rate, at 79.1 injuries per 100 million VRM, to people waiting/leaving (defined in NTD as an individual who is on transit property such as a platform, transit facility, or transit parking facility), followed closely by the streetcar rail injury rate.
  - Total injuries to light rail customers waiting/leaving were the third highest among all transit modes and had the second highest rate of growth of all modes—190% from 2008 to 2014.
  - Injuries to pedestrians not in crosswalks were higher in light rail than any other transit mode.
  - Total light rail injuries to pedestrians and cyclists were third highest, following transit bus and demand-response.

  - The growth in light rail injuries to pedestrians and bicyclists grew by over 300% from 2008 to 2014.
  - Injuries occurring at pedestrian or street crossings accounted for 83.2% of total light rail injuries, the highest among all transit modes.
  - For injuries occurring to pedestrians walking along tracks, light rail accounted for 65.2% of total injuries reported from 2008 to 2014.
- Fatalities
  - Fatalities in light rail were third highest of all transit modes.
  - Light rail had the greatest increase in the number of fatalities reported from 2008 to 2014 (116.7%), followed by streetcar (42.9%).
  - Light rail fatalities to occupants of other vehicles were the third highest of all transit modes.
  - Most light rail transit fatalities are associated with person collisions (86.6%).
  - Light rail fatalities to pedestrians not in a crosswalk and those in crosswalks were second highest of all transit modes, following transit bus.
  - Light rail had the largest increase in pedestrian-in-crosswalk fatalities from 2008 to 2014.
  - Light rail had the second highest number of fatalities to pedestrians walking along the tracks and had the largest reported increase in these fatalities.
  - For all transit modes, light rail reported the second highest number of fatalities to pedestrians/bicyclists.
  - Light rail had the highest number of fatalities to pedestrians crossing the tracks (74.5% of all fatalities in this category) and had the highest rate of increase (600%).
  - The increase in light rail collision fatalities was greater than all other rail modes combined.

In response to this identified area of safety risk, the team performed research in accordance with FTA Cooperative Agreement FL-2016-068-01 and under the leadership and direction of FTA's Research, Demonstration and Innovation and Transit Safety Oversight offices. The research team also obtained stakeholder input from CUTR's FTA Transit Standards Working Group.

Project objectives included the following and are reflected in this report:

- Background research/literature review and analysis on mitigation measures that have proven effective in improving light rail safety as reflected in research studies and in case study locations.

- Scan of existing and emerging technology applications that have proven/may provide improved transit safety.
- Case study research on existing light rail systems to include collection of safety data for injuries and fatalities associated with light rail collisions and examination of operating conditions, trends, challenges, and successes.
- Recommendations related to technologies that may be demonstrated to establish their efficacy to improve transit safety, including the reduction of injuries and fatalities.

Section 2

Research Method

In response to this identified area of safety risk, the team performed research in accordance with FTA Cooperative Agreement FL-2016-068-01 and under the leadership and direction of FTA's Research, Demonstration and Innovation and Transit Safety Oversight offices. The research team also obtained stakeholder input from CUTR's FTA Transit Standards Working Group.

Project objectives included the following and are reflected in this report:

- Background research/literature review and analysis on mitigation measures that have proven effective in improving light rail safety as reflected in research studies and in case study locations.
- Scan of existing and emerging technology applications that have proven/may provide improved transit safety.
- Case study research on existing light rail systems to include collection of safety data for injuries and fatalities associated with light rail collisions and examination of operating conditions, trends, challenges, and successes.
- Recommendations related to technologies that may be demonstrated to establish their efficacy to improve transit safety, including the reduction of injuries and fatalities.

Background Research and Literature Review

The research team performed an extensive research review of safety standards, street intersection designs and signals, audible and visual warning devices, vendor technical literature, and deployment of other US and international technologies that address light rail transit collisions.

In light rail transit, the risk of collisions with personal occupant vehicles and pedestrians/bicyclists at intersections and along track right-of-way is significant, resulting in injuries and fatalities, as indicated in Section 2. Transit agencies recognize these risks and track the locations of safety events and close calls and perform risk-based, comprehensive investigations, and root-cause analyses as part of standard operating practices and to advance safety risk management and safety assurance. Many of these measures, including technology applications and policy, procedural, and training-related mitigation measures, are documented and represented in the literature review.

There are research reports focusing on the technology and procedural mitigation measures taken by transit agencies, both within the US and in other countries, as well as those reflecting findings from testing and evaluation of various technologies. A number of these resources and associated findings are summarized below.

Light Rail Service – Pedestrian and Vehicular Safety[1] is a 2001 Transit Cooperative Research Program (TCRP) report that provides results of an examination of the safety of light rail transit in semi-exclusive rights-of-way where light rail vehicles operated at speeds greater than 35 mph through intersection crossings with streets and pedestrian pathways. The authors identified five topic areas with associated subtopics that represented the causal or contributing factors for collision events that occurred at 11 LRT systems. For each of these areas/ subareas, the authors provided possible solutions for consideration.

Phase II of the study included field testing of pre-signal systems and their demonstrated effectiveness. The authors suggested that the developed associated guidelines be considered in LRT system planning and design. The guidelines focused on six areas:

- System Design
- System Operation and Maintenance
- Traffic Signal Placement and Operation
- Automatic Gate Placement
- Pedestrian Control
- Public Education and Enforcement

The report was published in 2001, and although technologies have advanced significantly, the design elements presented are relevant and could still be considered by transit agencies for intersection and pedestrian designs. (Subsequent modifications to Part X, Traffic Controls for Highway-Light Rail Transit Grade Crossings, of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), reflect these design recommendations.)

Light Rail Vehicle Collisions with Vehicles at Signalized Intersections (TCRP Synthesis Report 79)[2] is a 2008 synthesis of practice that identifies the mitigation methods piloted and used by seven case study transit agencies to reduce collisions between Light Rail Vehicles (LRVs) and motor vehicles in environments where the light rail system operates through or adjacent to highway intersections controlled by conventional traffic control devices. Emphasis is placed on collisions that resulted from motor vehicle left-turn movements at intersections. The authors identified 34 countermeasures that may be used to reduce intersection collisions, many of which were deployed by case study agencies. Effective measures included LRV-activated "train approaching" warning signs (established as a standard practices at TriMet) and LRV-activated turn prohibition signs (e.g., "Left on Green Arrow Only," "No Right Turn," "No Turn on Red"), use of an "all-red" traffic signal phase to allow

[1] http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_69.pdf.
[2] https://www.nap.edu/read/14215.

LRVs to clear an intersection without motor vehicle movement, use of gates to restrict certain movements, lower train speeds through intersections (and lowering the speed limit for adjacent motorized traffic), signal preemption, police enforcement (issuing citations for traffic violations at intersections), photo enforcement (used by LA Metro at gated crossings), pavement treatments (e.g., in-pavement lighting and colored concrete patterns), and public outreach and education. They concluded that "the most effective means of mitigating collisions between LRVs and motor vehicles at signalized intersections is to physically separate LRV and motor vehicle movements."[3]

Improving Pedestrian and Motorist Safety along Light Rail Alignments (TCRP Report 137)[4] provides the results of a 2009 study that addresses pedestrian and motorist behaviors that contributed to LRT collisions and provides descriptions of measures that could be implemented along LRT alignments. The authors also cataloged the latest technologies, including safety devices and treatments and agency model practices in use at the time of report preparation that could be examined or deployed/instituted to address pedestrian and motor vehicle collisions with LRT systems. Additional benefits of this research were the inclusion of a systematic approach and methodology for performing risk analyses for safety measures and data collection/compilation guidance. Phase II of the project included telephone consultations with 22 State Safety Oversight (SSO) representatives and 32 local transit agencies and site visits to five LRT operating agencies, which allowed the research team to observe system operation and obtain stakeholder inputs.

Agencies included in the study addressed areas of risk through both active and passive physical measures and through education and enforcement programs. The researchers identified the following strategies used by these agencies: 1) give responsibility to the operators (the importance of LRV operator training); 2) increase motorist, pedestrian, and cyclist awareness by providing active, appropriate information (noting that active signals tend to be more effective than passive signage); 3) education; and 4) physical separation of LRT from space occupied by other modes.[5]

Light Rail Transit/Street Grade Crossing Safety System [6] was developed under Transportation Research Board (TRB) Transit Innovations Deserving Exploratory Analysis (IDEA) Project 68. The final report was issued in January 2014 and summarized efforts to develop and test an intelligent Light Rail Transit/Street Grade Safety System by SIL4 Systems that could be deployed by LRT agencies. The system provides an active, adaptive alert system to improve incident

[3] *Ibid*.
[4] https://www.nap.edu/catalog/14327/improving-pedestrian-and-motorist-safety-along-light-rail-alignments.
[5] *Ibid*.
[6] http://onlinepubs.trb.org/Onlinepubs/IDEA/FinalReports/Transit/Transit68.pdf.

recording for LRVs and their operators and to improve crossing safety for pedestrians, motorists, and/or workers. Features included:

- Active system that alerts trespassers/workers
- Improved alertness/response time
- Active system that applies braking
- Adaptive—system works only when train is approaching
- Maintains comprehensive record
- Adaptable/portable

Initially, the research team conducted a survey of key decisionmakers of 27 rail transit agencies to identify features perceived as important to enhance crossing safety. Surveys were followed by interviews with many respondents. From this engagement, the researchers established a review panel to provide feedback and guidance on the research and system design elements.

On-board components built or procured by SIL4 included a Vehicle Monitoring Platform (VMP) for event recording and train data storage; a Vehicle Communications Platform (VCP) for GPS, 3G, and Wi Fi communications; and a Train Operator Display (TOD). External components at highway and LRV crossings included:

- Outdoor surveillance camera, visible and IR range
- Wi-Fi transmitter/receiver with input/outputs for interfacing/controlling features at the crossing
- Light/strobe for visual warning and perhaps illuminating the scene just prior to train arrival.
- External train alarm with flasher
- IO device for expanded capabilities including interfacing with existing crossing equipment and/or syncing with surface traffic signaling

The crossing alarm sequence was designed to activate in response to any of the following inputs:

- Automatic activation via LRV based on LRV “distance to crossing” arrival threshold
- Automatic activation via LRV based on LRV “time to crossing” arrival threshold
- “Motion within crossing” per camera image detection versus a static image
- “Occupancy within crossing” per camera image detection versus an empty crossing
- Manual activation via train operator touch-screen button
- Automatic activation via LRV after cab alarm times out due to no braking command from Operator as measured by master controller position monitor

- Automatic activation via LRV after cab alarm times out due to no braking response of vehicle as measured by on-board accelerometer

Testing of the SIL4 system was conducted at Greater Cleveland Regional Transit Authority along corridors where incidents and close-call events were most prevalent. Based on both the static and dynamic testing performed on the system components, the following four features were effectively implemented, and the system could activate the crossing light/alarm from the vehicle given the 20-second preset "time to crossing" programmed in the system:

- Active system that alerts train operator
- Active system that alerts trespassers/workers
- Improved alertness/response time
- Active system that applies braking

The system could achieve a comprehensive record through the system's on-board data logger/event recorder and video recording. It was also determined that the SIL4 system is portable, noting the compact, low-profile, and lightweight characteristics of the system and the ease of mounting the system for temporary work applications.

Guidebook on Pedestrian Crossings of Public Transit Rail Services,[7] TCRP Report 175 published in 2015, presents many engineering/design-related treatment options to improve pedestrian safety at light rail, streetcar, and commuter rail crossings. The report identifies 34 pedestrian treatments within eight categories and includes four studies that examine pedestrian treatments implemented at those locations. (The report is supplemented by *TCRP Web-Only Document 63 – Treatments Used at Pedestrian Crossings of Public Transit Rail Services,* 2015.)

The guidebook examines the following categories of pedestrian treatments:

- Channelization
- Barriers (e.g., offset crossings, fencing, barriers at transit platform edges)
- Design elements (e.g., sight distance improvements, illumination, pedestrian refuges, sidewalk and pedestrian crossing surface improvements, bollards)
- Signage
- Signals
- Pavement markings
- Infrastructure (e.g., warning devices and gates)
- Operational practices/procedure modifications

[7] https://www.nap.edu/download/22183.

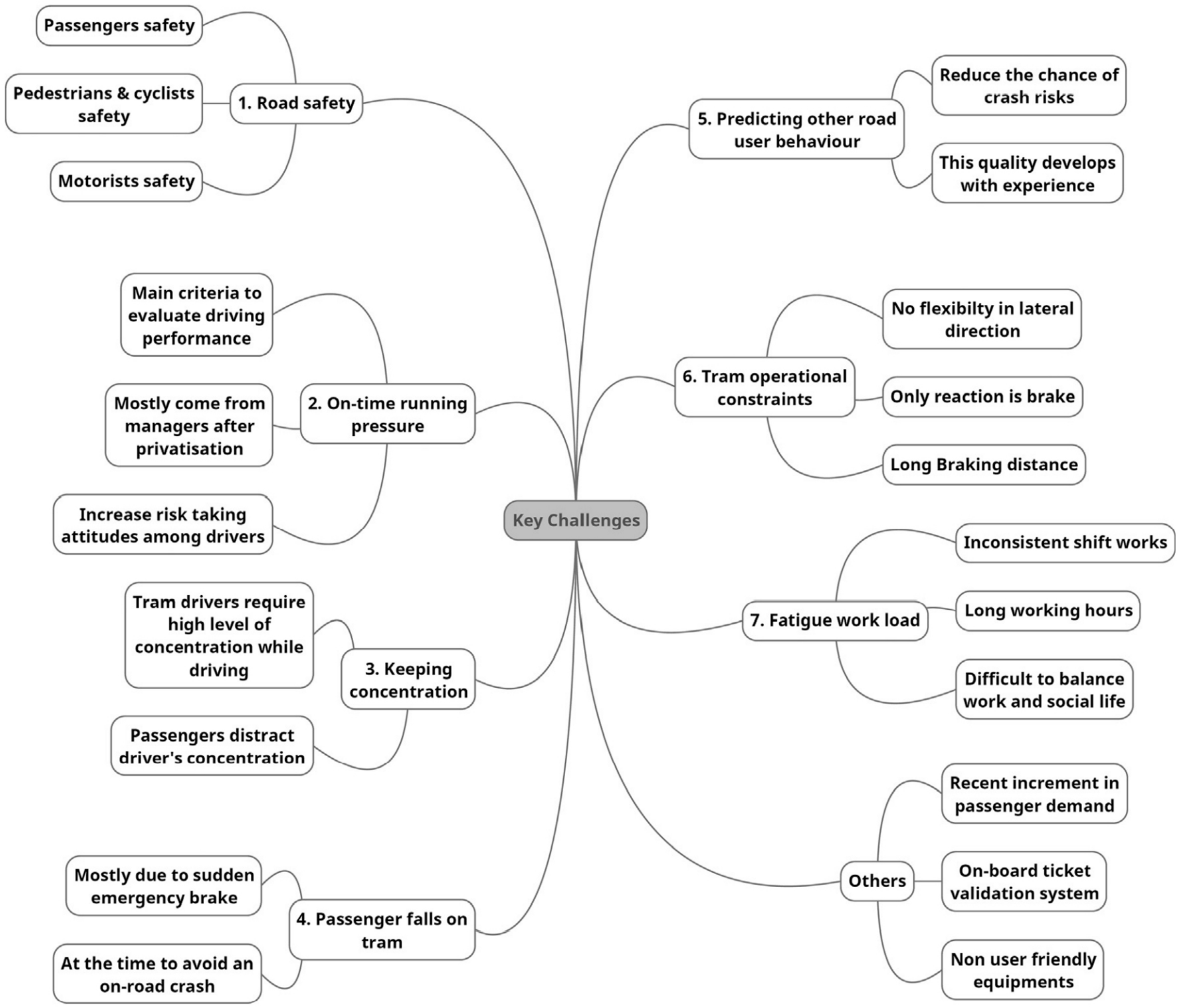
TCRP Web-Only Document 63 – Treatments Used at Pedestrian Crossings of Public Transit Rail Services[8] is a compilation of resources used in the research effort that led to the production of the Guidebook referenced above. It also contains detailed observations and findings from the project site visits (summarized in the Guidebook).

Perspectives from LRV operators in Melbourne, Australia were provided in "Key challenges in tram/streetcar driving from the tram driver's perspective-A qualitative study.[9] The researchers gathered input from 30 tram operators through a series of five focus group meetings. Tram operator challenges included:

- Safety for all people in and around the tram
- On-time running – no earlier than 50 seconds and no later than 6 minutes
- Keeping concentration on the road – passengers, cars, motorcycles, bicycles are distracting
- Constraints of tram operations –noting that operators have a "defensive tram driving" attitude, they do not have the ability to make lateral movements to avoid collisions
- Anticipating other road user actions in advance
- Passenger falls
- Fatigue – inconsistent shift work
- Lack of awareness of road users, including pedestrians and passengers; the operators specifically addressed unsafe behavior of passengers immediately before boarding and after alighting, often crossing unprotected traffic lanes to board the train and crossing in front of the tram after exiting the train
- Poor understanding and violation of road rules by motorists and pedestrians

Figure 2-1 graphically presents these challenges. Understanding these challenges leads to the questions on how these technologies can address these challenges.

[8] https://www.nap.edu/read/22181.
[9] https://www.sciencedirect.com/science/article/abs/pii/S1369847817300621.



Source: F. Naznin et al. (2017), Transportation Research Part F, 49: 44

Figure 2-1 *Key driving challenges identified by tram operators*

In "Driver Assistance System for Avoidance of Collision on Light Rail Vehicles,"[10] the author provides an update on a collaborative effort between Bombardier Transportation and the Austrian Institute of Technology (AIT) to install and test an optical driver assistance system (DAS) that would automatically alert LRV operators of possible potential hazards in front of and in the swept path of the vehicle through acoustic and/or visual warning signals. Completed in 2016, the paper also establishes functions for future testing, including exterior warning signals, activation of safety systems (e.g., autonomous braking), and autonomous driving. The project was undertaken to develop a technology that would aid in preventing LRV-on-LRV collisions, collisions with other road users

[10] http://railknowledgebank.com/Presto/content/Detail.aspx?ctID=MTk4MTRjNDUtNWQ0My00OTBmLTllYWUtZWFjM2U2OTE0ZDY3&rID=NDQ2MA==&sID=MjU=&ph=VHJ1ZQ==&qcf=&bckToL=VHJ1ZQ==.

(motor vehicles and pedestrians), and collisions with static objects in the track. The system uses "3D Stereovision" technology from AIT that has been adapted for LRVs. The DAS is based on picture-dependent sensor technology using three 3D cameras mounted behind the windshield and an associated evaluation unit and software. The software detects objects such as pedestrians and vehicles within the swept path and derives their distance from the LRV, size, direction of movement, and speed; it then determines the associated braking distance of the LRV and if there is a collision risk. If a collision risk is established, the system alerts the operator. In 2016, Bombardier had completed two initial trials of this system in Frankfort and Berlin, Germany. In 2017, Bombardier received the Innovation Leader in Rail Transport Award by the European Railways Clusters Initiative (ERCI) for its Obstacle Detection Assistance System for trams and LRVs. In December 2017, Duisburg, Germany, purchased 47 Bombardier Flexity vehicles (Figure 2-2), and in April 2018, Brussels, Belgium, purchased 175 Flexity Trams, all outfitted with this technology. CUTR/TTCI researchers will monitor these and subsequent deployments of the Bombardier obstacle detection system.

Figure 2-2 *Bombardier Flexity vehicle*

Bombardier BodyGuard™, as shown in Figure 2-3, is an external airbag for trams that prevents pedestrians from being trapped under a moving tram. Stereovision cameras mounted on LRVs identify and track movement on or near the track. In the event the monitors identify an imminent collision, the airbag deploys.

Figure 2-3 *Bombardier BodyGuard™*

Alstom Pegasus 101[11] is a modular automatic train protection (ATP) system that can be used to enforce speed limits or lineside signals, allowing high traffic levels and driver behavior improvements. The SIL2 ATP system was designed for use in tramway environments, is noted to improve the safety of operations, most effectively on lines containing high risk areas, and is compatible with mixed traffic areas or separated lines. The system has been available for ten years and deployed in over 500 trams in cities such as Brussels; Marseilles and Rouen, France; and Constantine, Switzerland. It can be easily installed with new signaling systems or for retrofitting existing systems.

Bosch's Tram Forward Collision Warning System[12] combines a radar sensor with a video sensor to detect cars, buses, nearby rail vehicles, and static objects on the tracks. Three components assist tram (LRV) drivers—multi-purpose camera, rail control unit, and mid-range radar sensor. Optical and acoustic warnings are issued if collision is imminent. If the operator does not respond quickly, the system initiates an automated braking system.

In 2015, the European Cooperation in Science and Technology (COST) Action TU1103[13] released "Operation and Safety of Tramways in Interaction with Public Space." TU1103 COST Action is a group of partners from 15 European countries

[11] http://www.alstom.com/Global/Transport/Resources/Documents/brochure2014/Pegasus101-Productsheet-English.pdf?epslanguage=en-GB.

[12] https://www.bosch-engineering.de/media/en/de/pdfs/einsatzgebiete_1/produktdatenblaetter/beg_productdatasheet_kollisionswarnung_de_lowres_160901.pdf.

[13] https://www.cerema.fr/fr/activites/mobilites/politiques-services-mobilite/transports-collectifs-intermodalite/activite-internationale/tu1103-cost-action.

that deal with the safety of urban tramways in relation to other uses of public space. Due to similar challenges to urban tram safety throughout Europe, the report was developed to share suggestions and identify models or best practices that address areas of risk for the industry based on input provided by multidisciplinary contributors in these representing countries:

- Austria
- Belgium
- Czech Republic
- France
- Germany
- Great Britain
- Hungary
- Ireland
- Israel
- Italy
- Netherlands
- Poland
- Portugal
- Spain
- Switzerland
- United Kingdom

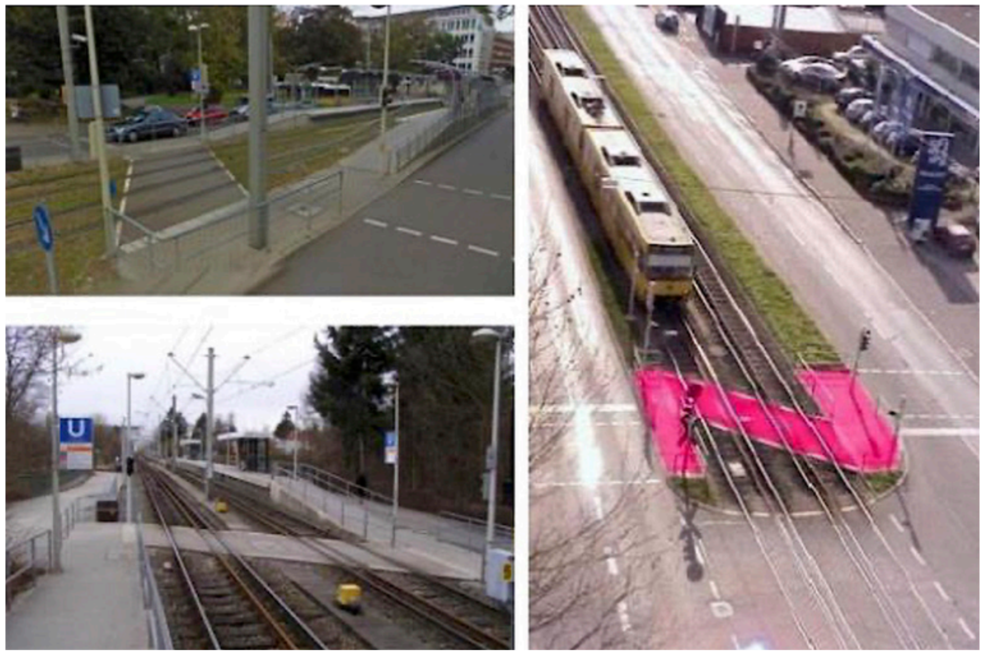
The report included:

- Review of existing regulations
- Analysis of accident statistics
- Value of standardized data collection and recommendations for ideal accident reporting
- Study of tramway infrastructure elements and associated hazards
- Success stories associated with data collection and analysis and with infrastructure designs for intersections, pedestrian crossings, and running sections

One of the success stories described in the report and presented during the 2015 COST conference on TU1103 in Frankfurt, Germany, was from Montpellier, France. In this example, the agency was experiencing incursion into the tram right-of-way by pedestrians displaced from pedestrian paths by unauthorized cars, trucks, and two-wheeled vehicles. The agency reduced tram speeds from 20 to 10 km/hour (12.4 mph to 6.2 mph), resulting in the following:

- Before the countermeasure – four pedestrian events/year, 2000–2011
- After the countermeasure – two accidents in 2012 and zero incidents, 2012–2015

During the conference (and included in the report), pedestrian safety at designated crossings was discussed. Specific hazards identified included those associated with pedestrian behavior, such as lack of situational awareness, dangerous behavior, and rule violations; those associated with infrastructure, including the absence of adequate sidewalks, platforms, and refuge areas; and poor design, including lack of/limited visibility, location, and configuration. The authors/presenter identified active and passive measures used to reduce passenger collisions. The success story was from Stuttgart, Germany, which uses the “Z-standard” (see Figure 2-4) at many of the city’s 500 pedestrian grade crossings. Although no data were provided that indicate a reduction in pedestrian interactions, the researchers identified this treatment as successful.[14]



Source: COST European Cooperation in Science and Technology

Figure 2-4 *Z Standard in Stuttgart, Germany*

However, there were data-supported improvements for the system in the transfer of the network from tram standards to what they term “light rail standards,” which denotes segregated alignment or “private” rights-of-way and include straightened track layout (minimum curve radius of 50m), separated platforms, and defined access points from street to platform. With these modifications, the total number of road crossings was reduced, and upgraded infrastructure resulted in the rebuilding of a number of existing road crossings. The analysis covered the period of 1997 through 2013. One modification at the Neckar-Werderstraße crossing was the placement of an additional signal for vehicular traffic making left turns on the opposite side of the crossing and placing the signal at a height lower than their standards for intersection signage. Collisions at the location decreased from an average of three per year from 1997 to July 2000 to an average of 0.5 per year from August 2000 to 2013.

[14] https://www.cerema.fr/system/files/documents/2019/04/tu1103_report_red.pdf.

Changes in traffic signaling were highlighted as a success in Vienna, Austria. At the Quellenstraße/ Herndlgasse crossing, the tracks are located in the central position of the street with a designated left-turn lane for cars. Herndlgasse, the cross street, is one-way. Prior to the signal changes, there were no separate signals for left turns, visibility of the signals was described as "not good," and there were no physical barriers between trams and cars. Traffic signal modifications included an additional separate green arrow signal for cars and other private vehicles going straight that is activated when the tram approaches from behind. Although the main traffic signal is red (meaning no left turns), vehicles traveling straight have a green arrow signal. The agency reported a "significant reduction in accidents" after these changes.

Source: COST European Cooperation in Science and Technology

Figure 2-5 *Vienna traffic signal, green arrow*

In Brussels, collisions with personal vehicles were occurring when vehicles were making left and right turns across separated tracks. Lane markers were changed, allowing vehicle movements in each lane as either straight or turn, not both, and directional traffic signals were used at intersections (see Figures 2-6 and 2-7). The report indicated that there was more traffic congestion along these corridors but there were significant reductions in personal vehicle on tram collisions.

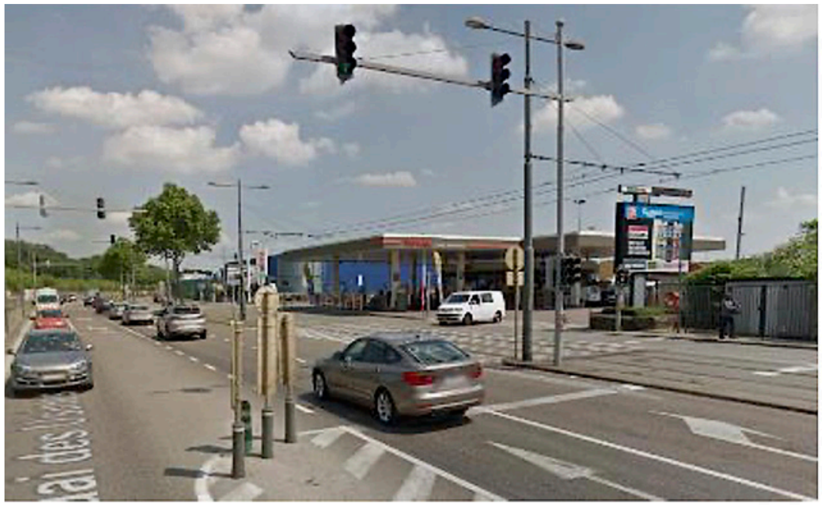


Photo credit: Google Earth, June 2017

Figure 2-6 *Brussels, Belgium left/right turns*

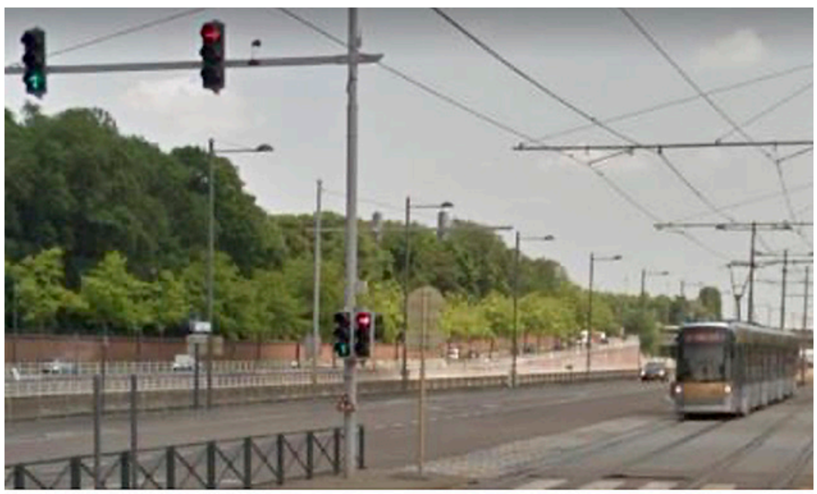


Photo credit: Google Earth, June 2017

Figure 2-7 *Turn signals*

In Bilbao, Spain along Ribera Street, pedestrian events were countered using in-pavement illuminated signs alerting pedestrians of approaching trams (Figure 2 8). The lights were installed in June 2009, and as of 2014, pedestrian collisions in the area had been reduced by 60%.

Source: COST European Cooperation in Science and Technology

Figure 2-8 *In-pavement lighting, Bilbao, Spain*

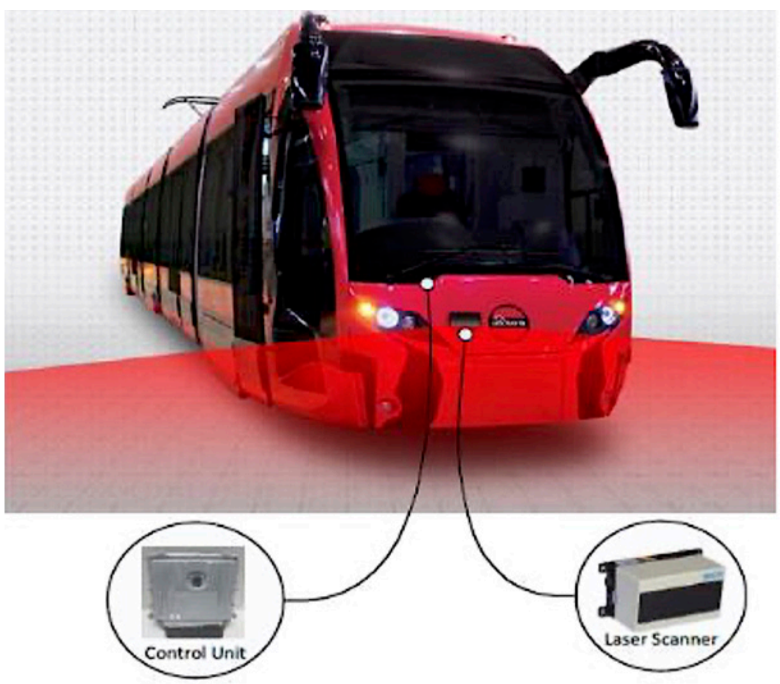
Additional success stories were provided with the majority addressing collisions with personal vehicle left-turn movements. Countermeasures included improved lighting and signage, better signal timing, improved lane markings, use of plastic street bollards to delineate the tram path, pavement marking treatments at intersections (paint or pattern markings), pavement markings warning pedestrians at crossing points (Dublin, Ireland, used prefabricated thermoplastic symbol markings), and restricted left-turn movements by personal vehicles. Increasing the visibility of signage and signals and simple practices such as removing or cutting bushes that reduce sightlines were also highlighted as effective. Another note provided was that although construction in the area of tramways creates its own safety risks to the system, this construction activity can provide opportunities for intersection improvements such as intersection designs and changes in signage and signaling.

In "Development of a Prototype Retrofit Bumper for Improved Light Rail Vehicle Safety,"[15] the authors describe an LRV end-mounted reusable bumper to improve crash compatibility of LRVs with motor vehicles. Originally presented through TRB's IDEA Program with prototype development sponsored by a subsequent FTA project, the demonstration and commercialization of the LRV bumper system is being supported by FTA through its Innovative Safety, Resiliency, and All Hazards Emergency Response and Recover (SRER) demonstration program. The grantee, Applied Research Associates, Inc., in partnership with the Sacramento Regional Transit District (RT), is working with Voith, the vendor that will be developing, fabricating, and demonstrating a front-end bumper/coupler design for LRVs. Major tasks of the project include

[15] http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=2323332.

the LRV bumper and coupler design engineering and crash energy management (CEM) analysis, four prototype fabrications (bumper with coupler), envelope and operational testing, and crash testing for model validation. The initial target market will be approximately 1,000 LRVs. It is expected that the design will improve LRV safety and will result in reduced injuries and fatalities associated with LRV collisions with motor vehicles, pedestrians, and bicyclists. The CUTR/TTCI research team will continue to monitor this SRER as part of this research effort and in accordance with CUTR's evaluation of FTA's safety research demonstration programs.

"Initial Results of Testing a Multilayer Laser Scanner in a Collision Avoidance System for Light Rail Vehicles"[16] (2018) presented a detection and tracking application that could be used for collision avoidance in light rail. The proposed system was applied to an LRV (tram) called "Silkworm," manufactured by Durmazlar Machine, Inc., in Bursa, Turkey, with initial experimental testing performed at the manufacturer's test facility. The CAS uses a laser scanner sensor and control unit, both mounted in the front of the LRV (Figure 2-9). The system is designed to detect both static and moving objects within a 110-degree field of view from the front of the train and will alert the train operator of an imminent possible crash and will also activate braking systems and disengage the throttle to prevent collisions.



Source: Durmazlar Machine, Inc. From source report: https://www.mdpi.com/2076-3417/8/4/475/htm

Figure 2-9 *Sick Lidar Digital-Multilayer Range Scanner*

[16] Luy, M., Cam, E., Ulamis, F., Uzun, I. and Akin, S.I., "Initial Results of Testing a Multilayer System Scanner in a Collision Avoidance System for Light Rail Vehicles,' *MDPI Applied Science*s, Basel, Switzerland, March 2018. https://www.mdpi.com/2076-3417/8/4/475/htm

Field testing of the units included two different objects, pedestrian and train, with various configurations on train collision avoidance. Scenarios included LRV on same line, pedestrian on route of test vehicle, and another LRV and multiple pedestrians along route of test vehicle. Findings of this initial research indicate that the rate of collision avoidance is significant due to the three-phase warning system employed—visual warnings for LRV operators, acoustic warning for pedestrians, and automatic braking. The laser scanning sensor successfully detected all objects. The next phase of testing will include driving in street environments and introducing adverse weather conditions. Further research will include new methods for either laser/camera fusion or laser/radar fusion.

In research performed for and dialogue among members of APTA's Streetcar Subcommittee and car builders, practitioners, and sub-suppliers, a safety checklist for tramway operating environments was developed; recommendations were provided for general characteristics and those specific to the light rail (tram) vehicles:

- General:
  - Low-floor vehicle designs
  - High-performance braking
  - Door obstacle detection (to prevent passengers being trapped in doors)
  - Driver vigilance system (master controller dead man) and event recorders
  - Video surveillance (including in-cab cameras) and silent alarms
  - Use of industry standards
- Tramway/vehicle specific:
  - Full skirting – no exposed couplers
  - Rounded ends with low bumpers to deflect objects
  - Improved cab visibility and ergonomics
  - Indicator lights and audible warnings optimized for the specific operating environment
  - Additional standee accommodations to limit movement during hard braking

Existing Industry Standards

In the U.S., there are standards relevant to LRV and component designs. The American Society of Mechanical Engineers (ASME) Safety Standard for Structural Requirements for Light Rail Vehicles and Streetcars (ASME RT-1) [2015],[17] Section 3.2, Leading End Design for Protection of Street Vehicles, includes requirements for front-end geometry and bumper height (ASME is

[17] https://www.asme.org/codes-standards/find-codes-standards/rt-1-safety-standard-structural-requirements-light-rail-vehicles/2020/drm-enabled-pdf.

updating ASME RT-1). Fire safety, specifically smoke and toxicity, is prescribed in NFPA 130. In addition, the Public Utilities Commission of the State of California (CPUC) issued General Order 143 (GO 143) that provides Safety Rules and Regulations Governing Light Rail Transit (revision pending). GO 143B provides requirements for equipment, lighting, vehicle construction, operating speeds, right-of-way standards, traction and power, operating rules, testing and maintenance, and event reporting.[18]

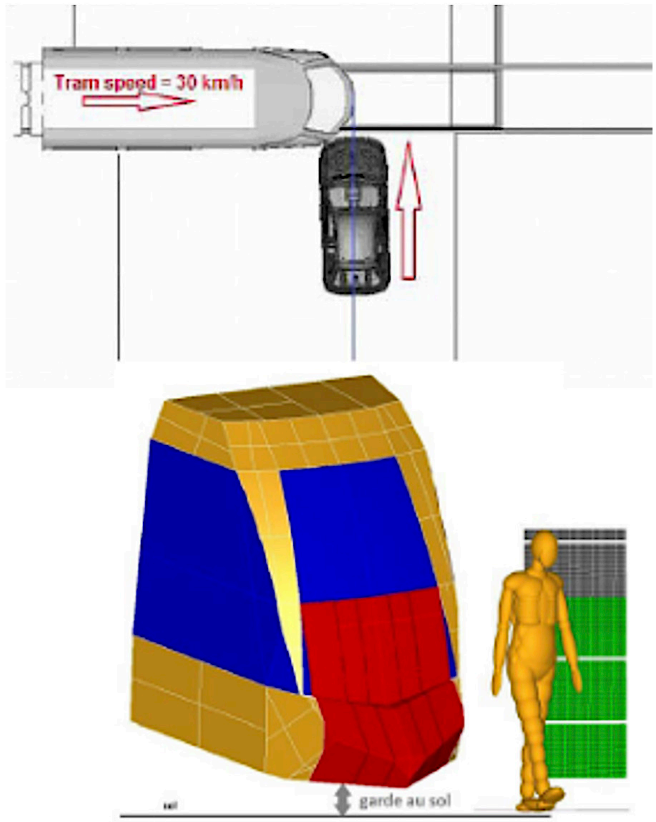
In Europe, EN standards have been established for light rail (tram) vehicle and subsystem designs and fire protection (EN 45545-2:2013, A1:2015), and tram operators in the EU must comply with these standards.

In France, Le Service Technique des Remontées Mécaniques et des Transports Guidés STRMTG (France) adopted the Tramway Front End Design standard[19] that requires:

- Designing and validating the shape of the leading end of the LRV to minimize pedestrian injury
- Validating the effectiveness of underrun protection
- Evaluating propensity to derail when struck in a perpendicular collision with a motor vehicle at the front corner

STRMTG's *Technical Guide to Safety in Tramway Driver's Cab*[20] was initiated to cover cab visibility and ergonomics and quantify the testing for visibility/field of vision for LRVs. The requirements defined in the guide apply to all new railway rolling stock running on tramway, rail or tires, as well as to tram-trains when they are required to travel in an urban environment in the same way as a tramway. STRMTG's *Safety of Tramway Operating Areas Guide* [21] was released in October 2017 and proposes a methodology for the safe design, operation, and maintenance of tramway maneuvering areas. It recognizes that dynamic signaling may be necessary in some cases to prevent collisions between trains or derailments.

[18] http://docs.cpuc.ca.gov/published/Graphics/598.PDF.
[19] http://www.strmtg.developpement-durable.gouv.fr/en/IMG/pdf/tramway_front_end_design_technical_guide_v2016-10-06_en_v1.pdf.
[20] http://www.strmtg.developpement-durable.gouv.fr/en/IMG/pdf/Safety_in_tramway_drivers_cab_technical_guide_Guide_Securite_des_postes_TW_v3-1.pdf.
[21] http://www.strmtg.developpement-durable.gouv.fr/IMG/pdf/guide_securite_des_zones_de_manoeuvre_tramway_version_1_internet.pdf.



Source: Technical Agency for Ropeways and Guided Transport Systems

Figure 2-10 *STRMTG Tramway front-end design*

In 2017, STRMTG issued its Standard *function de veille des tramways* (driver vigilance system for tramways) that was developed in response to increases in accidents/ passenger injuries that occurred with the deployment of dead man braking applications. It addresses driver distractions that are common in mixed traffic operations and provides recommended timing values and braking performance to limit injury severity in these engagements.

In 2014, STRMTG and the Center for Studies and Expertise on Risks, the Environment, Mobility and Development (CEREMA) issued a report providing recommendations for the lighting of tramway platforms based on standards and best practices in France and elsewhere in Europe. The recommendations include a call for highly directive lighting to increase tram operator's visibility at night.

Main Points – Literature Review and Background Research

The research team performed an extensive research review of safety hazards, safety standards, street intersection designs and signals, audible and visual warning devices, vendor technical literature, and deployment of other US and international technologies that address light rail transit collisions. Main points associated with risks and risky behaviors and mitigation techniques are included below.

Risks and Risky Behaviors

- Failure of motor vehicle drivers to observe and comply with traffic control devices
  - Motor vehicle left turn movements in front of LRV
  - Motor vehicle operators proceeding through red lights
  - Motor vehicle right turn movements in front of LRV
  - Sideswipes in shared/non-separated LRV alignments
- Poorly-timed intersection signalization
- Too many active signals, passive signage/safety warnings, postings at intersections
- Pedestrian behaviors both at intersections and along light rail operating alignment
- Confusion exhibited by both motor vehicle operators and pedestrian/ bicyclists
- Line-of-site operation has some design and operational challenges

Measures and Technology Deployments

- Supplemental bumper/underrun protection
- Energy absorbing pumpers
- Driver assistance systems
- Driver vigilance, including use of facial scanning for fatigue detection
- Left turn prohibitions or limitation
- Signal priority
- Speed/signal enforcement
- Gating – two- and four-quadrant
- Grade separation/segregation from mixed traffic
- Training of LRT operators
- Public education and awareness

Section 3

Light Rail Case Studies

The research methods for this report included a series of RTA case studies to collect safety data for injuries and fatalities associated with light rail collisions, examine the operating conditions, trends, challenges, and successes of these agencies, and gather stakeholder input to further inform the research team. The research team performed case study examinations of seven U.S. public transportation agencies that are operating light rail and streetcar systems, including:

- Greater Cleveland Regional Transit Authority (GCRTA)
- Hillsborough Area Regional Transit (HART)
- Massachusetts Bay Transportation Authority (MBTA)
- Metropolitan Transit Authority of Harris County (Houston Metro)
- Los Angeles County Metropolitan Transportation Authority (LA Metro)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Tri-County Metropolitan Transportation District of Oregon (TriMet)

A questionnaire was developed (Appendix A) to formalize the approach to pre-visit data collection and to identify areas of focus for interviews with transit agency personnel.

Each case study summary includes system characteristics and safety trends. During the site visits, interviews were conducted with agency personnel to establish the challenges faced; mitigation or countermeasures, including technologies, implemented; and the impact of those applications on overall system safety. Any specific lessons learned, or other feedback provided by transit agency personnel are also indicated. Countermeasures deployed by case study agencies are categorized[22] as follows:

- Physical Barriers
- Traffic Signals
- Signal Displays
- Traffic Signal Phasing/Priority/Preemption
- Pavement Markings/Treatments
- Public Outreach/Education
- Enforcement
- Other (speed modifications, cameras, driver training, procedural changes)

Technical aspects of the design of the LRT system, intersection design and signalization, technologies applied, other safety modifications, and associated findings are presented in Appendix B, "Light Rail Technology Scan and Case Studies," a report issued by TTCI.

[22] https://www.nap.edu/read/14215.

Agency policies and procedure documents and process summaries collected as part of site visit activities are included in Appendix C.

Greater Cleveland Regional Transit Authority (Cleveland, Ohio)

General System Information

The Greater Cleveland Regional Transit Authority (GCRTA) provides public transportation services to Cleveland and the surrounding suburbs of Cuyahoga County and is the largest transit agency in Ohio. GCRTA is a political subdivision of the State of Ohio and is governed by a ten-member Board of Trustees charged with managing and conducting its affairs. Although GCRTA operates one heavy rail line and one light rail line, the bulk of the agency's service consists of buses, including regular fixed-route bus, bus rapid transit (BRT), and paratransit buses for customers with disabilities. The 2017 National Transit Database (NTD) agency profile for GCRTA's light rail service is as follows:

Table 3-1 *GCRTA Operating Characteristics*

Annual Passenger Miles	14,721,876
Annual Train Revenue Miles	776,474
Annual Unlinked Passenger Trips	2,468,330
Vehicles Operated Maximum Service	13

Operational Characteristics (Operating Hours, Types of Service Provided, Etc.)

The light rail system at GCRTA was constructed in stages between 1913 and 1930 and was subsequently reconstructed in 1981. The newest portion of the light rail line, the Waterfront Line, was completed in 1996. GCRTA has a 34-vehicle light rail fleet that operates on 15.3 miles of double track, of which 2.8 miles are shared with heavy rail vehicles. GCRTA is the only transit agency in North America to operate both heavy and light rail vehicles on the same segment of track. The light rail line is branched at the east end (Blue Line along Van Aken Boulevard and Green Line along Shaker Boulevard), serves 34 low-platform stations and operates approximately 21 hours per day (4:00–12:00am), seven days per week. Single light rail articulated bi-directional vehicles are used in typical service with two-car trains used for special event service.

Most of the light rail system operates at-grade, using traffic signal controls at intersections, and about 40% of the light rail system is fully grade-separated. GCRTA uses controlled interlocking and pushbutton route selectors along the light rail line. Typical operating environments are shown in Figures 3-1 and 3-2. As of 2018, the light rail schedules require nine cars operated in maximum service, which is four fewer cars than reported to NTD for 2017, as shown in the 2017 NTD agency profile above. Schedules require 83 rail operators to support both light and heavy rail operations.

Photo credit: TTCI

Figure 3-1 *Downtown Cleveland approaching Lake Erie*

Photo credit: TTCI

Figure 3-2 *Green Line, Shaker Heights*

Operator Qualifications and Training

GCRTA is dedicated to continuous improvement, as emphasized by their annual Rail Operations Rule Book updates and biennial training program. Safety is the focal point of the culture at GCRTA, as evident through the holistic approach to training and hazard identification. One key aspect to training that is necessary for the successful implementation of Safety Management Systems (SMS) is the documentation of the training each personnel receives. Refresher and/or remedial training is provided as needed and is used to address hazards that are identified through the many hazard identification mechanisms in place at GCRTA.

All GCRTA personnel undergo emergency response training to ensure they have a full understanding of their roles and responsibilities during an emergency incident. The level of training is dependent upon the role of the personnel, and all personnel are trained on emergency plans and procedures for which they may be responsible to implement.

Accident/Incident Management

Clear coordinated and defined communication lines help incident management operate smoothly. GCRTA's Integrated Communications Center (ICC) serves as the central management center for all light rail incidents. When an incident occurs, a single service-quality supervisor responds to the incident and acts as the Incident Commander and is responsible for coordinating actions of all responding entities, such as the fire department, emergency medical services, and police. The ICC serves as the central incident management source for GCRTA and communicates and controls all train movements, adjusting service and schedules as necessary until the scene is cleared for regular service.

GCRTA remains ready to respond to emergencies through regularly scheduled drills and exercises, which ensure the adequacy of emergency plans and procedures, the readiness of personnel to perform in an emergency, and the effective communication between GCRTA and emergency responders. Following each drill, evaluations are performed to identify areas of future improvement. This consistent evaluation of plans and procedures allows GCRTA to be nimble in its approach to emergency response, making improvements proactively and not reactively following an emergency occurrence. GCRTA credits much of its emergency response success with deliberate coordination with external emergency agencies, recognizing that communication outside of the agency can be just as important as the communication within the agency.

Safety Trends

Figure 3-3 displays the trend in light rail collisions at GCRTA between 2007 and 2017 by type of collision. Personally-operated vehicles (POVs) account for the largest share of total collisions, with nearly 38% of all light rail collisions in that period. Although collisions with debris account for just over 17% of all light rail collisions in that period, in 2016 collisions with debris accounted for more than 64% of all light rail collisions.

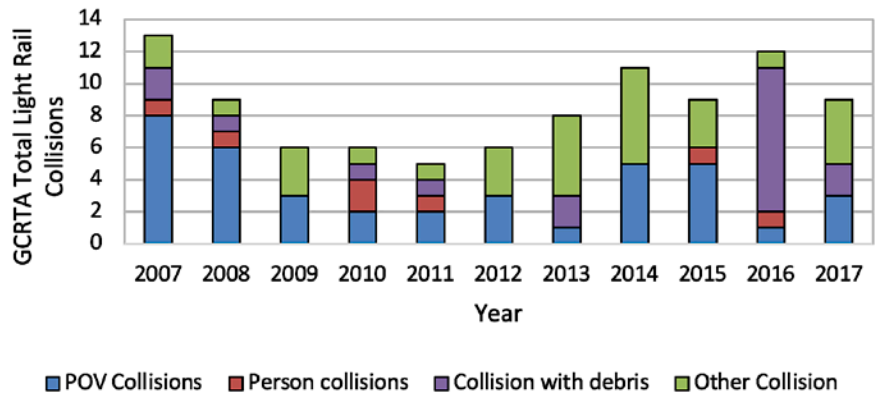


Figure 3-3 *GCRTA light rail collisions by type, 2007–2017*

Figure 3-4 shows the trend in preventable light rail collisions by year for 2013 through 2017, the past five full years of available data. The decreasing trend in preventable collisions is impressive and indicates that the safety efforts at GCRTA are working as intended. Figure 3-5 shows the share of operator seniority for operators involved in preventable collisions between 2007 and 2017, with 62% of all preventable collisions involving an operator with 0–4 years of operating experience.

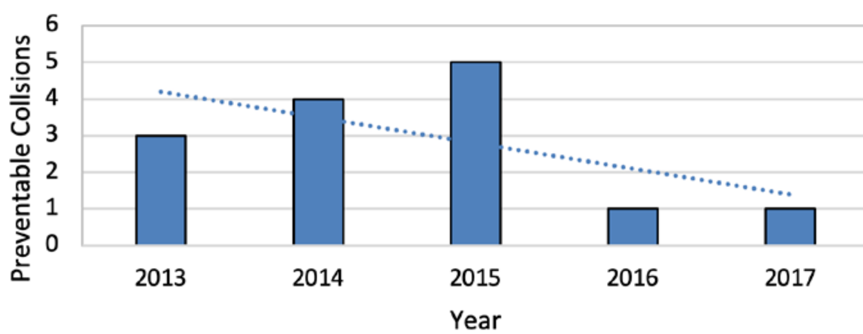


Figure 3-4 *GCRTA preventable collisions, 2013–2017*

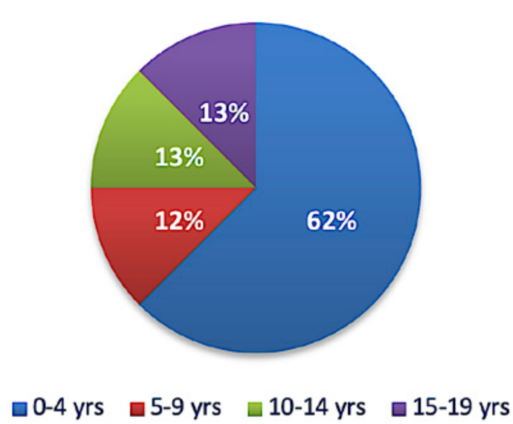


Figure 3-5 *GCRTA preventable collisions by operator seniority*

Areas of Concern

Although GCRTA is operating an aging light rail system that runs through a historic bedroom community, the frequency of collisions is low. The most challenging type of collisions are left-turning personal vehicles, especially illegal left turns (examples of configurations where left turns present challenges are shown in Figures 3-6 and 3-7) and unfamiliar roadway users. GCRTA event data provided and analyzed for this research supports the stated challenges, with about 34% of all collisions involving POVs. GCRTA considered the possibility of adding parking lot-style gates to prevent some illegal turning movements; however, due to the historic nature of the communities served by the light rail line, parking lot-style gates were not acceptable. One way to minimize the severity of light rail collisions, especially with personal vehicles, is through low operating speeds. GCRTA has a maximum operating speed of 45 mph; however, light rail trains typically do not exceed 25 mph.

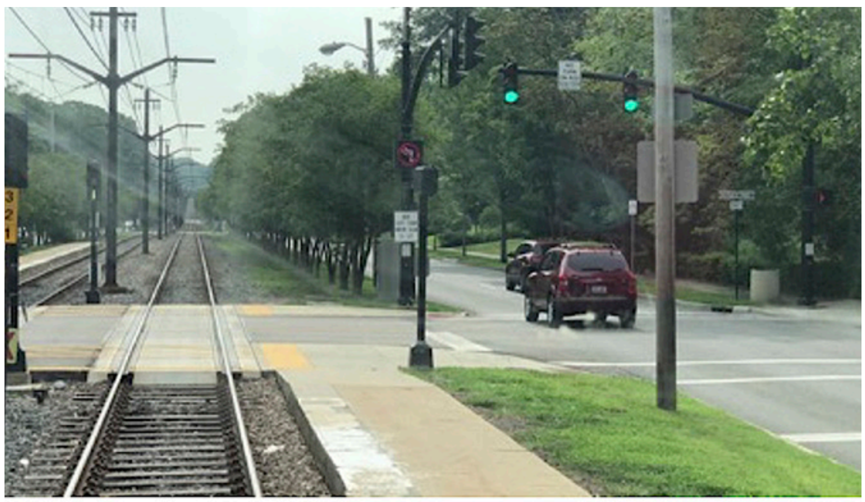


Photo credit: TTCI

Figure 3-6 *Left-turn situation*

Photo credit: TTCI

Figure 3-7 *Left-turn situation where Blue and Green lines meet*

Extreme weather is one concern that is unavoidable for GCRTA. The safety team remains on high alert when extreme weather is imminent, and all safety supervisors remain ready to respond. Both ice and snow build-up contribute to additional challenges for GCRTA. Icy weather can cause the overhead catenary to contract, which may require de-icing of the overhead catenary. Additionally, high temperatures have the potential to cause the overhead catenary to sag. Tightening the overhead catenary or a constant tensioning system (found at GCRTA's Waterfront area) can address this problem. Fall can also be a challenging time of year, as leaves and sap can cause slippery conditions on the rail. To ensure that leaves, snow, or ice are not an issue, GCRTA routinely runs non-revenue vehicles to clear the rail prior to running revenue service.

Technologies and Other Safety Applications

To combat left-turning personal vehicle challenges, GCRTA uses a combination of static and active blank-out signage to warn drivers of an approaching train, prohibiting left turns into the path of the light rail vehicle. Examples of static and blank-out signage are shown in Figures 3-8 and 3-9.

Photo credit: TTCI

Figure 3-8 *“No Left Turn” static sign*

Photo credit: TTCI

Figure 3-9 *“No Left Turn” blank-out sign*

GCRTA also employs crossing gate protection at rail crossing signals on the Waterfront Line, as shown in Figure 3-10. Fencing is also frequently used at GCRTA to deter pedestrians from crossing the tracks in unwanted areas, as shown in Figure 3-11.

Photo credit: TTCI

Figure 3-10 *Double-gated crossing*

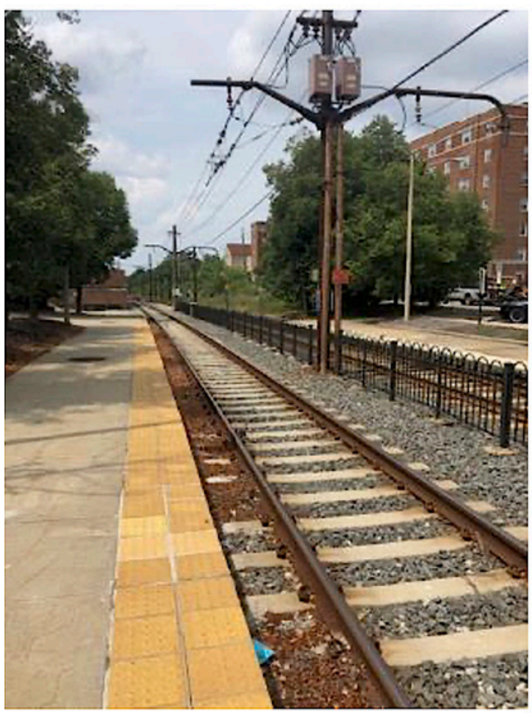


Photo credit: TTCI

Figure 3-11 *Fencing*

GCRTA's rail system safety is maintained via many control and communication features, such as two-way radio communication with all trains, Automatic Block System (ABS) signals in selected areas, and Computerized Consolidated Train Dispatching System (CTDS) on part of the light rail line. Automatic interlocking with CSX Railroad at West 3rd on the Waterfront Line is in place to ensure that the proper sequence of movements is followed when interacting with the freight line. Absolute block procedures are used throughout the system as one way of ensuring that only one train at a time occupies the same line within a block section to reduce the likelihood of train-on-train collisions.

GCRTA trains also have cab signal testing capabilities at the entrance to the main line from all yards to allow operators to check the functionality of the cab signaling prior to providing service on the main line.

GCRTA uses posted speed control circuits with Automatic Train Stop (ATS) on certain approaches, and there are also master controller dead man features on all rail vehicles. If the master controller handle does not remain horizontal during operation, the train will commence full braking.

GCRTA trains are equipped with roadway worker protection technology that alerts train operators and wayside workers when they are near each other. The research team witnessed this technology in use and working as intended in conjunction with the flagging process in place in areas where workers were in the operator's line of sight.

Other Modifications or Procedural Actions

GCRTA uses a proactive and predictive approach to risk management in accordance with the integration of SMS. GCRTA promotes safety as a core value rather than a priority. Through committed leadership and data-driven performance management, GCRTA has made remarkable strides in its safety performance. By identifying clear roles, responsibilities, and accountability via effective communication, GCRTA has shown how employees at all levels of the organization can contribute to improved safety performance. By allowing employees to be involved in the development and review of policies, for example, employees feel more valued and appreciated, increasing their promotion of a holistic safety culture. Additionally, listening to employees when hazards are identified and responding in a timely manner fosters pride and ownership at all levels of employment, leading to an improved safety culture.

One key aspect of risk management is hazard identification. GCRTA has a non-punitive hazard reporting policy that allows all employees to report close calls or unsafe conditions without fear of retribution. GCRTA has a hazard analysis process in place to identify safety issues and concerns and to provide policy, process, or equipment to modify or eliminate an identified hazard. The agency takes a holistic approach to hazard identification using both inductive, bottom-up and deductive, top-down methodologies. Whereas the bottom-up approach identifies the failure of system components to identify possible effects on the total system, the top-down approach defines the undesired event or hazard and deduces the combinations of conditions that could potentially produce that hazard. Through the top-down deductive approach, a fault tree analysis is performed to provide a concise description of the possible occurrences and ways to mitigate the problem areas that would contribute to that occurrence. They can prioritize the identified hazards using a data-driven approach to prudently apply limited resources to mitigate the most severe hazards.

Internal hazard identification sources are abundant at GCRTA using hazard reporting forms, a hazard safety hotline; hazard reporting emails; in-person hazard reporting; loss prevention audits; vehicle defect reports; incident reviews, investigations, and reports; safety analysis testing, inspections, and audits; non-compliance reports; malfunction reports; passenger reports; and more. Additionally, GCRTA is proactive is reviewing hazard identification from outside sources as well, such as the American Public Transportation Association (APTA), FTA, the National Transportation Safety Board (NTSB), and the Federal Railroad Administration (FRA), to take advantage of other industry hazard findings.

GCRTA added the "See Something, Say Something" hotline in Summer 2018, which allows a person to call or text an emergency to GCRTA Metro Police Department. Pamphlets are placed on each GCRTA LRV to inform riders of the hotline. The pamphlet, in part, states, "In light of tragic events across the country, RTA and Transit Police are continuing their commitment to the safety of customers, passengers, and employees." GCRTA built upon the Department of Homeland Security's "See Something, Say Something" campaign to offer a safe and discrete way to notify Transit Police dispatchers of suspicious or criminal activity. The "575-EYES See Something, Text Something" campaign is designed to allow customers to send SMS text, photo, and video messages to GCRTA Transit Police. Dispatchers are notified of a live chat and can reply and communicate with the reporter and push the messages to responding officers when necessary.

Successes

GCRTA touts impeccable safety statistics on its light rail line despite challenges with aging infrastructure and operation in a historic bedroom community. Many challenges that other agencies experience due to mixed-use travelways were designed out of the GCRTA system, with about 40% of the system fully grade-separated. Additionally, the consistency in signaling, warning signs and signals, appears to be beneficial to the traveling public and reduces the confusion associated with varying rail identification markings. Future safety improvements may include additional gate installation to reduce the likelihood of left-turning collisions with light rail vehicles. However, with the operating environment at GCRTA, the installation of gating does not seem to be a viable option.

The exceptional communication lines with the safety team from both front-line employees and upper management contribute significantly to GCRTA's ability to proactively and predictively identify hazards and solutions to mitigate or eliminate hazards before an incident occurs. The SMS approach to rail system safety integrated into GCRTA is proof of a committed leadership team, a maturing safety culture, and data-driven performance management.

Hillsborough Area Regional Transit (Tampa, Florida)

General System Information

Hillsborough Area Regional Transit Authority (HART) provides public transportation for Hillsborough County, Florida, with fixed-route local and express bus service, door-to-door paratransit service, flex route neighborhood connector service, and BRT. In addition, HART manages the TECO Line Streetcar, a 2.7-mile line that runs in downtown Tampa through the Channelside District and Ybor City. The 2017 NTD agency profile for HART's light rail service is as follows:

Table 3-2 *HART Operating Characteristics*

Annual Passenger Miles	504,470
Annual Train Revenue Miles	66,163
Annual Unlinked Passenger Trips	286,685
Vehicles Operated Maximum Service	3

Operational Characteristics (Operating Hours, Types of Service Provided, Etc.)

Tampa's first electric streetcar was built in the 1890s and operated through 1946; in 2002, the modern electric streetcar was revived. Since 2011, HART has reported the streetcar to FTA as a light rail mode. The mission of the streetcar is to "offer a dynamic new component to Tampa's transportation system by providing attractive, reliable, comfortable, convenient, and safe streetcar service to residents and visitors alike." The streetcar line in Tampa operates from 12:00–10:00pm Monday through Thursday, 11:00–1:30am on Friday and Saturday, and 12:00–8:00pm on Sunday. The headway is 20 minutes until 1:00am and 30 minutes after 1:00am. When hockey games, parades, or other special events occur on weeknights, streetcar service is extended through

12:00am. HART also provides parallel bus service to the streetcar, which provides extended service beyond the streetcar's operating hours.

The 2.7-mile streetcar line connects downtown Tampa and the Channelside District through historic Ybor City, and expansion is being discussed to accommodate the growing downtown area and the Marion Street Transitway. The entire track system operates at street grade on a dedicated right-of-way with one freight interlock crossing. There are 11 stops and 18 at-grade vehicle intersections along the track and additional pedestrian crosswalks. HART's typical streetcar track configuration has the track off to one side of the road using a small concrete median to separate the streetcar lane from vehicular traffic, as shown in Figure 3-12.

Photo credit: TTCI

Figure 3-12 *Typical track configuration*

The streetcar operates at speeds of up to 20 mph, with some restricted speed areas in which the maximum speed does not exceed 10 mph. Typical braking uses a brake shoe mechanism on the outside of the wheel, but operators also may use a wheel sanding system and a hand brake that uses induction current to stop the streetcar in emergency situations. Operators sounds a whistle as they approach an intersection, with whistle posts located within 100 ft of each intersection, indicating where the whistle should be engaged.

Operator Qualifications and Training

Motormen are required to pass signal refresher training every six months in regard to their operations at their freight interlock crossing.

Accident/Incident Management

HART uses National Safety Council (NSC) and Transportation Safety Institute (TSI) definitions to define preventability for both bus and rail incidents. Through contractual agreements, HART has an accident review board that consists of two union members and two management representatives, with the Director of Safety and Security as the swing vote in the case of a tie. HART does not have its own dedicated transit police, instead depending on the Tampa Police Department when necessary.

Safety Trends

HART's streetcar line has an impressive safety record, with no reported fatalities and only two collision-related injuries between 2014 and 2017. These favorable safety statistics can be at least partly attributed to the slower operating speeds of both the streetcar and local vehicular traffic. Most safety-related issues that occur can be attributed to line-of-sight challenges at intersections. HART began using Industry Safe© to track rail accidents and incidents in January 2018. Given this recent data transition, HART provided the research team with data for 2014 through 2017. HART also uses Industry Safe© to track near-misses in line with SMS implementation and has noticed an immediate decrease in accidents. All near-misses are reported to dispatch and triaged as quickly as possible.

As shown in Figure 3-13, the majority (84%) of all rail collisions at HART involve personal vehicles, only 4% involve pedestrians, and 11% involve other types of collisions; only two injuries were reported in the four years of data provided. The dotted line in the chart shows a downward trend in total rail collisions, and the green solid line shows the trend in streetcar unlinked passenger trips (UPTs) on the secondary axis. The black squares indicate the trend in rail-related injuries, of which there were two in four years, between 2014 and 2017.

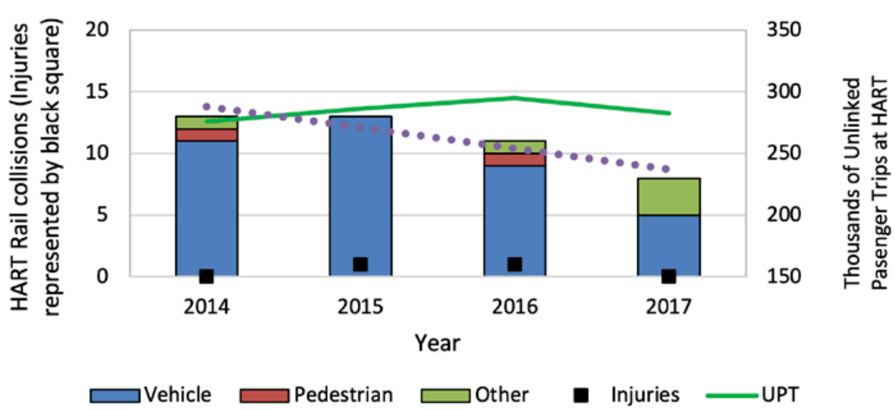


Figure 3-13 *HART rail collisions by type, 2014–2017*

Figure 3-14 displays the time distribution of each rail collision that occurred at HART between 2014 and 2017. The asterisk next to "Morning" in the legend indicates that this is out of normal operating hours. More than half of all rail collision events occurred during midday between peak hours of vehicular traffic. One of every three rail collision events occurred between 7:00pm and 1:00am. An analysis of rail collisions by month, shown in Figure 3-15, reveals that June and July had the highest share of all rail collisions, accounting for 33% of all collisions between 2014 and 2017.

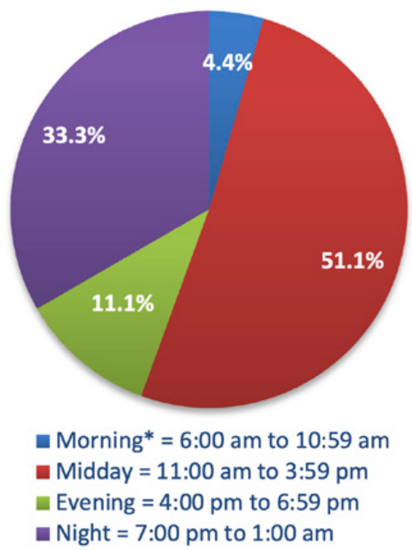


Figure 3-14 *HART collisions by time of day, 2014–2017*

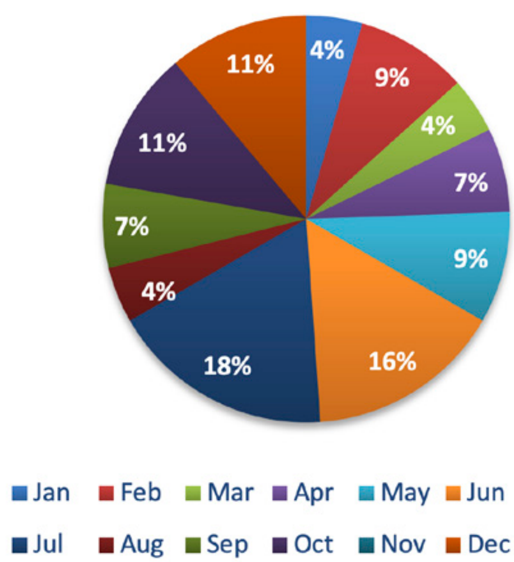


Figure 3-15 *HART collisions by month, 2014–2017*

Areas of Concern

HART experiences one specific type of collision more than any other. Due to the track configuration being off to one side of the street, vehicles approaching from a cross street on the side nearest the track often encroach onto the tracks while attempting to turn, increasing the risk of getting struck by an oncoming streetcar that cannot immediately stop. The problem motorists encounter when coming to a stop at the designated point is a lack of visibility of traffic on the street where the tracks are located . Having the streetcar tracks and a crosswalk in front of them when stopped at a stop sign often puts motorists in a position where there is not a clear line of sight to the left and/or right to see oncoming traffic, as shown in Figure 3-16.

Photo credit: TTCI

Figure 3-16 *Poor line of sight from cross street*

If a vehicle wants to turn left in the example given in Figure 3-16, it has to move forward onto the tracks to see traffic approaching from the right. Meanwhile, a streetcar could be approaching from the left with no time to stop before colliding with the vehicle on the tracks. This situation also occurs from parking areas located on the track side of the street.

Another potential hazard in this configuration could arise from vehicles traveling in the same direction as the streetcar; a vehicle driver may not notice the streetcar in their blind spot and turn right into the path of a streetcar. Figure 3-17 shows an example of an intersection at which this potential right-turn conflict could occur.

Photo credit: TTCI

Figure 3-17 *Potential right-turn conflict*

Technologies and Other Safety Applications

HART uses passive and active signage at grade crossings to warn vehicle operators of the streetcar. An example of active signage is shown in Figure 3-18, which illuminates only when a streetcar is approaching. An example of the passive signage employed at HART is displayed in Figure 3-19.

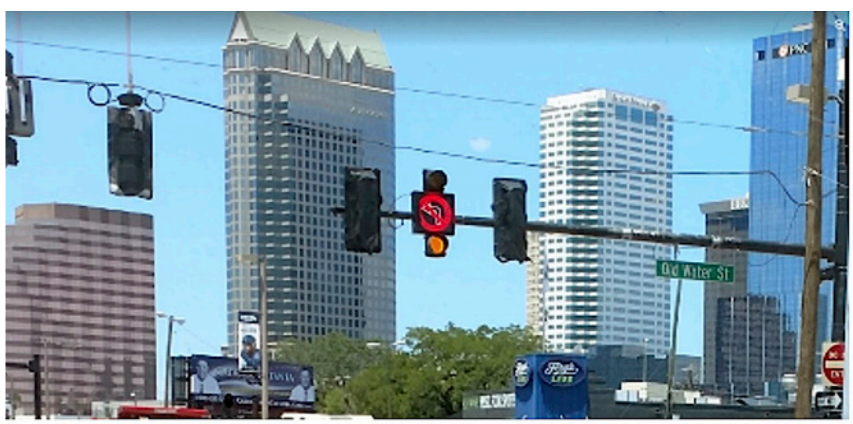


Photo credit: TTCI

Figure 3-18 *Active warning signage*

Photo credit: TTCI

Figure 3-19 *Passive warning signage*

At one location a parking lot-style gate is used at the exit of a parking lot to prevent vehicles from encroaching onto the tracks when a train is approaching (Figure 3-20). The parking lot-style gate is working well, given the limited space available for mitigation measures in this area.

Photo credit: TTCI

Figure 3-20 *Parking lot-style exit gate*

HART now offers free Wi-Fi on its streetcars, which allows passengers to stay connected while traveling on the streetcar. This system is also used to support HART's Flamingo Smart Card app, streamlining the ticketing and boarding process. The app also allows passengers to use a regional fare structure for rides between Hillsborough and neighboring Pinellas County, with plans to expand the regional fare structure to other neighboring counties.

In 2015, the Tampa Hillsborough Expressway Authority (THEA) was awarded a $17 million contract from US Department of Transportation (DOT) to implement the Tampa Connected Vehicle Pilot Program, a partnership with the Florida DOT, HART, and other public and private organizations. The goal of the pilot is to reduce congestion and improve safety and efficiency through connected communication between personal vehicles, pedestrians, public transit vehicles, traffic signals, etc. To accomplish this connectivity, THEA and other partners have installed 40 wireless communication roadside units, 10 on-board units on HART buses, 10 on-board units on HART streetcar trolley cars, and 1,500 privately-owned vehicles that travel the study area regularly. Buses equipped with on-board units can communicate with traffic signals to prioritize bus movements when necessary to keep buses on schedule. This signal prioritization has obvious applicability to the streetcar as well; streetcars that are equipped with on-board units can communicate with connected personal vehicles to relay information about vehicles crossing the tracks and reduce the risk of collisions.

SeeClickFix is a website/mobile app that allows citizens to report any issue; the report is sent to the appropriate community official. HART collaborates with SeeClickFix to allow the public to report any concerns they have regarding the streetcar or bus lines or other supporting infrastructure, such as sidewalks or crosswalks. The app then forwards that reported information to the appropriate entity to streamline the mitigation process. For instance, if a bus stop is inaccessible due to a downed tree or other obstruction, a rider can report that obstruction to the transit agency, which can then send personnel to remove the obstruction and allow service at that stop to resume. Geolocation ability and attachment of supporting photos allow the responding agencies to have the appropriate materials necessary to mitigate the issue.

Other Modifications or Procedural Actions

HART strives to continuously improve customer service. To understand the rider perspectives, HART conducted the "Voice of the Customer" surveys in four waves between August 2015 and January 2017. The surveys revealed that about 75% of HART riders are transit-dependent, approximately 80% feel safe while riding and waiting for public transit, and about 90% agreed that it was easy to access route and schedule information. HART is using the information gathered to make important decisions regarding quality of service.

HART recognizes the importance of public outreach and conducts outreach through various public workshops and community events to emphasize safety and promote transit use within the community.

Successes

Although HART has a relatively small rail system, it still has some challenges. Vehicles turning into the path of a streetcar are clearly its primary collision-related problem. Having higher visibility signage and lighting may assist the public's awareness. Innovative mitigation measures such as parking lot-style exit gates show promise where standard railroad gates cannot be installed due to lack of space. Connected vehicle technology appears to have significant potential in preventing collisions with pedestrians and vehicles, through both active and passive countermeasures that can increase the awareness of both the vulnerable road users and streetcar operators to potential collision. HART's partnership with the connected vehicle pilot project will help leverage newly-advancing technologies, such as collision avoidance warnings and detecting the presence of pedestrians on or near the rail line. Connected vehicle technology has potential implications to reduce future safety risk.

Massachusetts Bay Transportation Authority (Boston, Massachusetts)

Massachusetts Bay Transportation Authority

General System Information

MBTA is one of the oldest public transit systems in the US and provides services to the Boston metropolitan area and surrounding communities. In 1964, it became an individual department within the Commonwealth of Massachusetts before transitioning to a division of the Massachusetts Department of Transportation (MassDOT) in 2009. It is overseen by two separate governing bodies, MassDOT and the Fiscal and Management Control Board. MBTA directly operates heavy rail, regional commuter rail, electric trolley buses, motor buses, light rail, and ferry. Light rail services are provided on the Green Line and the Mattapan Line. MBTA's Green line is described as the most heavily used light rail system in the US. The current Green Line Extension (GLX) project will add 4.5 miles to the line from its current terminus in Cambridge to Somerville and Medford (scheduled opening in 2021). The 2017 NTD agency profile for MBTA's light rail service is as shown in Table 4-3.

Table 3-3 *MBTA Operational Characteristics*

Annual Passenger Miles	171,740,181
Annual Train Revenue Miles	3,845,486
Annual Unlinked Passenger Trips	64,538,406
Vehicles Operated Maximum Service	156

Operational Characteristics (Operating Hours, Types of Service Provided, etc.)

MBTA is a multimodal agency with rail operations including, among other modes, light rail and heavy rail operating along five rail lines:

- Red Line – heavy rail divided in two branches, 168 vehicles during peak hours
- Orange Line – heavy rail on a single branch, 96 vehicles during peak hours
- Blue Line – shortest heavy rail line on a single branch, 72 vehicles during peak hours
- Green Line –busiest light rail line divided in four branches, B, C, D, and E, 146 vehicles during peak hours; D branch operates on exclusive right-of-way
- Mattapan Line – shortest light rail on a single branch, 4 vehicles during peak hours

MBTA operates approximately 20 hours per day, every day of the year, from 5:00–1:30am Monday through Saturday and 6:00–1:30am on Sundays. MBTA train operators may work 14–16 hours per day but never more than six consecutive hours of train operations. The Department of Public Utilities (DPU) determines the maximum weekly overtime each operator is permitted, currently limited to 20 hours.

MBTA light rail operates at low speeds due to the operating nature and age of the system. The average operating speed is 20–25 mph with a 40-mph maximum allowable speed. The maximum speed allowed approaching platforms and intersections is 10 mph, which is strictly enforced.

MBTA has approximately 127 miles of revenue track, with 25 miles of dedicated track in each direction. In addition, MBTA light rail has ten miles of non-revenue track used for maintenance, yard, and vehicle changes. There are just over 34 revenue miles of light rail track with no grade separation.

Light rail trains consist of two cars with two operators onboard, one for each car; light rail passengers pay the fare on board, and both operators collect the fare and one directly operates the train. Exceptions to the two-car consist is on the Mattapan Line, for which the train consists of a single (PCC) car or during very off-peak hours (late night, early morning, weekends, etc.) a single-car train.

The types of vehicles in use and the age of the light rail fleet are as follows:

- Ansaldo Breda Type 8 LRV 3800-3894 – age 1998–2007 (Figure 3-21)
- Presidents' Conference Committee (PCC) Streetcar vehicles (Figure 3-22)
- Kinki-Sharyo Type 7 LRV vehicles 3700-3719 – age 1997 (Figure 3-23)
- Kinki-Sharyo Type 7 LRV vehicles 3600-3699 – age 1986-1988

Photo credit: MBTA

Figure 3-21 *Ansaldo Breda Type 8 LRV 3800-3894*

Photo credit: MBTA

Figure 3-22 *Presidents' Conference Committee (PCC) vehicle*

Photo credit: MBTA

Figure 3-23 *Kinky-Sharyo Type 7 LRV 3700-3719*

Operator Qualifications and Training

MBTA employs 430 full-time and part-time train operators, 230 of whom operate the Green and the Mattapan light rail lines as of 2018. Additionally, they schedule new hire training courses as needed, rather than on fixed schedules. Train operator candidates are not required to have previous experience, must be at least age 18, and must hold a current driver's license for the State of Massachusetts; a Commercial Driver License (CDL) is not required to be considered for the operator position. Candidates need to pass a physical test to prove their ability to climb, bend, and walk without assistance. Their vision is tested, including a colorblindness test, and they must complete a sleep apnea questionnaire and pass the pre-employment FTA drug and alcohol screening.

MBTA's initial training program duration is 40 days, consisting of classroom, yard, and on-vehicle instruction. Most days of training contain at least two hours of classroom and/or yard instruction; the remainder of the day is devoted to hands-on training, in-vehicle operation, and other duties that are essential to qualify as an operator in the Light Rail Division. During the entire course, candidates are tested to ensure comprehension of the material studied, and a score of 70% is required to pass the exams; all exams must be passed to pass the training course. Once certified as operators, candidates are released to their districts where they start the on-the-job-training (OJT) with a designated line instructor. At the end of the OJT segment of the training, candidates are fully qualified to maneuver trains on the line they will operate. They spend a short period on the extra board until the first bid is opened. MBTA conducts route bids every four months. Operators can change between routes if there is an open position on another light rail line; however, they must re-apply and qualify for the new line. There is a small pay differential between routes.

Mandatory refresher training is conducted on an annual basis and lasts a minimum of eight hours. Topics are selected by the Safety Department and focus on identified safety trends for the current year. Remedial training is mandatory after an operator is charged with a preventable (recordable) accident and occurs before the operator is assigned to a route; training duration varies depending on the severity of the accident. The Training Department is also responsible for training operators who wish to transition to track inspectors, which requires precise eligibility criteria. Generally, inspectors are selected from operators or instructors who have at least three years of experience in their previous positions.

Accident/Incident Management

In 2014, MBTA adopted its *Accident Investigation Manual*, a comprehensive collection of information and policies to guide the conduct of exhaustive investigations when an accident or incident occurs. In the manual, MBTA defines an accident as "an unexpected loss-causing event that results in a fatality, bodily injury, occupational injury/illness, property damage, system disruption and/or environmental damage." Incidents are defined as "unexpected events or near misses that result in loss or the potential of loss and are incorporated under the term "accident." Losses include death, injury, property damage, occupational injury/illness, environmental damage, and system failure or disruption. Near-misses are defined as "perilous near-miss or close-call incidents that imminently could have resulted in a catastrophic or critical event or failure that was averted due to human intervention or other factors." The agency adopts the National Safety Council definition of preventability, "accidents where the operator of the light rail vehicle could have taken some action that would have prevented the accident from occurring. This preventability standard does not establish or seek to establish any degree of legal liability that may or may not exist with respect to an accident."

MBTA personnel are required to report all accidents, incidents, or near-misses involving MBTA personnel or property to the Operations Control Center (OCC). The OCC records the incidents in the dispatcher's log, which is then reviewed by the MBTA Safety Department. However, initial accident investigation is the responsibility of the Training Department. Light rail instructors are tasked with accident reviews and respond on scene as needed. They conduct the investigation and determine preventability based on statements, video review, and vehicle data. Many incidents are reportable to the State Safety Oversight agency, the Department of Public Utilities (DPU). If the incident is DPU reportable, the investigation becomes the responsibility of the MBTA Safety Department, which receives input from all departments and provides recommendations focused on preventing future occurrences. MBTA tests for fitness for duty as part of post-accident activities but also conducts the same tests when operators sign on, which is part of their accident prevention policy. Supervisors have the authority to remove operators from service if they have reasonable suspicion of fatigue or use of alcohol or drugs.

In 2017, MBTA selected a contractor to perform a comprehensive study of all branches for Green Line operations that included traffic signal optimization, transit signal priority, auto left-turn prohibitions, and train crossing intersection times. The study revealed certain intersections at which the timing of traffic signals could be improved to allow the uninterrupted movement of trains through the intersection. MBTA Transportation Management met with City officials to request adjustment of traffic signal timings to allow for safe passage of trains through these intersections.

MBTA has a comprehensive close-call program, which requires personnel to report close-call/near-miss incidents to the OCC. These incidents are added to the daily dispatcher logs, which is then reviewed and logged into MBTA's incident recording database, Industry Safe©. Once the Safety Department completes the investigation, a written response is provided to the originator of the close-call report and, if necessary and possible, corrective actions are developed and implemented.

MBTA compiled exhaustive policies regarding internal inspections and safety audits. Light rail track inspections are performed three times per week on revenue tracks and once per week on yard and storage track, and ultrasonic rail testing is conducted once per year. Additionally, geometry testing is conducted four times per year and optical rail tests are performed twice per year. If one of these inspections shows track or line damage, speed and operating restrictions are implemented until the proper repairs are made.

MBTA has developed public information campaigns delivered at schools and churches to educate the public on how to use the system safely. In 2014, MBTA initiated the "Eyes Up, Phone Down" campaign to encourage individuals to remain vigilant around Green Line tracks. Additionally, MBTA partners with Operation Life Saver (OLI), a nonprofit public safety education and awareness organization dedicated to reducing collisions, fatalities, and injuries associated with highway-rail crossings and trespassing on or near railroad tracks. In September 2017, MBTA worked with OLI as part of Rail Safety Week to increase rail safety education by focusing on rail grade crossings and railroad rights-of-way. Safety personnel conducted public outreach at rail stations, including the North and South stations. MBTA and OLI regularly conduct safety blitzes throughout the Greater Boston Metro area.

Safety Trends

Figure 3-24 shows a general declining trend in all types of collision events recorded at MBTA from 2008 through 2017. MBTA personnel credit speed reductions and a comprehensive set of rules and regulations as key elements that contributed to the five-year reduction in collision events between 2013 and 2017 . Personnel also believe the increased frequency of inspections and internal safety audits contributed to the decrease. MBTA's goal is to continue with this declining trend with a goal of zero collision events.

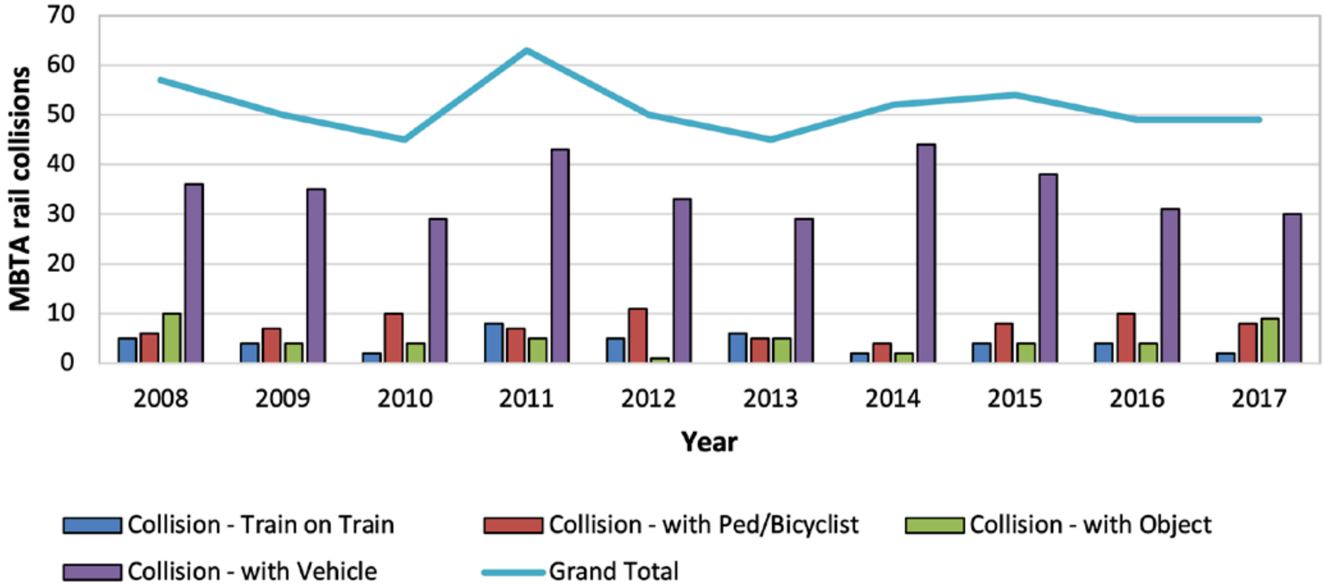


Figure 3-24 *MBTA collisions by type, 2008–2017*

MBTA has a commendable proactive approach to safety, and through its established close-call program, all employees strive to accomplish the collision elimination goal. MBTA reduced at-grade collision events through the promotion of an extensive training program, as noted above, and through the establishment of frequent unannounced inspections conducted by the Safety Department, such as speed control.

The onsite review highlighted several areas with potential for collisions due to the age and operating nature of the system. Figure 3-25 shows the number of accidents by location, revealing a low number of recent events in those locations.

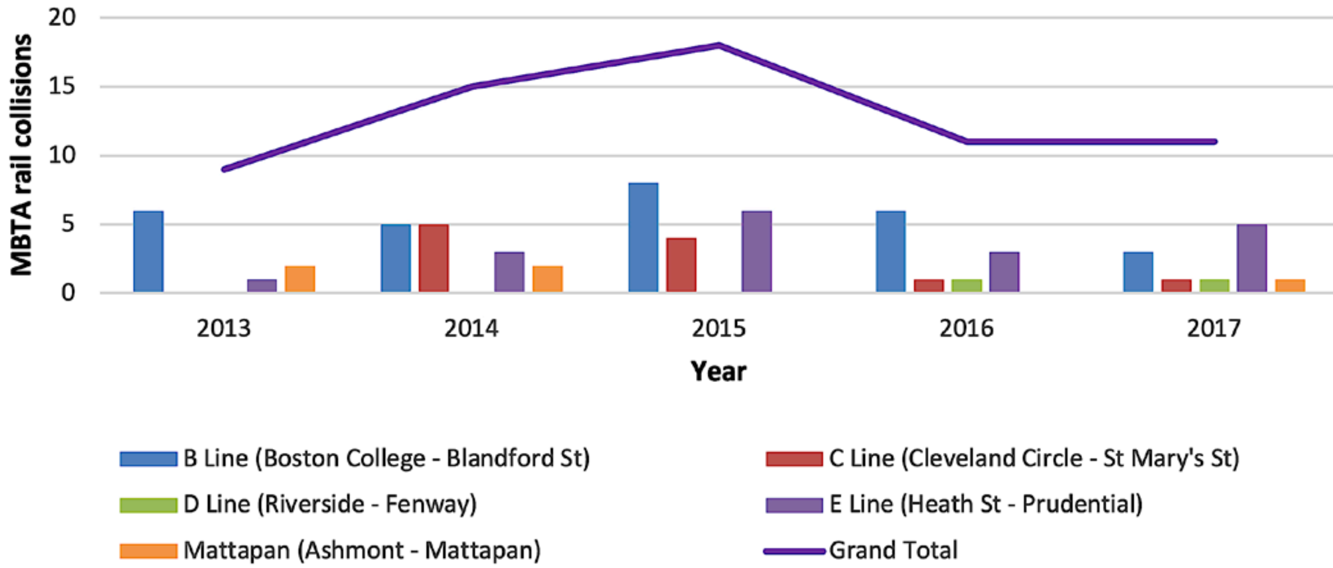


Figure 3-25 *MBTA collisions by type, 2013–2017*

Areas of Concern

The majority of MBTA light rail collisions involve personal vehicles. According to the data provided by MBTA, the frequency of collisions with vehicles is approximately three to four times that of collisions with pedestrians and cyclists. This personal vehicle collision trend may be attributable to the congested nature of the operating environment, with frequent crossings and shared lanes with motor vehicles (Figures 3-26 and 3-27).

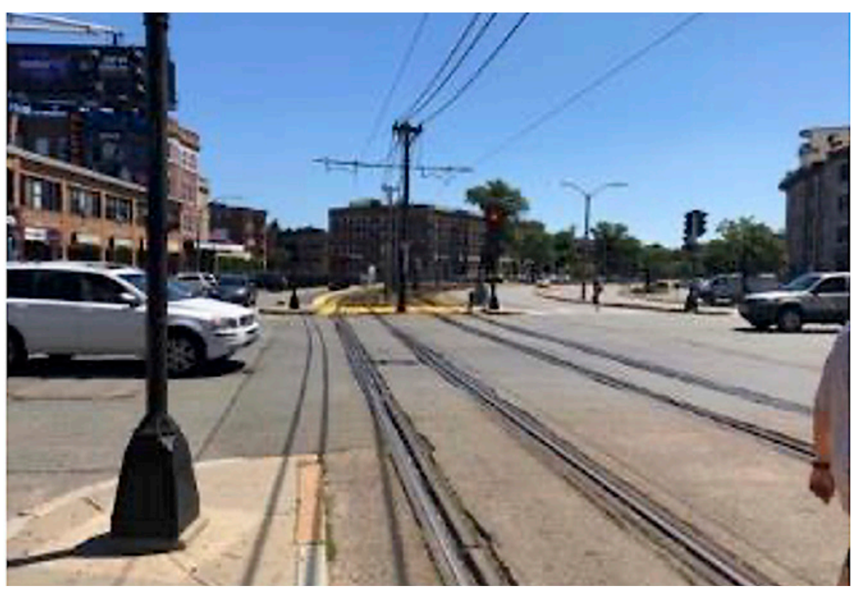


Photo credit: TTCI

Figure 3-26 *Typical level crossing*

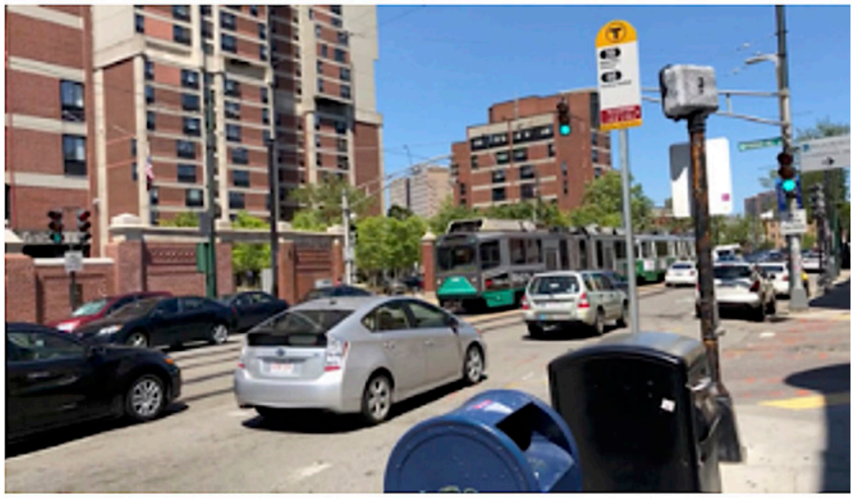


Photo credit: TTCI

Figure 3-27 *Shared-lane environment*

MBTA's main light rail segment of concern is the E branch on the Green Line, where the trolley operates in mixed-use traffic, as shown in Figure 3-28. In this area, most collisions are due to public inclination to turn in front of the train, both legally and illegally (Figure 3-29). The agency studied the possibility of implementing guarding systems such as gates, but this segment of the line has limited space for these types of improvements. In shared-lane environments, clearance is also an issue (Figure 3-30), which can result in track fouling and "sideswipe" incidents.

Photo credit: TTCI

Figure 3-28 *Green Line operating in mixed-use traffic*

Photo credit: TTCI

Figure 3-29 *Illegal left turn*

Photo credit: TTCI

Figure 3-30 *Reduced clearance situation*

MBTA is studying the potential advantages of Transit Signal Priority (TSP) to improve the safety and operations of its light rail line. If adopted, MBTA's light rail trains will be equipped with wireless signal transmitters to indicate the approach of a light rail vehicle, which will subsequently extend a green signal to allow the train to clear the intersection prior to the signal changing red. TSP may also shorten red signals to allow the light rail train to move more efficiently.

As the age of infrastructure reaches its intended lifespan, it contributes to added safety and operational concerns at MBTA. Additional focus on maintenance is required to ensure that safe operations continue. Each city in which MBTA operates is responsible for the installation, maintenance, and repair of street crossing signals. MBTA has excellent relationships with the jurisdictions through which their trains pass. However, the unavoidable communication delays and budgetary and scheduling constraints related to necessary changes may occasionally contribute to increased risk.

Technologies and other Safety Applications

As noted, MBTA is one of the oldest transit systems in the US, with horse car on rail segments built as early as 1856, long before many of the roads and buildings currently along or adjacent to the track were built. Therefore, the nature of most crossings does not allow installation of automated barriers or traffic signals. In an effort to maintain low accident rates, the agency continues to implement safety applications that demonstrate a proactive approach to safety.

MBTA is in the early stages of installing a system called Green Line Train Protection (GLTP), which is designed to improve train-on-train protection requirements, signal enforcement (block, interlocking, speed, distance), train-on-train enforcement (signal and separation), over-speed derailment protection at high-risk locations, and switch enforcement. To protect work zones and roadway workers, MBTA uses Protran's worker protection system, which is intended to decrease braking time and braking distance while improving operational safety and is being integrated into the existing system. In addition, MBTA is increasing the track circuit frequency from 25 hertz to 100 hertz on the Green Line.

Another important success is the installation of fencing that divides the tracks in opposite directions, preventing pedestrians from crossing the tracks in unintended areas (Figure 3-31). Installation of fencing stemmed from reported close calls obtained through MBTA's close-call program. The installation of the fencing has lowered the pedestrian close-call rate and eliminated all train-pedestrian collisions since its implementation. The Safety Department created a form that operators carry with their daily paperwork on which they can report concerns or close calls such as hard braking due to pedestrians on the tracks. Operators can return this form to the agency anonymously or directly if they desire follow-up communication. The agency has anecdotally noted that this system is successful.

Photo credit: TTCI

Figure 3-31 *Fence separating tracks in opposite directions*

Other Modifications or Procedural Actions

There appeared to be minimal physical mitigation implementations for collision avoidance in high-risk locations such as crossings, aside from typical traffic and pedestrian signaling and signage. Signage encouraging pedestrians to look for trains at pedestrian crossings has been installed (Figure 3-32), and most pedestrian crossings are painted yellow to increase their visibility, especially at night (Figure 3-33).

Photo credit: TTCI

Figure 3-32 *Pedestrian signage*

Photo credit: TTCI

Figure 3-33 *Typical pedestrian crossing*

MBTA's comprehensive policies and procedures significantly reduce accident rates. As the operating environment limits structural modifications and implementation of new technologies, MBTA developed procedures and an extensive training program that have effectively improved safety, as reflected in the reduction of collisions. The low-speed limit implemented at the platforms (Figure 3-31), stops, and intersections, procedures focused on improving operator alertness, and a mature safety culture dedicated to preventing occurrences rather than reacting to events all contribute to the low collision rates.

Photo credit: TTCI

Figure 3-34 *MBTA platforms*

Successes

As noted, MBTA credits its policies, procedures, and training program for the low accident rates between 2007 and 2017. Another important success is the installation of fences that divide the tracks in opposite directions, preventing pedestrians from crossing over the tracks. In addition, public campaigns and outreach programs implemented in schools and churches also have produced favorable results in terms of lowering accident rates and increasing customer service satisfaction. Twice per year, the agency installs public information kiosks in strategic parts of the city, including underground stations, to promote the system and educate customers on transit safety topics such as boarding, alighting, trespassing, and use of wireless devices while waiting on the train; MBTA also visits schools and churches for the same purposes. MBTA reported that its outreach program has contributed to lower accident rates between trains and pedestrians and increased customer satisfaction.

Metropolitan Transit Authority of Harris County – Houston METRO (Houston, Texas)

General System Information

The Texas State Legislature authorized the creation of local transit authorities in 1973. In 1978, Houston-area voters approved the creation of METRO and approved a one-cent sales tax to support its operations. METRO opened for business in January 1979 and provides bus, METRORail light rail lines, and METROLift complementary paratransit services. METRORail consists of three light rail lines; the Red, Green, and Purple lines have 22 miles of rail to serve the greater metropolitan area of Houston. METRO'S light rail fleet consists of 76 vehicles. The Red Line opened in 2004 as the Main Street Line and is 12.6 miles long; it carries 55,000 passengers daily, making it one of the nation's most traveled lines, based on passenger boardings per track mile. The Purple Line (6.7 miles) and the Green Line (3.2 miles) opened in May 2015. The 2017 NTD agency profile for Houston METRO's light rail service is as shown in Table 3-4.

Table 3-4 *Houston METRO Operational Characteristics*

Annual Passenger Miles	52,480,736
Annual Train Revenue Miles	2,077,909
Annual Unlinked Passenger Trips	18,532,122
Vehicles Operated Maximum Service	54

Operational Characteristics (Operating Hours, Types of Service Provided, etc.)

METRO operates three light rail lines. The legacy Red Line opened in January 2004 and services 25 stations along the route. The system grew with addition of the Green and Purple lines in May 2015. The Green Line has nine stops, and the Purple Line has ten stops, four of which are shared between the Purple and Green lines.

METRO'S rail lines operate with slight line variations from 3:30–1:40am during the week and 4:30–2:40am on weekends. The frequency of the light rail service varies from 6-minute headways during peak travel times to 20-minute off-peak headways.

The system is constructed almost entirely at-grade with street level, with both dedicated and shared lanes with vehicular traffic in densely-populated areas. METRO is an open system; persons on the track are not defined as trespassers.

With an open system and 10–13 crossings per operating mile, the system has inherent system-wide safety risks.

Allowable maximum speeds can vary depending upon location. In most areas where there is high pedestrian and vehicular traffic, this speed is 25 mph; in other locations where the system operates on exclusive right-of-way with gated crossings, maximum speeds reach 40 mph. Figure 3-35 shows a common track configuration, particularly along the Red Line, which consists of two parallel tracks located along street medians with median platforms intermittently placed between the tracks for patron train access. METRO employs approximately 150 train operators, most of whom have fewer than three years of train operating experience.

Photo credit: TTCI

Figure 3-35 *Common track configuration*

Operator Qualifications and Training

METRO uses the Smith System© for training, which provides all trainees with documented training requirements and outlines the rules, policies, and conditions that apply to light rail train operators. At the onset of training, trainees must confirm by signature they understand what is expected of them. New operators must complete a comprehensive 10-week training program in which they receive 120 hours of classroom study, 56 hours of basic vehicle troubleshooting, experience operating in the yard, shop training, and 20 hours of driving on the rail line with line supervisors. They subsequently move to revenue service where they are required to obtain 60 hours of OJT with a veteran operator. Upon completion of OJT, trainees are sent back to the classroom for review and final exams. METRO consistently strives for continuous improvement, and each trainee is tasked with evaluating the training course and instructor upon completion of the training program. These evaluation responses are used to improve future training.

METRO recognizes the importance of refresher training as well, and biennial refresher training is required for each light rail operator. Performance evaluations are completed after initial or biennial recertification training. Each operator also is assessed quarterly, including ride checks of at least six stations. With the recognition that operator ride checks are a necessary task required to ensure that operators perform their duties in a safe and compliant manner, METRO conducts routine ride checks in addition to quarterly and re-certification ride checks.

METRO representatives noted the value in using videos from their train-based camera systems for training curriculum. With all stations and trains outfitted with video surveillance cameras, video footage of close-call and collision events is easily accessible. METRO also uses close-call footage in its public outreach efforts.

Accident/Incident Management

METRO is working to stay ahead of the safety compliance curve and is in the process of transitioning its System Safety Program Plan (SSPP) into a Public Transportation Agency Safety Plan (PTASP) in accordance with FTA's SMS framework and recently released PTASP final rule (49 CFR Part 673), which is more holistic and predictive as opposed to reactive. To support these efforts, METRO is adding an SMS Manager whose sole responsibility will be SMS development, implementation, and sustainability.

When a collision/incident occurs at METRO, an alert is initiated, and METRO Police and field supervisors respond. Once onsite, METRO Police conduct an investigation, and field supervisors send operators for post-accident drug and alcohol testing in accordance with FTA requirements. All investigation reports must be completed within 30 days of an event. Passenger statements are collected only from passengers who were injured. A Ruling of Preventability is determined through METRO'S Safety Team, which then submits a letter stating the preventability ruling. If a Corrective Action Plan is required, the Safety Team discusses the plan with the parties involved and the plan in finalized.

Safety Trends

Houston METRO experienced a 40% increase in all incidents from 2013 through 2017, which corresponds with expansion of the legacy Red Line in 2013 and addition of the Green and Purple lines in 2015. Additionally, in February 2017, the newly-added Green Line was extended, dramatically increasing the service area. This expansion correlated with a 39% increase in light rail ridership from January 2013 to April 2018 (just prior to research team site visit). With nearly equal increases in ridership and incidents, the rate of incidents per rider has been constant over time. However, because of the increase in total incidents, METRO dedicated significant manpower and funding to reduce the number of safety-related incidents and holistically improve system safety. The agency is dedicated to making its community safer for all modes of transportation.

METRO representatives indicated that the most common collision type is related to turning vehicles. An analysis of the agency's incident database revealed that since the inception of its light rail system in 2004, 43% of all incidents were related to turning vehicles, with left-hand turns across tracks being particularly troublesome. In total, 24% of all incidents were attributed to red signal violations by other vehicles. Additionally, fouling (object/person interfering/trespassing on rail right-of-way) and pedestrian incidents accounted for 14% and 11% of total incidents respectively, as shown in Figure 3-36.

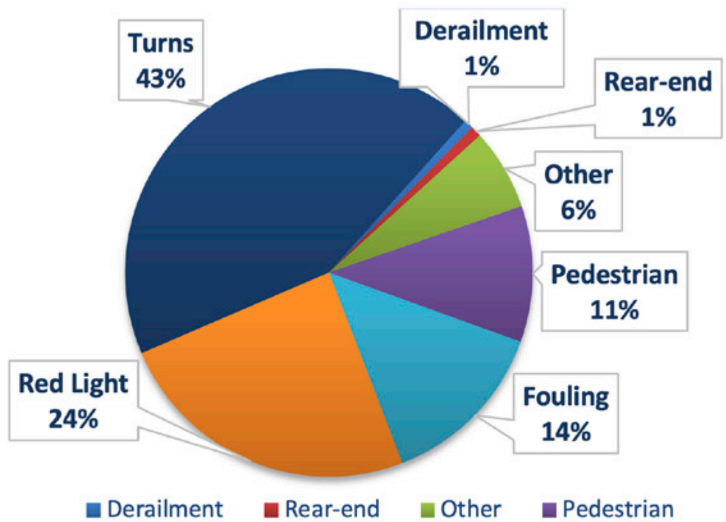


Figure 3-36 *METRO incidents by type, 2004–2017*

Figure 3-37 shows the number of incidents by month for 2015–2017. Although there were more incidents occurring in June 2015, there was variability for the years that follow, with the majority of events in 2016 occurring in May and in 2017 in January. Although service and incidents both increased at METRO from 2013 through 2017, it is notable that for 2015–2017, the trend decreased.

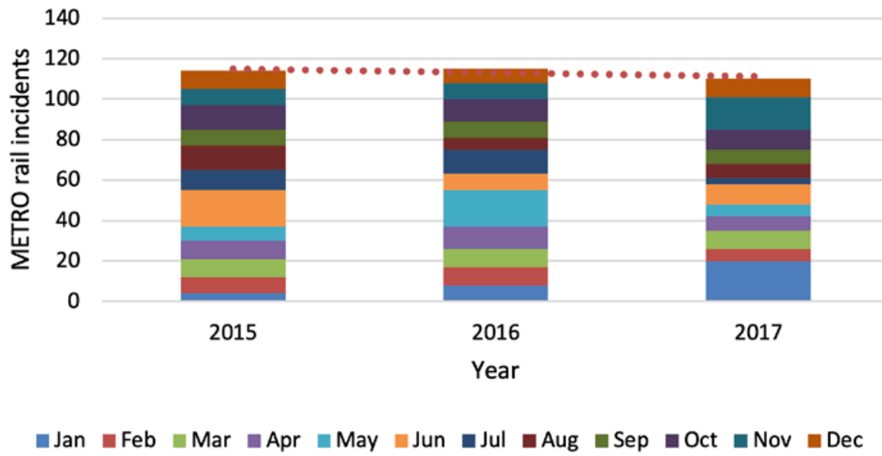


Figure 3-37 *METRO incidents by month, 2015–2017*

Areas of Concern

Approximately three of METRO's 23 light rail system track miles are shared-use lanes, which present additional challenges. Shared-use lanes, including those in the Medical District, accounted for 35% of all of METRO's light rail collisions since May 2015, many of which were with personal vehicles at these shared-lane locations. Among these POV collisions, the most common involved vehicles turning into the train path. More specifically, turning incidents were usually left-hand turns. Given the common median track configuration, vehicles making left-hand turns need to cross the track. In locations where it is a legal turn, the left-hand turn lane is sometimes shared with the train, as shown in Figure 3-38.

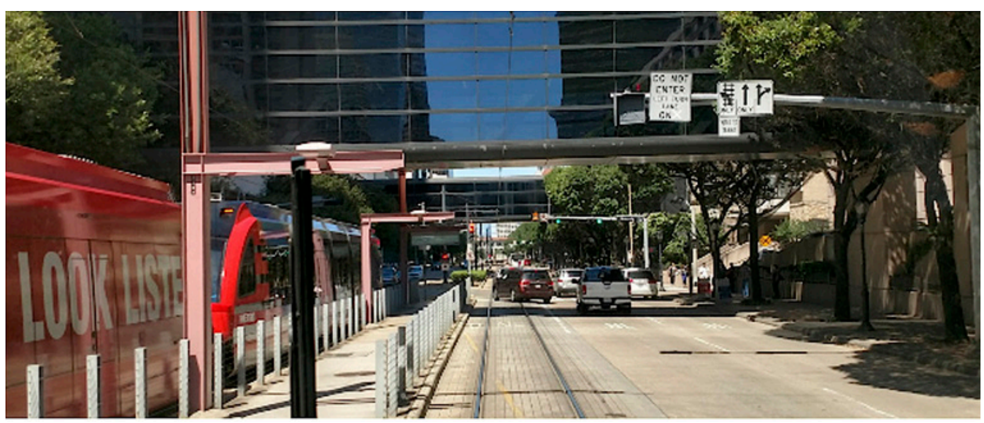


Photo credit: CUTR

Figure 3-38 *Shared left-turn lane*

Many METRORail collisions are with personal vehicles. Among these, the most common involves vehicles turning into the train path, usually left-hand turns. Given the common median track configuration, vehicles making left-hand turns need to cross the track. In locations where it is a legal turn, the left-hand turn lane is sometimes shared with the train, as shown in Figure 3-38.

Another left-turn situation involves a non-shared left-turn lane. In this configuration, the train may strike vehicles attempting to make a left turn from the adjacent lane. This occurs at intersections where it is both legal (with signaling) and illegal (without signaling) to turn left at the intersection. Figure 3-39 and 3-40 are examples of both situations. "Turtleback" delineators are used to prevent vehicles from encroaching upon the rail in these areas.

Photo credit: TTCI

Figure 3-39 *Legal left turn from adjacent lane*

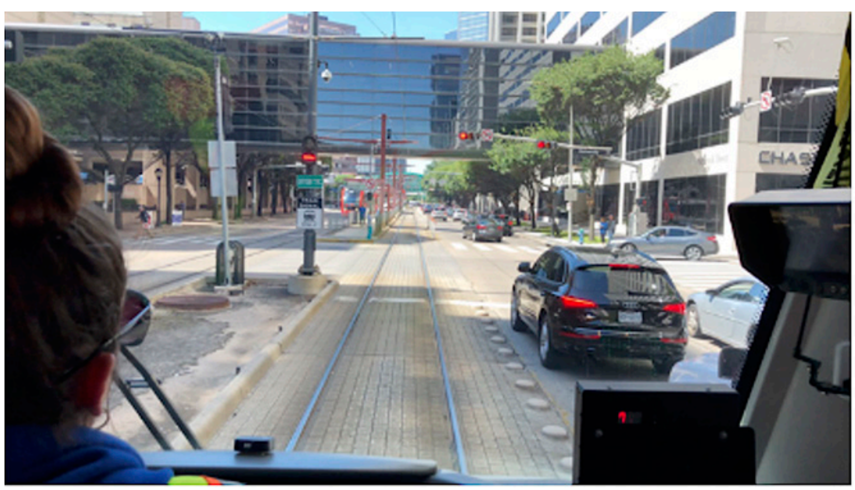


Photo credit: TTCI

Figure 3-40 *Illegal left turn from adjacent lane*

The Red Line that operates in the Medical District presents unique challenges for the agency. Emergency vehicle traffic, substantial pedestrian volumes, and personal vehicle drivers present light rail operators with challenges. METRO, at least partially, credits its thorough and ongoing operator training that focuses on defensive driving and anticipating actions with the successful 13% reduction in incidents along this corridor since 2015. METRO does not rely solely on training to improve system safety. In this section of track, METRO is also piloting a Bluetooth Proximity Alert System (BPAS) technology to alert pedestrians when a train is approaching (Figure 3-41). This system is activated by a Bluetooth beacon on the train when it approaches and begins audible English and Spanish messages that warn pedestrians of an approaching train with an intermittent bell sound. However, it is also activated as the train leaves because there is a Bluetooth beacon at both ends of the train, which potentially causes confusion about whether a train is approaching or departing the area.

Photo credit: TTCI

Figure 3-41 *Bluetooth-enabled audio warning device*

It is important to note that after collisions, a Ruling of Preventability is determined by METRO's Safety Team, which then submits a letter stating the ruling. If a Corrective Action Plan is required, the Safety Team discusses the plan with the parties involved and the plan is finalized. Houston METRO reported to the research team that most METRO collisions are non-preventable.

Houston hosted the Super Bowl in 2017, and the resulting influx of visitors to the area was significant. There were extreme challenges throughout the time leading up to, during, and following the event, including unprecedented pedestrian crowds and vehicular traffic in METRO's service area.

Technologies and Other Safety Applications

METRO uses magnetic train stop technology, which automates a forced stop if a train operator runs a red signal. This technology was implemented to prevent train-on-train collisions. It also uses various high-visibility signage, lighting, and blank-out signs to alert motorists and pedestrians of train traffic, as shown in Figures 3-42 and 3-43.

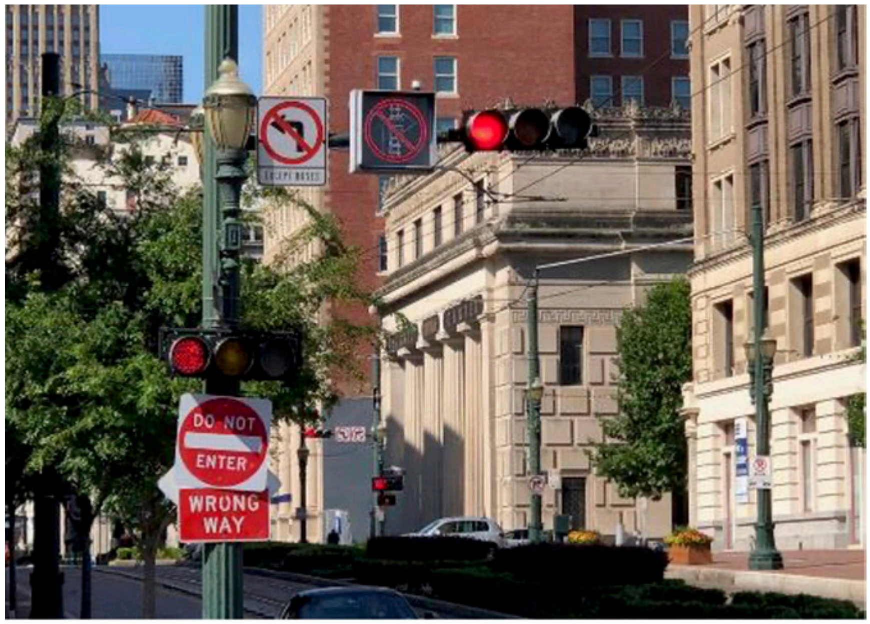


Photo credit: TTCI

Figure 3-42 *Traffic signaling no right turn as train approaches*

Photo credit: TTCI

Figure 3-43 *Traffic signaling no left turns permitted*

METRO is in the process of installing fencing along the midtown corridor at all rail stations and around all adjacent parks, as shown in Figure 3-44. This fencing is used to delineate separation between vehicular traffic lanes and light rail track lanes and to deter pedestrians from crossing into undesirable areas. By making pedestrian crossing more difficult, the fencing allows for the channelization of pedestrian traffic to the safest crossing areas, where light rail operators are more vigilant and expect pedestrian traffic. METRO has also implemented fencing around school zones to encourage safe behavior, as shown in Figure 3-45.

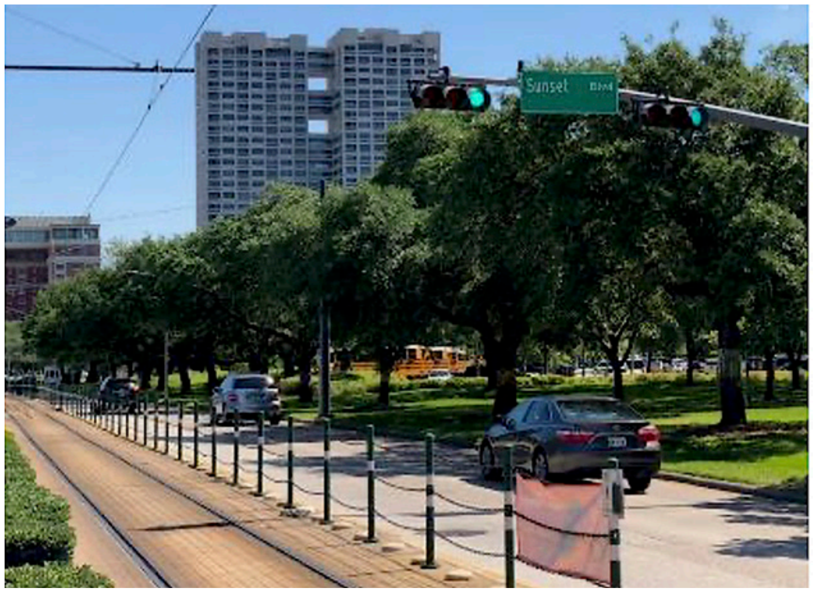


Photo credit: TTCI

Figure 3-44 *Fencing along METRO light rail line*

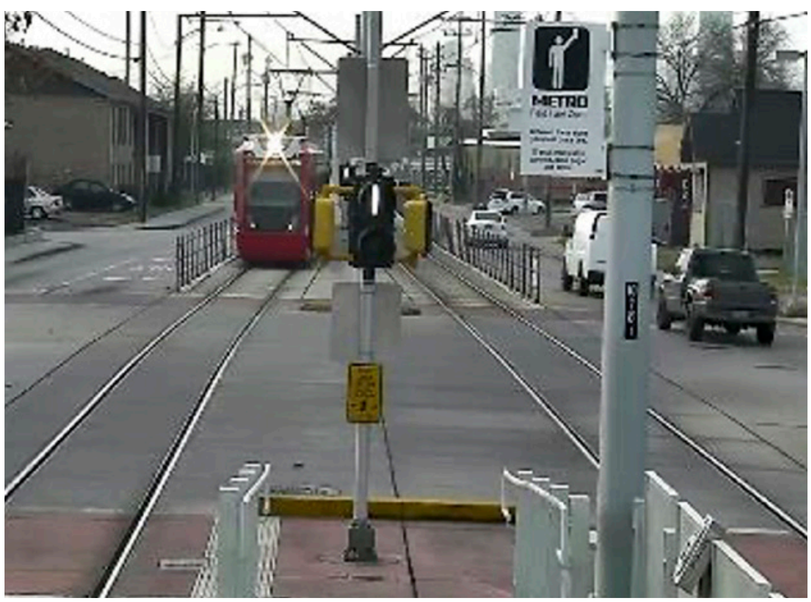


Photo credit: Houston Metro

Figure 3-45 *Fencing around school zone*

In 2009, METRO started an initiative to add a light-emitting diode (LED) red outline backplate lighting to the outer frame of signaling for red traffic signals. The outer frame light illuminates during train approach and augments the red traffic signal, as depicted in Figure 3-46. This initiative was put in place to combat red-light signal violation collisions by personal vehicles with light rail vehicles. The additional red lighting around the signal mitigates other visual background lighting. The 2009 initiative has proven to be successful enough to encourage METRO to procure additional LED backplate traffic signals in 2018.

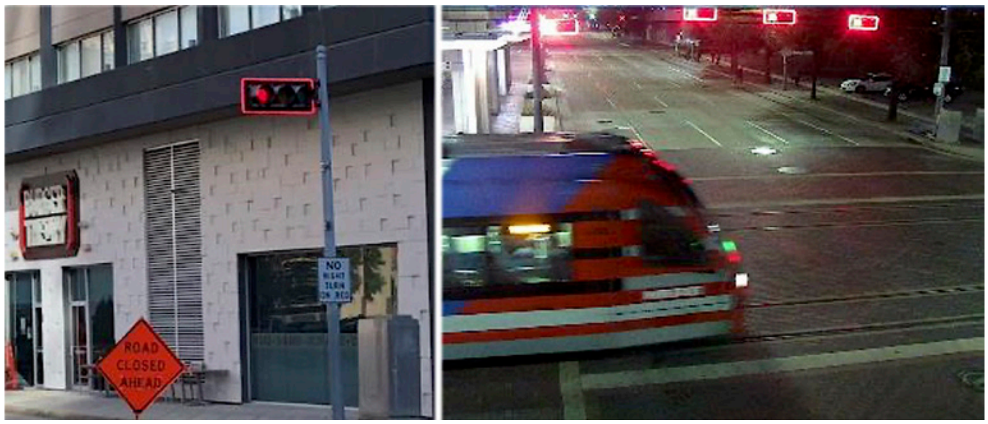


Photo credits: TTCI (left), Houston METRO (right)

Figure 3-46 *Red Light Enhancement Initiative*

In the Medical Center area along METRO's light rail line, there was a test initiative to reduce left-turn and red-light-related collisions with personal vehicles. Part of the initiative included the installation of embedded lighting along intersections that would illuminate red when crossing was prohibited. Although the lighting was prominent from dusk to dawn, most crashes occur during the day when sunlight washes out the embedded lights. Additionally, maintenance of the embedded lighting was difficult, and water was impossible to keep out. The lighting ultimately was not reliable, and maintenance was discontinued. METRO described this use of embedded lighting as an unsuccessful initiative.

METRO is procuring and installing cab-mounted inward-facing cameras that will improve incident investigations. Light rail vehicles already possess forward- facing cameras. As noted, all METRO stations are under constant video surveillance.

Much of METRO's safety improvement successes are due to a willingness to try new applications and test ideas using pilot initiatives. If initiatives prove to be successful, they are implemented further. METRO shares lessons learned and encourages new approaches. The support the Safety Team receives from accountable executives at METRO is undeniable and evident in day-to-day operations.

Other Modifications or Procedural Actions

METRO is in the process of drafting, designing, implementing, or procuring many new safety initiatives, including reconstruction of problem intersections, installation of quad-gates at one unsafe intersection, re-design and construction of other installed traffic signal arm gates, re-timing and re-coordination of traffic signals, and more. Also, the agency has improved crossings using high visibility pavement markings, as shown in Figure 3-47.

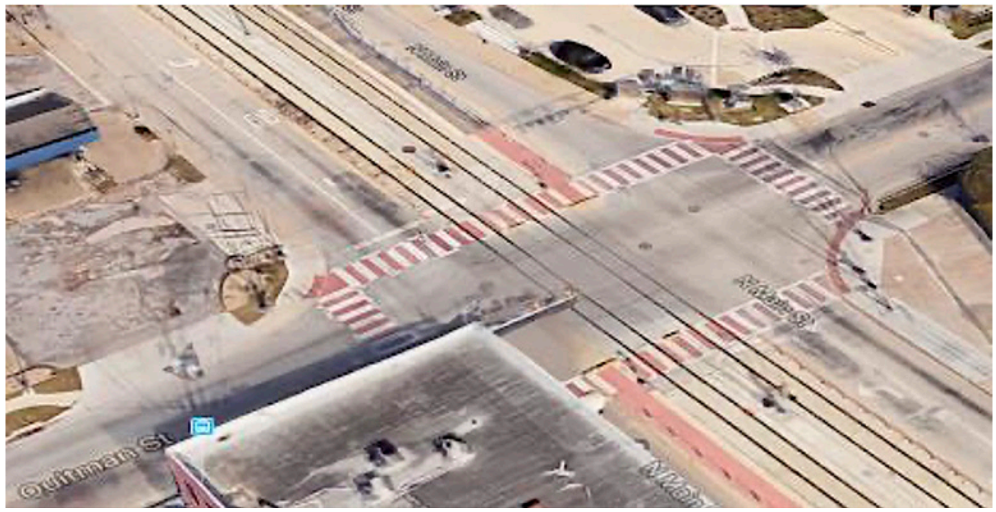


Photo credit: Houston METRO

Figure 3-47 *High visibility pavement markings at crosswalks*

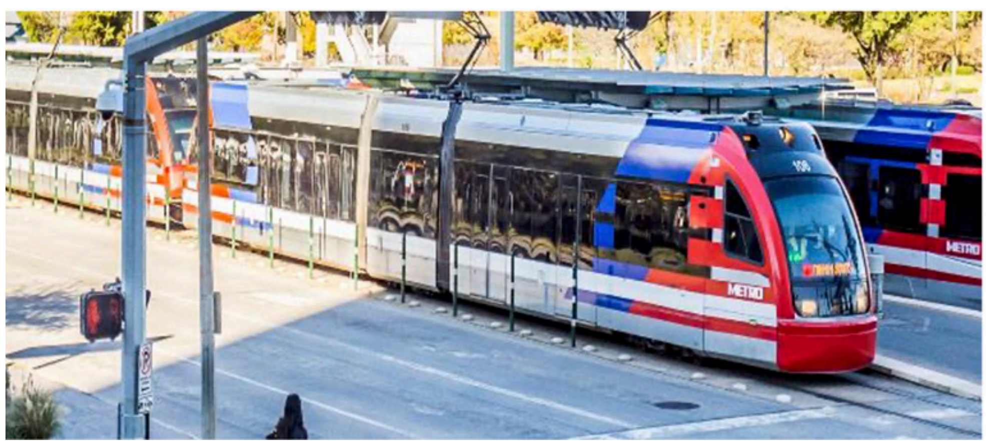


Photo credit: Houston METRO

Figure 3-48 *METRO light rail vehicle wraps*

METRO is also implementing the Japan-innovated industrial safety method known as “shisa kanko” (point and call). This method is a safety standard used in Japan’s railway system and other countries and requires the train operator to point and call out safety warnings and signals. For example, train operators and platform attendees point at and vocalize the meaning of rail safety signals and timetables as they stop at a station, indicating the speed and signals at the station, pointing at surveillance monitors, and other actions.[23] This pointing method has been credited for the reduction of workplace errors through a physical (pointing) and vocal (calling out) technique, which raises the consciousness of operators. This implementation is in the demonstration phase.

METRO implemented an extraordinary public safety campaign that highlights the nationally-acclaimed "Think Rail" program. Prior to the new light rail lines being tested at METRO, the Safety Team was challenged with educating Texas students on rail safety. In-school safety lessons and educational materials were provided to all students who attended schools located within a half-mile of a track alignment; students who attended schools outside the half-mile radius were provided with educational materials and parent education presentations. Through this program, METRO reached more than 33,000 students at 46 schools and over 2,000 children at 32 daycares/after-school programs. In addition, METRO safety professionals presented at more than 100 Parent/Teacher Organization meetings and provided training for crossing guard supervisors.

The agency's safety outreach is not limited to schools. METRO remains active in its community, with safety representatives spreading their message to "think, look, and listen" around rail at community meetings, neighborhood events such as YMCA Healthy Kids Day, the Cesar Chavez Parade, and talks at public libraries and the Children's Museum Free Family Night. METRO also partners with Girl Scouts and Boy Scouts to provide the opportunity to earn light-rail safety patches and railroad merit badges. METRO also includes adults in its outreach campaigns, partnering with the University of Houston, Houston Parks and Recreation Department, the Harris County Tax Collector, etc. To highlight the dangers associated with risky behavior around the light rail lines, METRO also releases videos of close-call incidents to local media outlets with the safety message to "stay alert, stay alive."

Successes

METRO's community outreach is very impressive; it has advertisements in medical facilities and its Operation Lifesaver Team consists of eight individuals who focus on outreach to schools. Through the efforts highlighted, METRO has educated tens of thousands of members in its community to think safety when they think rail.

[23] https://www.youtube.com/watch?v=9LmdUz3rOQU.

METRO has implemented many safety improvement technologies and training initiatives to reduce incidents and mitigate the severity of incidents that occur. Not all initiatives work as envisioned, and it is valuable to understand what did not work and why in addition to what is working. The embedded road lighting was not as successful due to maintenance issues. However, adding an LED red backplate light to the outer frame of red traffic signals was successful in reducing red light violations, resulting in the installation of more LED red backplate lighting. Additionally, fencing has been successful in deterring pedestrian movement across the tracks.

When asked to provide guidance to transit agencies establishing new light rail lines, advice from METRO was to avoid shared lanes. Although shared-lane intersections only account for 17% of total light rail intersections, 2.3 shared-lane intersection collisions occur for every 1 collision at non-shared intersections. The disproportionate share of collisions and near-misses that occur at intersections with shared lanes corroborate METRO's advice to avoid similar designs when possible.

Los Angeles County Metropolitan Transportation Authority (Los Angeles, California)

General System Information

LA Metro was formed in 1993 through a merger of the Southern California Rapid Transit District and the Los Angeles County Transportation Commission. Metro is governed by a 13-member board of directors that includes five Los Angeles County supervisors, the mayor of the City of Los Angeles, three mayoral appointees, four City Council members from cities other than Los Angeles, and one non-voting gubernatorial appointee. LA Metro serves an area with a population of over 9.6 million with transit bus, light rail, heavy rail, and BRT and is the third largest public transit provider in the US. Security and law enforcement services on Metro property (including buses and trains) are provided by the Los Angeles County Sheriff's Department's Transit Services Bureau via contract, in conjunction with the Metro Transit Enforcement Department, the Los Angeles Police Department, and the Long Beach Police Department. Metro has four light rail lines—Blue Line, Green Line, Gold Line, and Expo Line. The 2017 NTD agency profile for LA Metro's light rail service is as shown in Table 4-5.

Table 3-5 *LA Metro Operational Characteristics*

Annual Passenger Miles	427,260,143
Annual Train Revenue Miles	6,272,460
Annual Unlinked Passenger Trips	62,085,975
Vehicles Operated Maximum Service	161

Operational Characteristics (Operating Hours, Types of Service Provided, etc.)

LA Metro is a multimodal agency with rail operations that include light rail and heavy rail. The system has six rail lines, four of which are light rail lines that operate along 88 miles of track, and two that are heavy rail lines that operate along 17.5 miles of track. The six lines include:

- Blue Line – oldest light rail line, built in 1990
- Green Line – light rail line on fully exclusive right-of-way
- Gold Line – light rail in street running environment
- Expo Line – light rail system that goes to Santa Monica beach
- Red and Purple lines – heavy rail, running fully underground

LA Metro complies with the hours-of-service regulations issued by the California Public Utilities Commission (CPUC), allowing operators to operate trains a maximum of 11 hours and 40 minutes daily; CPUC regulations allow operators a maximum of 12 hours of train operation.

The maximum allowable light rail operating speed is 55 mph on exclusive right-of-way, and the maximum speed on street running service is 35 mph. Metro staff indicated that it is difficult to consistently sustain the 35-mph speed because of the proximity of stations and having to stop trains at the intervening street intersections, which typically do not have full pre-emption. The speed approaching platforms and intersections varies along the system and is regulated by Automatic Train Control (ATC) in areas that have a cab signal system.

Operator Qualifications and Training

LA Metro employs 375 full-time train operators. New operators are selected from the bus operator pool using evaluation criteria from their bus operator record review to ensure that criteria are applied consistently to all applicants. Metro reserves the right to pro-rate operators with fewer than 36 months of working time in all categories to maintain a fair scoring ratio. That 36-month period is extended for any leave of absence. To be considered as a train operator, candidates are evaluated on many criteria, including absences, tardiness, rule violations, major rule violations, avoidable accidents, suspensions, formal hearings, and customer complaints.

Operators are screened by seniority and notified of the results in writing. Successful candidates are subsequently invited to participate in the physical agility phase. Train operator initial training is nine to ten weeks and comprises three weeks of classroom instruction and six to seven weeks of route training. Students first operate trains with certified instructors and no passengers for at least ten hours. Upon satisfactory completion of this phase, the candidate transitions to revenue service operation with a certified line instructor until they are qualified to operate the train unsupervised. Classroom instruction generally hosts 25 students using two to three instructors, resulting in a ratio of 8–12 students per instructor.

LA Metro has annual mandatory refresher training, with at least four hours dedicated to safety-related topics. Refresher training is also provided for Quarterly Proficiency Line Rides (on the revenue route operated) and for return to duty for one to two days of training after being off duty 60–90 days and one to three weeks of training after being off duty for more than 90 days. Remedial training is mandatory after each preventable/unpreventable accident and must be completed before the operator can be scheduled for active service.

Accident/Incident Management

LA Metro defines accidents and incidents in accordance with 49 CFR Part 674 as mandated by FTA. The agency reports events that meet the thresholds defined by regulation to the CPUC and the State Safety Oversight Agency.

LA Metro has a Collision Investigation Team (CIT) comprising four full-time professional accident investigators tasked with responding to major incidents involving Metro Bus, rail, and non-revenue vehicles (NRV); they are available to perform investigations 24 hours per day. CIT members are required to have a law enforcement background in accident investigation and reconstruction and to successfully complete Transportation Safety Institute (TSI) courses in accident investigation (for both rail and bus). This team does not determine preventability; it gathers all facts and evidence and conducts interviews of persons involved in the accident.

Metro also has an Accident Review Board that performs up to three tier reviews to determine preventability. The first review tier consists of a three-person board that includes the Transportation Director (or assistant), the Transit Operations Supervisor, and a Line Instructor. The second tier is the Appeal Board, which consists of a division management representative who is not on the first-tier board, a Union (SMART-TD) representative, and an Accident Review Officer (designated by the Chief Labor Relations Officer). In the event the case reaches arbitration, it is submitted to an independent safety specialist. The third tier is the arbitration process, which is binding on all parties.

LA Metro has established local safety committees at each facility that meet monthly to discuss specific safety and security trends and topics. The agency's close-call program is comprehensive and effective. LA Metro's SAFE 7 form is used by employees to report any type of hazardous conditions or near-miss incidents. Once the form is completed, it is submitted to the immediate supervisor, who provides a written answer on the same form, and returned to the employee who reported the hazard/near-miss. In cases where resolution of the identified issue is beyond supervisor responsibilities, the form is submitted to management for resolution. If necessary, copies of the completed forms are also submitted to the safety department for follow-up and resolution.

Safety Trends

LA Metro representatives identified three major safety trends on the light rail system—vehicles colliding with oncoming trains, pedestrian collisions, and suicides. Most occur on the Blue Line, which is the oldest light rail route with the most recognized safety challenges. Figure 3-49 shows the incident rate per 100,000 train miles by light rail line. For this analysis, actual train miles were used as the denominator, including miles accrued during pre-revenue operation before extensions were open to the public. Although the Blue Line has the highest incident rates among LA Metro light rail lines, a decreasing trend is shown in data from 2011 and 2017, indicating a safety improvement. The Gold Line accident rate trend also slightly improved, and the Expo and Green lines experienced slight increases in reportable incident rates. The low reportable incident rate on the Green Line is attributable to its exclusive right-of-way operating environment.

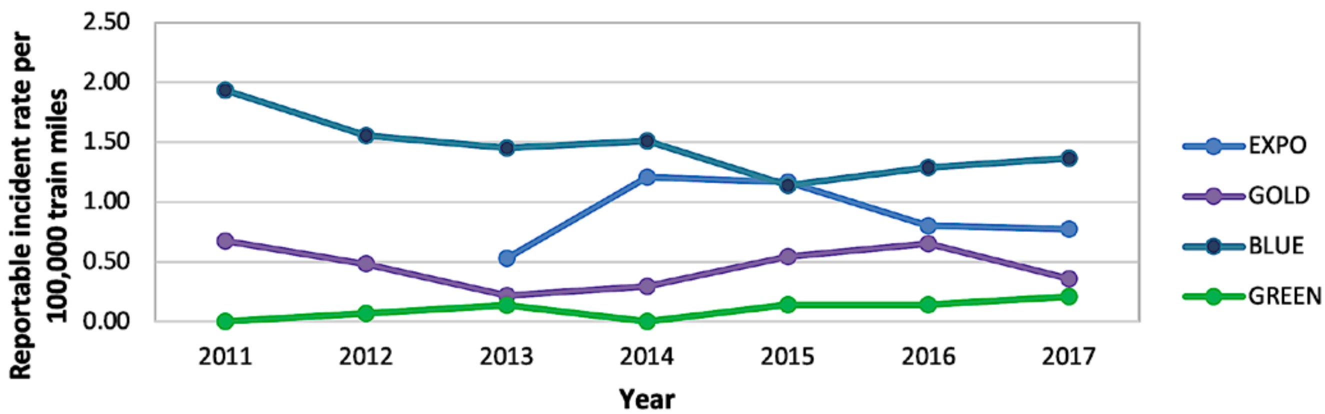


Figure 3-49 *CPUC reportable incident rate per 100,000 actual train miles, FY 2011–2017*

Focusing on reportable incidents involving personal vehicles and pedestrians by light rail line, data reveal that more than half (54%) of all reportable incidents occur on the Blue Line, as shown in Figure 3-50. Accidents between personal vehicles and trains are mostly attributable to illegal left turns across the track. The Blue Line poses the greatest system risk due to the number of grade crossings where left turns are permitted. The agency is mitigating the issue by conducting a pilot project that involves the installation of a gate for the left-turn lane.

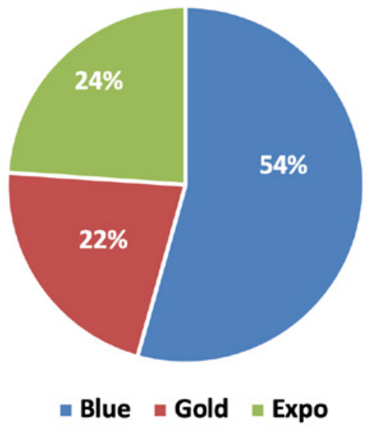


Figure 3-50 *Reportable auto plus pedestrian incidents by light rail line, 2017*

Suicides are the other most concerning trend identified by LA Metro and are increasing, with nine cases from 2014 through 2017 and many other cases of attempted suicide. The agency has established a suicide prevention program to mitigate this issue.

Areas of Concern

A major area of concern, as noted, is illegal left turns made by personal vehicles. To combat this, LA Metro has installed photo enforcement cameras and left-turn gates as a pilot to prevent the illegal vehicular movement.

Street-running grade crossings along the Blue Line are another area of concern due to the reduced space available to install gates and other safety devices. The crossings in these locations are signalized, using traffic lights for motorists, train signals for train operators, and active and passive signage and signals for pedestrians and motorists. LA Metro grade crossings are evaluated during the environmental and design phases. The agency uses a Board-adopted Grade Crossing Safety Policy for Light Rail Transit to determine which crossings can be operated at-grade and which may need to be grade-separated. An *ad-hoc* committee composed of safety personnel, operation personnel, CPUC members, City and County representatives, and other affected parties further evaluates the crossings by conducting field evaluations of proposed grade crossings to identify potential safety issues and incorporate mitigation strategies in their design. LA Metro uses the principle of "three E's" of safety— Engineering, Education, and Enforcement—in the design of all grade crossings.

Another concern LA Metro representatives highlighted during the onsite visit was "second-train incidents," where people are focused on catching a berthed train and encroach upon the track without paying attention to another train coming in the opposite direction. The same scenario occurs with turning personal vehicles watching one direction and encroaching upon the track in front of an oncoming train from the opposite direction. Figure 3-51 shows examples of intersections where "second-train incidents" have the potential to occur. To address this concern, LA Metro has installed active LED "Look Both Ways" signs at most station locations in cab signaled areas, which consist of a graphic sign depicting a train symbol and an arrow that alternates direction from left to right whenever a train approaches the intersection, reminding pedestrians to look both ways before crossing the tracks.

Photo credit: TTCI

Figure 3-51 *Examples of two-track intersections along LA Metro's rail line*

Technologies and Other Safety Applications

LA Metro is proactive at identifying, analyzing, and mitigating safety issues and concerns and is piloting a new method to reduce collisions between left-turning personal vehicles and trains. This new method consists of installing a gate on the left-turning lane that prevents personal vehicles from entering the track while the train is approaching, as shown in Figure 3-52. The gate arm is interconnected with the traffic signal and is considered a supplemental warning system. The primary safety system is the traffic signal itself. Once the left-turn arrow changes to red, the gate lowers, blocking the lane. LA Metro has been tracking the effectiveness of the pilot; the gating system is expected to be incorporated into the standard design of the Crenshaw Line.

Photo credit: TTCI

Figure 3-52 *Left-turn gate arm*

LA Metro has established design standards for signalized grade crossings that consist of two- or four-quadrant gates for vehicles (Figure 3-53) and pedestrians (Figure 3-54) and swing gates that open toward the pedestrian, forcing them to step back to gain access to the crossing, which prevents pedestrians from running onto the track (Figure 3-55). Additional grade crossing elements include ringing bells, LED alternately flashing railroad signals warning of the approaching trains (Figure 3-56), signs indicating the prohibition of left-turn movements, and photo enforcement cameras. “Motorman lights” are also installed to warn operators if the gates are not operating properly, as shown in Figure 3-57. A flashing light means no problem. A steady light indicates that the gate is not functioning properly, and the operator needs to reduce speed, call the Rail Operations Control (ROC), and stop before entering the intersection.

With all incorporated grade crossing design standards, crossings are fully sealed from traffic when the train is approaching. LA Metro’s goal is to install this standard design at all intersections where possible. The agency recently spent more than $30 million on the Blue Line to install pedestrian gates and swing gates at all gated crossings to incorporate their design philosophy.

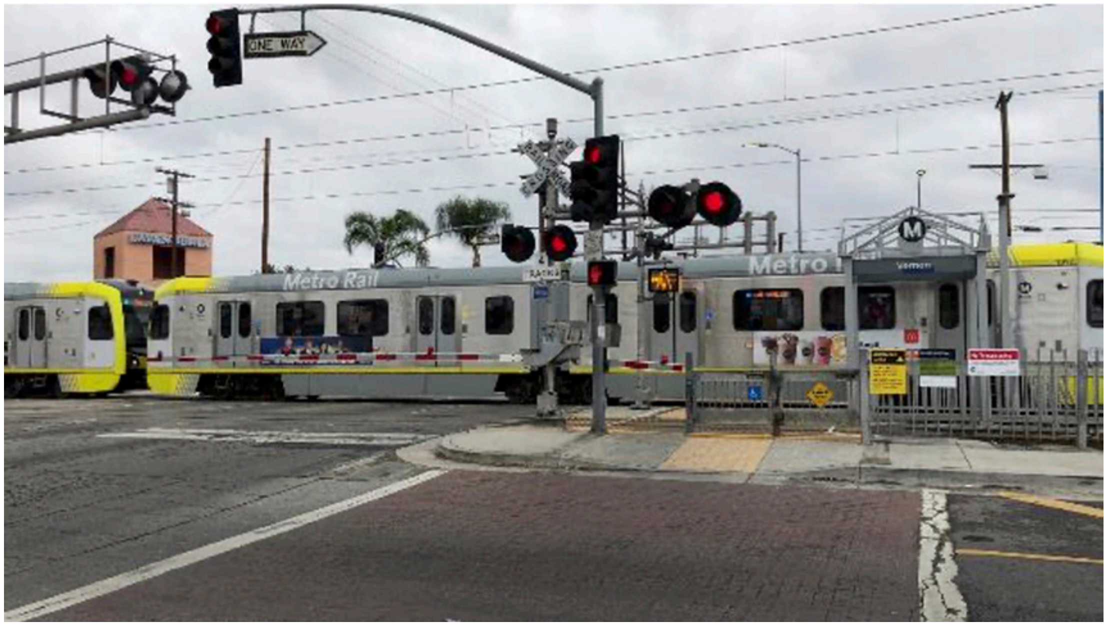


Photo credit: TTCI

Figure 3-53 *Two-quadrant arm gate*

Photo credit: TTCI

Figure 3-54 *Arm gates for pedestrians*

Photo credit: TTCI

Figure 3-55 *Swing-gate for pedestrians*

Photo credit: TTCI

Figure 3-56 *LED signals warning of approaching train*

Photo credit: TTCI

Figure 3-57 *Motorman signals*

Other Modifications or Procedural Actions

In addition to the left-turn gate pilot project, LA Metro employed internally-illuminated raised pavement markers (IIRPM) at certain crossings along the Gold and Blue lines as a pilot project to mitigate illegal left-hand turns. The IIRPMs can be installed where there is insufficient space to install a left-turn gate system. These red lights, which are installed parallel to the tracks, switch on when the train is approaching the intersection and provide an additional warning to personal vehicle drivers of prohibited left turns. The agency found these lights to be very effective and is evaluating the feasibility of expanding installation at additional locations. The IIRPMs are installed so they can be observed by motorists in the left-turn pocket lane, those who travel perpendicular to the tracks through the intersection, and by pedestrians who use the crosswalk and cross perpendicular to the tracks

Photo credit: LA Metro

Figure 3-58 *Internally-illuminated raised pavement markers*

In addition to safety interventions on the right-of-way, LA Metro trains have cameras in passenger areas and operating cabs. One camera is the cab faces forward, one is focused on the operator, and a third is part of the SmartDrive® system, which is triggered by a significant change in G-force (brakes, accelerations, etc.) and is in the process of being retrofitted on all railcars, saving a record 15 seconds before and 15 seconds after an event. These camera systems are used for commendations, discipline, and investigations of close-call incidents and accidents.

LA Metro trains are also equipped with Protran© worker protection technology. This secondary warning system alerts operators if workers are present on the track and alerts workers on the track when a train is approaching. The agency is monitoring the probable positive effects of this system because accident/incident data are not complete due to recent implementation.

Successes

LA Metro attributes several innovative programs and interventions collectively to its success in lowering its collision rate. The close-call program has proven effective through corrective action results; an example is the installation of fences to prevent pedestrians from crossing the track in undesired locations. These fences (Figure 3-59) were installed upon operator requests through the close-call program.

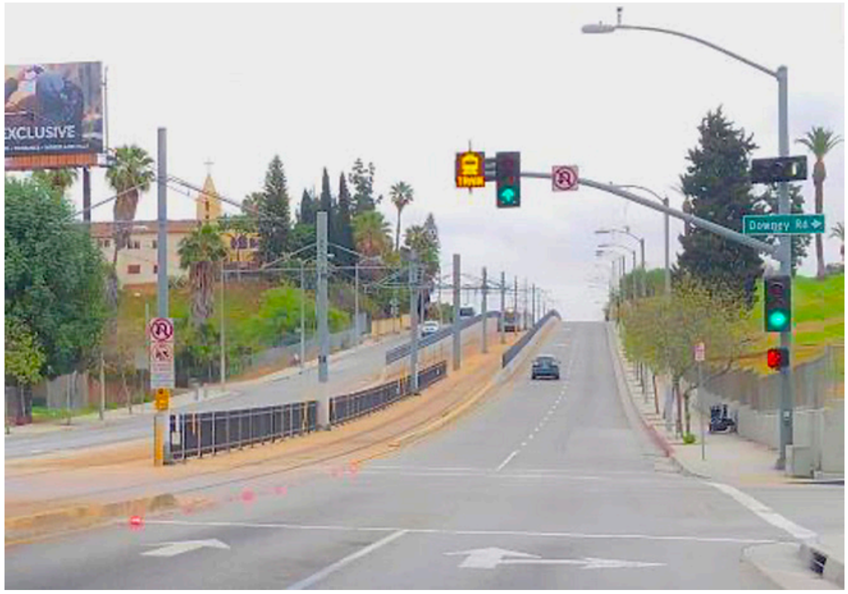


Photo credit: TTCI

Figure 3-59 *Fencing Installed to prevent pedestrian crossings in undesired locations*

LA Metro has a proactive and successful suicide prevention program. Each train station and all grade crossings have signs (Figure 4-60) indicating contact information for assistance, if needed. Based on accident trends, the agency installed signs at locations where individuals were observed to commit suicide, such as the end areas of platforms and at grade crossings. Metro also trained key personnel on behaviors that typically are exhibited by persons contemplating suicide and how to approach these individuals and offer assistance.

Photo credit: LA Metro

Figure 3-60 *Suicide Crisis Line signage*

LA Metro is also proactive in accident prevention. An innovative strategy is photo enforcement at grade crossings to deter unsafe behaviors by motorists. Most crossings are outfitted with cameras that take photos of vehicle drivers and license plates when motorists violate traffic and railroad signals. Each violation generates a $500 ticket that is issued and processed automatically by LA Metro, and the vehicle driver receives three points against their driver's license. LA Metro receives a portion of all fines collected to partially offset the cost of the program.

In addition to engineering efforts and enforcement programs, LA Metro has a comprehensive and innovative Metro Community Education (MCE) Department comprising 16 people who address rail safety through comprehensive, ongoing programs that focus on the three E(s) of rail safety. Within the MCE, the Transit Safety Program conducts safety presentations at schools within a 0.5-mile radius of all street-running Metro Lines (Blue, Expo, Gold, Crenshaw/LAX). It also conducts safety presentations at recreation centers, libraries, senior centers, and other community organizations within a 1.5-mile radius of street-running Metro Lines that are interested in learning about Metro. These safety presentations provide rail safety information and invaluable life skills that include ridership etiquette, trip planning, and security awareness. At the request of schools or community centers, the presentations are followed by a rail safety orientation tour, where participants are provided with hands-on travel training and further education about Metro's transit system. The program embeds itself in the community for the life of the line; staff also engage with the community continuously by participating at local community events. Metro's Community Education includes additional programs:

- **Rail Safety Ambassador (RSA) Program** – Retired Metro bus/rail operators are posted at key rail crossings and locations to observe and report safety behaviors of pedestrians and vehicles; they educate pedestrians on rail and pedestrian safety to help promote safe ridership.
- **Rail Safety Orientation Tour and Field Trip Programs** – This is a hands-on approach on how to use Metro and is offered to schools within a 0.5-mile radius of the Blue, Expo, Gold and Crenshaw/LAX lines. It is available to any school student (grades 1–12) in LA County once they successfully complete an e-learning curriculum.
- **On the Move Riders Program (OTMRP)** – This program is designed to bridge the mobility gap among older adults and persons with disabilities through educational presentations at senior centers and independent living facilities and at community events; it is facilitated by FTA Section 5310 grants, increasing the program's capacity to outreach to the five major regions of Los Angeles County (San Fernando Valley, San Gabriel Valley, South Bay, Gateway Cities, and Westside/Central).

- **Local Community Events** – MCE participates in local events to promote transit safety in and around Metro's operating system and to educate the public on the ease of using Metro.

MCE has worked on numerous safety campaigns, including the production of "Safetyville" videos, in which viewers take a trip to Safetyville to explore common safety-related issues in and around train tracks and stations. The series of six videos tackles issues such as running to catch a train, lack of attention while driving a car near tracks, and failure to follow posted safety instructions. The videos have been effective and well-received, reaching over four million people on YouTube since their launch. The videos have also received worldwide recognition and continue to garner attention on the agency webpage and at events.

MCE has also worked with the navigation software app Waze as a tool to inform a targeted group of drivers along the Blue, Expo, and Gold line rail alignment as they approach identified "problem" areas where vehicular violations are the highest. The campaign included generating safety messages as drivers approached specific intersections:

- "Heads up! Watch for trains."
- "Do not stop on train tracks."
- "Watch for trains when turning."
- "Never go around lowered gates."

MCE works very closely with other departments at LA Metro to develop new ideas to address important safety topics or issues. It also helps to communicate detours due to construction and educate older adults in their communities on how to ride the system safely. Future outreach focus will occur at middle schools and high schools and through digital announcements at gas stations and fast-food establishments.

An example of the success of the outreach program is how it addressed an increase in the frequency of people crossing the tracks illegally in a specific area, which was associated with Transportation Network Company (TNC) (e.g., Uber, Lyft) pick-up and drop-off locations. A field assessment identified that TNC drivers picked up and dropped off people adjacent to the rail right-of-way where there is no pedestrian crossing, thus forcing users to cross the track at that point. The department contacted Uber management to resolve the issue.

Southeastern Pennsylvania Transportation Authority (Philadelphia, Pennsylvania)

General System Information

The Southeastern Pennsylvania Transportation Authority (SEPTA) provides regional public transportation services via bus, heavy rail, commuter rail, light rail, and electric trolley services in an urbanized service area with a population of over 5.4 million, including Delaware, Montgomery, Bucks, Chester, and Philadelphia counties. SEPTA was created by the Pennsylvania legislature in August 1963 and is a State authority with a 17-member Board of Directors that includes representatives from the City of Philadelphia, the five counties in the service area, four legislative appointees, and a gubernatorial appointee. SEPTA's Transit Police Department has approximately 260 officers operating in seven patrol zones. The 2017 NTD agency profile for SEPTA's light rail and streetcar systems is as shown in Table 3-6.

Table 3-6 *SEPTA Operational Characteristics*

Annual Passenger Miles	62,557,838
Annual Train Revenue Miles	3,307,488
Annual Unlinked Passenger Trips	25,766,746
Vehicles Operated Maximum Service	121

Operational Characteristics (Operating Hours, Types of Service Provided, etc.)

SEPTA is a multimodal agency and has a light rail system with nine routes that serve over 120,000 riders per day. Six routes operate entirely within Philadelphia, including routes 10, 11, 13, 15, 34, and 36. One high-speed route, Route 100, operates on an exclusive right-of-way for most of the line and connects the 69th Street Transportation Center with Norristown Transportation Center, serving Delaware and Montgomery counties. Two inter-urban routes, 101 and 102, respectively connect Media and Sharon Hill to the 69th Street Transportation Center.

SEPTA light rail service operates across approximately 122.6 miles of track almost entirely at street grade on embedded track with dedicated and shared lanes. The maximum operating speed is 45 mph; however, due to the environment in which the system operates, the maximum operational speed is generally 25 mph. SEPTA's light rail fleet includes the following:

- Kawasaki Heavy Industries (1980–1981) – 141 cars (112 single and 29 double) (Figure 3-61)
- SEPTA Norristown N-5 by ABB Sweden (1993–1994) – 26 cars in total (Figure 3-62)
- President's Conference Committee (PCC II) car by St. Louis Car – 18 cars used exclusively on Route 15 Trolley Line (Figure 3-63)

The City of Philadelphia or the local municipality is responsible for maintenance and signals at each intersection, including grade crossings. It is notable that the term "grade crossing" does not reflect the traditional railroad concept of a highway road/rail crossing. For street-running operations, FTA defines all public roadway intersections as grade crossings.[24]

Photo credit: SEPTA

Figure 3-61 *Kawasaki Heavy Industries single-ended (left) and double-ended (right) cars*

Photo credit: http://www.philadelphiatransitvehicles.info/multimedia/displayimage-24-716-_451_at_Victory_Ave_Yard_May_31_1993_.html

Figure 3-62 *Norristown car*

---

[24] https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary.

Photo credit: TTCI

Figure 3-63 *PCC II car*

Operator Qualifications and Training

SEPTA has a comprehensive set of rules and regulations focused on providing the highest achievable level of safety and reliability. SEPTA's training program is comprehensive and includes evaluation and testing of trainees on their understanding of these rules, regulations, and corresponding agency policies. The training program is divided into three main segments:

- Classroom instruction with rules, regulations, and agency procedures explained and tested for retention
- Vehicle training with a certified instructor where the route is practiced without passengers on board
- On-route training with a certified line instructor where the student observes and practices the daily operations in revenue service with a veteran operator

SEPTA light rail operators are selected from a pool of external applicants. Selected candidates must have a CDL with passenger endorsement and a clean driving record. Operators receive training and are certified specifically on routes in the district to which they will be assigned. If an operator wants to be assigned to a route in another district, they must first complete training for the new district.

SEPTA recognizes the importance of refresher training and provides annual operator recertification focused on emphasizing salient rules and procedures, reiterating the importance of operator awareness of the uniqueness of the system in a mixed traffic environment. Defensive driving techniques typical of light rail operations are also included in the refresher curriculum, including accounting for differences between stopping distance, clearance issues, and the inability to avoid collisions by steering. Remedial training is determined on a case-by-case basis and is specific to the causal factors of an event. It generally occurs in a classroom and on-route. A certified instructor must certify the operator's ability to return to duty.

Accident/Incident Management

SEPTA defines an accident/incident as an expected or unintentional loss-causing event that results in a fatality, bodily injury, or property or vehicle damage. SEPTA adopted the National Safety Council definition of preventability, which includes three main clarifications regarding collisions:

- Preventable – operator either contributed to the collision or failed to take an action that would have prevented the collision
- Unpreventable – operator could not have prevented the collision because it occurred as a result of actions taken by other persons or objects
- Chargeable – operator is solely responsible for the collision

SEPTA has a robust accident and incident management program, as highlighted in its multi-modal SSPP. The program is a continuous and dynamic effort focused on the identification and resolution of hazards that can cause injuries to passengers and operators with consequent interruption of operations. The cornerstone of this process is the hazard resolution process, which encompasses four main elements:

- Identification of hazards and loss potential
- Development of a corrective action plan (CAP) to eliminate or mitigate the hazard
- Implementation of the CAP, which includes communication and training
- Ensure that measures adopted during the CAP are effectively working

SEPTA's accident/incident management program oversees prevention, investigation, and corrective actions. The prevention phase details all actions focused on collision avoidance. Investigation occurs immediately following a collision and focuses on identification of the root causes of the event. Extensive documentation is produced and analyzed to ensure that the best corrective actions are considered. Corrective actions are established because of the investigation and are focused on eliminating the root causes of the incident and potential systemic issues that may affect other modes as well. These actions are also documented for compliance purposes to ensure that system safety updates and applicable mitigation measures are implemented, if necessary.

SEPTA's internal accident/incident reporting threshold is detailed in its SSPP. When a collision occurs, the Control Center is notified immediately and directs the call to the appropriate personnel. The notification includes SEPTA and local police, fire and rescue units, transportation management, and, if necessary, SEPTA's system safety personnel. SEPTA has a safety officer on-call who will respond appropriately to collisions or incidents.

Safety Trends

There was a marked increase in collisions on SEPTA's light rail system from 2010 to 2018, as shown in Figure 3-64. During the same period, the trolley line also experienced an increase in collisions (Figure 3-65). From early 2017 through May 2018, there were decreases in collision events for light rail and trolley services due to many collision mitigation efforts, as described later in this section.

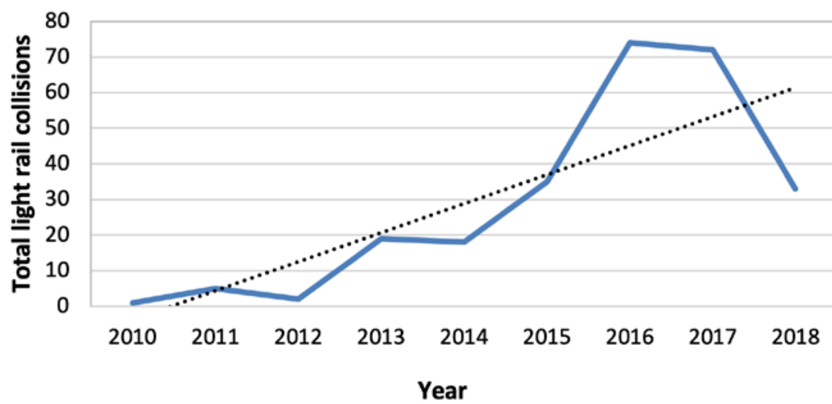


Figure 3-64 *SEPTA total LR collisions, 2010–2018*

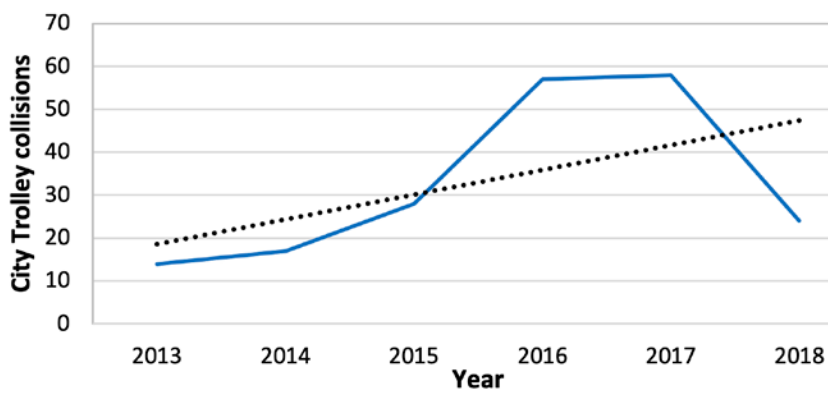
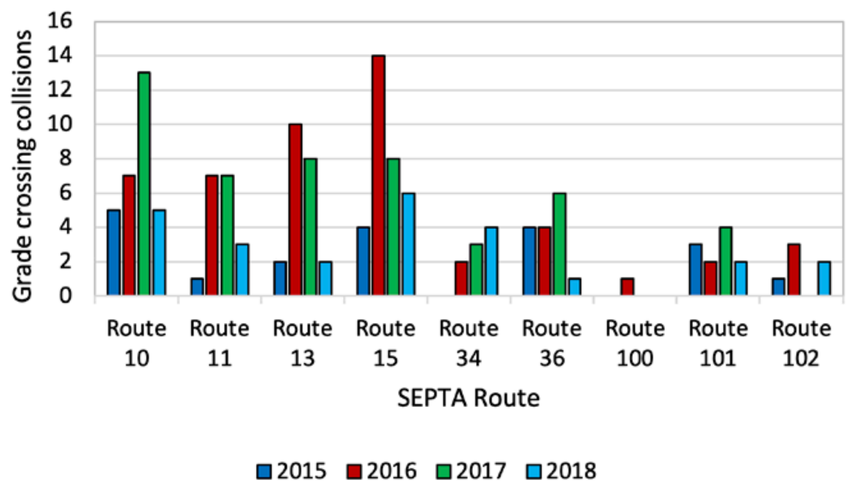


Figure 3-65 *City Trolley Lines collision trend, 2013–2018*

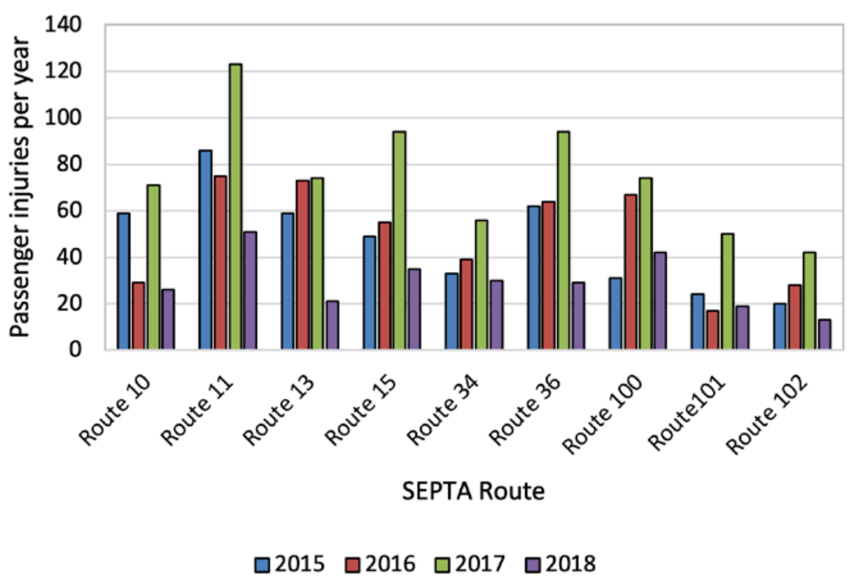
SEPTA identified routes 10, 13, and 15 as those that register the highest number of collisions with POVs making illegal left turns. SEPTA representatives believe that the frequency of this collision type is due to the environment in which these routes operate—shared lanes with POVs through densely-populated areas with high pedestrian traffic. Route 100 also had an increasing collision trend with fixed objects, such as objects on the tracks including tree limbs and other debris, bumper posts, or parked vehicles.

Grade-crossing collisions are another type of collision at SEPTA, especially on the light rail lines that operate in mixed traffic (Figure 3-66). As previously noted, due to FTA's definition of a grade crossing for street-running operations, all roadway intersections with street-running light rail operations are considered grade crossings. Additionally, this grade crossing definition requires SEPTA to report light rail grade crossing incidents that would not have been reportable if the incident involved a rubber-tire bus rather than a light rail vehicle. Since 2015, SEPTA recorded an annual average of 42 passenger injuries, with the trolley lines having the highest rate (Figure 3-67).



Source: SEPTA

Figure 3-66 *SEPTA grade crossing collisions, 2015–May 2018*



Courtesy of SEPTA

Figure 3-67 *SEPTA passenger incidents/injuries, 2015–May 2018*

Areas of Concern

SEPTA's light rail service and trolley lines operate in an environment where trains share lanes with motor vehicles, which is a contributing factor to increased incident rates. Motor vehicles contribute to the many hazards identified by the research team on the case study site visit. The first identified hazard is associated with vehicles either unexpectedly turning or switching lanes in front of an oncoming trolley. As the track transitions from a dedicated lane to a shared lane, the necessary merges (Figure 3-68) create hazard risk. The potential for a hazard occurs where there is a shared lane on a multilane street, as well as at intersections with turn lanes (Figure 3-69). Another common type of collision with vehicles occurs from clearance issues and track fouling. There are single-lane streets where very little clearance is available between the light rail vehicle and parked cars. Operators are trained to recognize the situation, stop service, and have the vehicle moved if necessary (Figure 3-70).

Photo credit: TTCI

Figure 3-68 *Traffic merging into dedicated lane*

Photo credit: TTCI

Figure 3-69 *Turning scenario*

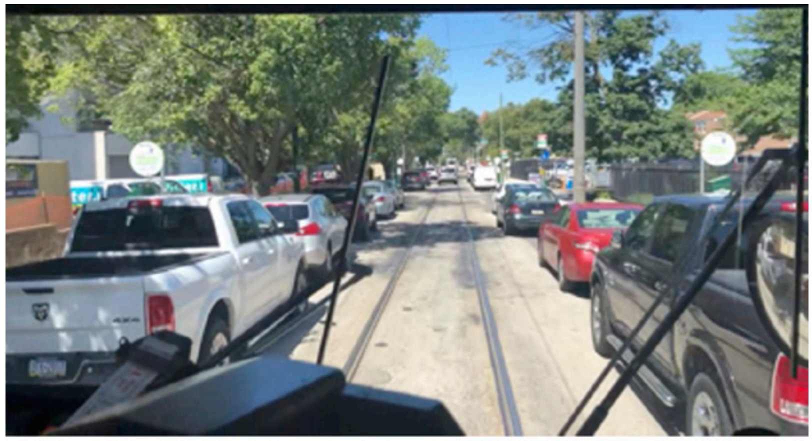


Photo credit: TTCI

Figure 3-70 *Clearance issue due to parked cars*

Related to clearance and track fouling, one of the most common hazards is due to the front and rear of the trolley swinging out into adjacent traffic lanes on a curve. If operators and motorists are not cognizant of these situations and do not maintain proper lateral distances, resulting collisions could occur (Figures 3-71 and 3-72). To combat this potential hazard, light rail vehicle swing clearance issues are emphasized in new hire training and in annual re-certification training.

Photo credit: TTCI

Figure 3-71 *Corner of trolley swinging out in curve*

Photo credit: TTCI

Figure 3-72 *Center of PCC II encroaching inside lane*

Technologies and other Safety Applications

SEPTA uses various signage and common traffic signaling to help maintain public awareness and prevent collisions (Figures 3-73 and 3-74). The agency also conducts extensive public outreach to educate customers and the public on how to stay safe around rail environments.

SEPTA is in the process of investigating some onboard collision avoidance technologies originally designed for buses to detect potential collisions and exploring the possibility of adapting them to its light rail vehicles and trolleys. These technologies are meant to increase operator awareness, particularly in blind spots, and alert them of potential collisions. Systems that are being investigated include Protran's Blind Spot Awareness System©, Mobileye Shield+ Collision Avoidance System©, and TCT's Train Intelligent Detection System (TIDS).

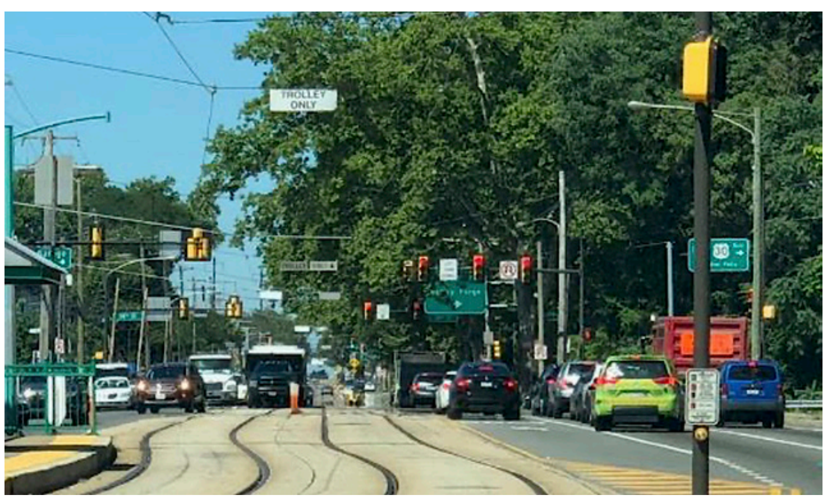


Photo credit: TTCI

Figure 3-73 *Trolley-only sign for dedicated lane*

Photo credit: TTCI

Figure 3-74 *Sign illustrating clearance in turn zone*

Other Modifications or Procedural Actions

SEPTA emphasizes that its light rail operation in Philadelphia predominantly includes traditional streetcar movements in a mixed-traffic, congested, urban environment on narrow streets. Crossings negotiated by SEPTA trolley routes are merely multimodal street intersections. SEPTA's main mitigation actions include operator training (initial and annual refresher), ongoing rules and compliance testing focused on street operations, and signage on the rear of the trolleys alerting drivers to not pass on the right (Figure 3-75).

Photo credit: TTCI

Figure 3-75 *"Do Not Pass On Right" sign, back of trolley*

SEPTA is considering tying signaling systems to traffic signals to provide right-of-way to light rail vehicles approaching intersections.

SEPTA implemented communication-based train control (CBTC) in the City Subway Tunnel portion of its light rail line, which provides centralized supervision from SEPTA's integrated Control Center and improves safety and performance in the tunnel. System installation included civil works, track switch replacement, and upgrades to the existing signaling system including installation, testing, and commissioning. SEPTA is in the process of installing CBTC on its 101 and 102 Media and Sharon Hill lines with an expected completion date in 2020.

Other modifications under consideration at SEPTA include street delineators to protect island platforms in mid-street dedicated right-of-way, signage at portals where light rail vehicles transition from mixed street to tunnel, "No Left Turn" signs, and at least one flashing sign from a private driveway warning that a light rail vehicle is approaching.

Successes

SEPTA personnel highlighted two main programs of which it is exceptionally proud—the close-call employee reporting system and outreach programs.

In 2016, SEPTA instituted a confidential close-call reporting system, known as C3RS, on its commuter railroad. This program was accomplished through a Memorandum of Understanding (MOU) between SEPTA, FRA, and the unions. The objectives of this program are:

- Accumulation of confidential data on unreported or under-reported unsafe acts
- Event analysis of reported data by peer review teams
- Identification of corrective action by the parties to remedy identified safety hazards
- Provision of assistance by FRA in its safety oversight role
- Publication of general trends and statistics by government agencies

This program has been very effective, and SEPTA is developing a similar confidential reporting program for use by its transit employees.

The second important success the agency shared is the outreach program developed to educate the public and employees on a variety of safety topics. SEPTA's Safety Department manages and disseminates safety messages throughout the entire system and uses outreach campaigns developed by Operation Lifesaver. Anyone can request a safety presentation by contacting SEPTA's Safety Department; members of the department travel throughout their jurisdiction to deliver it. Requests for safety education presentations have come from public schools, churches, and colleges. Figure 3-76 shows SEPTA's safety education bus.

Photo credit: SEPTA

Figure 3-76 *SEPTA education bus—Operation Lifesaver*

Station Safety Blitzes are another initiative to promote safety across the system. Started in 2002, the blitzes are held throughout the year at various rail and transit stations, targeting areas where events have occurred or areas of high vehicular and pedestrian volumes. The safety campaigns remind customers to make safe choices and avoid distractions while walking near SEPTA vehicles or riding on them. Employee Education Blitzes are also held, and employees are encouraged to participate. Twice per year, SEPTA holds Employee Safety Awareness Day, "Never Too Busy for Safety." During this event, employees and managers meet for 20–30-minute safety topic discussions. Community Safety Awareness Day, another initiative focused on promoting safety, is a large-scale customer safety education event led by SEPTA's System Safety Division (Figure 3-77).

Photo credit: SEPTA

Figure 3-77 *SEPTA Community Safety Awareness Day*

Although SEPTA has many challenges, especially related to light rail operations in mixed traffic, its dedicated safety team uses proactive innovative approaches to mitigate risk. Installation of CBTC on its light rail tunnel environment and the expansion of that technology are proof of SEPTA's dedication to safety improvements. SEPTA also is considering piloting new collision avoidance technologies on its light rail vehicles, which will provide the industry with valuable insight into the viability of these systems in rail environments.

Tri-County Metropolitan Transportation District of Oregon – TriMet (Portland, Oregon)

General System Information

The Tri-County Metropolitan Transportation District of Oregon, historically and locally referred to as TriMet, provides public transportation service in the Portland, Oregon region, which encompasses portions of Multnomah, Washington, and Clackamas counties. Created in 1969 by the Oregon legislature, TriMet is a municipal corporation of the State of Oregon with powers to tax, issue bonds, and enact ordinances. TriMet is overseen by a seven-member Board of Directors appointed by the Governor of Oregon and has its own district boundary, which incorporates an area of approximately 533 square miles. TriMet provides transit services (fixed-route bus, light rail, commuter rail, and paratransit services) 22 hours per day, 7 days per week. The Metropolitan Area Express light rail service, which is the object of this study, is known as MAX Light Rail. The 2017 NTD agency profile for TriMet's light rail service is as shown in Table 4-7.

Table 3-7 *TriMet Operational Characteristics*

Annual Passenger Miles	216,465,191
Annual Train Revenue Miles	4,428,550
Annual Unlinked Passenger Trips	40,198,185
Vehicles Operated Maximum Service	116

Operational Characteristics (Operating Hours, Types of Service Provided, Etc.)

As noted, TriMet provides a wide range of transit services. The MAX Light rail service has approximately 122 miles of track on 5 lines:

- Blue Line – Hillsboro, City Center, Gresham
- Red Line – Airport, City Center, Beaverton
- Yellow Line – Expo Center, City Center, Portland State University (PSU)
- Green Line – Clackamas, City Center, PSU
- Orange Line – Milwaukie, City Center

All five MAX lines serve Portland's downtown area. Two of the many bridges that cross the Willamette River, which runs directly through the downtown area, are used by the light rail system. One line, the Blue Line, is over 30 miles long and operates in both urban and suburban environments.

Maximum operating speed varies from 20 to 55 mph due to the diversity of the areas of operation; 55 mph is the maximum speed on exclusive rights-of-way, 25 mph is the maximum allowable speed when the train is approaching an intersection, and 20 mph is the speed limit when approaching or departing a platform.

The MAX operates at street grade with a mixture of shared (with bus) and dedicated lanes, semi-exclusive right-of-way, and exclusive right-of-way. Track alignment varies significantly from one area to the next; in some locations, the tracks are located on one side of the street, and in other areas the tracks run in the middle of the roadway.

Portland Streetcar is owned by the City of Portland, not by TriMet. TriMet provides rail operators, training, and maintenance services for the Portland Streetcar, but it does not have any authority on the streetcar system or the management of operations.

TriMet's hours of service policy is in review for possible update. Safety-sensitive employees (rail operators, supervisors, maintenance employees, maintenance of way [MOW] employees) follow this policy, which mandates no less than nine hours off-duty between shifts; rail supervisors get a minimum of seven hours off-duty between shifts.

Operator Qualifications and Training

TriMet's operational workforce consists of 221 train operators, and 35 streetcar operators are provided to the City of Portland for its streetcar system.

Training for new operators consists of 11 weeks of comprehensive classroom and on-route instruction. The Training Department schedules an average of four classes per year, limiting class size to a maximum of nine students per class; in the past, class size was restricted to no more than 13 students per class, but reduced class sizes resulted in a significant retention improvement. The agency mandates refresher training every year, which includes content related to best practices. Remedial training is also mandatory after a preventable accident or after multiple customer complaints.

Train operators are selected from the active bus driver pool. Generally, more operators than needed are trained, with the objective of creating a pool of trained rail operators to call upon as needed. Therefore, bus operators may be trained on rail operations but remain a bus operator until a train operator position becomes available. Once an operator accepts a rail operator position, that operator is committed to the Rail Division for at least one year of service, barring disqualifying medical conditions. Operators who wish to return to bus transportation may do so on the effective date of their Spring sign-up, provided that the employee gives written notice of intention to do so prior to the Spring sign-up and has completed one year of required continuous service prior to the effective date of the Spring sign-up.

Accident/Incident Management

TriMet has an extensive accident and incident management program. In over 36 years of rail operation, the agency has not experienced any fatality involving operators or employees.

TriMet's safety officers rotate 24 hours on-call and respond to safety and security accidents/incidents as needed. Events are reported to TriMet's Operation Control Center (OCC) and classified into one of three levels, depending on the seriousness:

- Level I – requires safety officer to be on scene as soon as possible (generally injury or fatality, multi-vehicle)
- Level II – requires safety officer intervention via phone or radio, but no presence on scene is required (minor events that may or may not have minor injuries)
- Level III – only a reporting requirement

TriMet's Safety Information Management System (SIMS) is used for recordkeeping, safety audits, internal and external inspections, and incident investigations. The agency also maintains a color-coded spreadsheet used to track accidents and incidents with reporting requirement triggers for the NTD, SSO, and FRA, as examples. The agency also maintains a "heat map" that displays the location and frequency of accidents and provides an immediate visual indication of the areas where intervention may be beneficial.

TriMet established an Accident Review Committee that is responsible for discussing each accident and determining preventability adapted from NSC guidelines. TriMet employs separate committees for each transit mode (bus, paratransit, and rail operations) and reviews preventability determinations of safety-related incidents on a 24-month basis. TriMet will terminate any operator that has 4 preventable accidents in a 24-month period; however, there is a one-time-only "last chance agreement" the first time an employee incurs four preventable accidents within a 24-month period.

TriMet has a comprehensive accident policy, which was under review during the site visit. The current policy includes an appeal process and codes for each type of accident.

TriMet does not have a formal policy on close calls/near-misses, which are generally reported voluntarily by operators. The agency does track close calls focused on safety and customer service (customer complaints). On-board video recordings are examined upon an operator's request, a customer complaint, or an accident/incident (in accordance with the Collective Bargaining Agreement with their Union). The agency releases close-call videos to the public for educational purposes, but the data are not tracked to confirm a decrease in frequency/severity of accidents due to this outreach program.

TriMet adopted a second-chance wireless communication policy that prohibits the use of any wireless communication device while the vehicle is in movement. Wireless devices may be carried with the employee but must be turned off and stowed when the employee is in both active and inactive cabs. The first policy violation requires a minimum three-day suspension, and the second violation results in termination. However, TriMet personnel noted that without inward-facing cameras in train cabs, enforcement is difficult.

Safety Trends

Collisions are rare and random events; thus, some judgment is necessary when examining the trends of collision rates, taking into consideration environmental and special event factors, which influence collision frequency. TriMet experienced a slight increasing trend in collision rates from 2013 through 2018 (Figure 3-78).

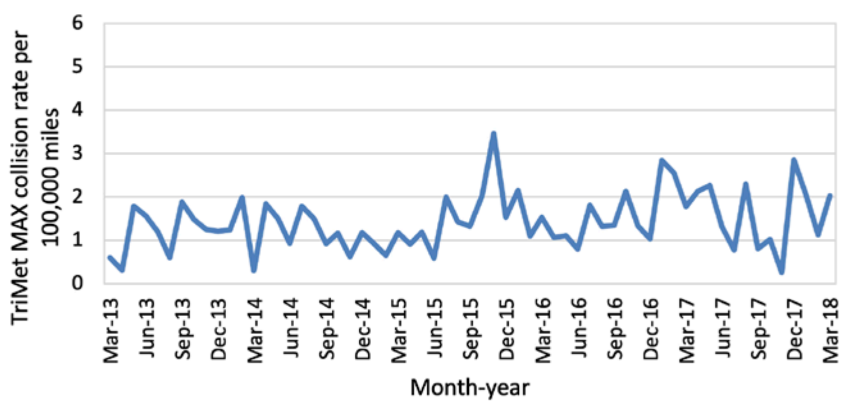


Figure 3-78 *TriMet MAX collision rate per 100,000 miles, 2013–2018*

Vehicle collisions are the most frequent type of light rail collision at TriMet, followed by pedestrian collisions (Figure 3-79). In both cases, the agency experienced a slight increasing trend during the last eight years. However, an examination of the past year of collision rate data from February 2017 to February 2018 reveals that TriMet has been successful in reducing the rate of light rail collisions with personal vehicles, as shown in Figure 3-80.

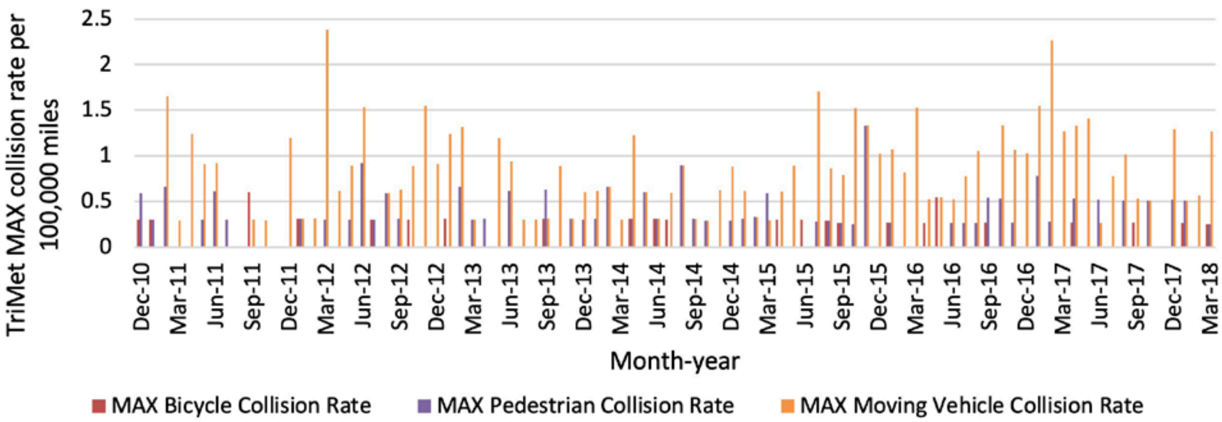


Figure 3-79 *TriMet MAX collision rate per 100,000 miles by type, 2010–2018*

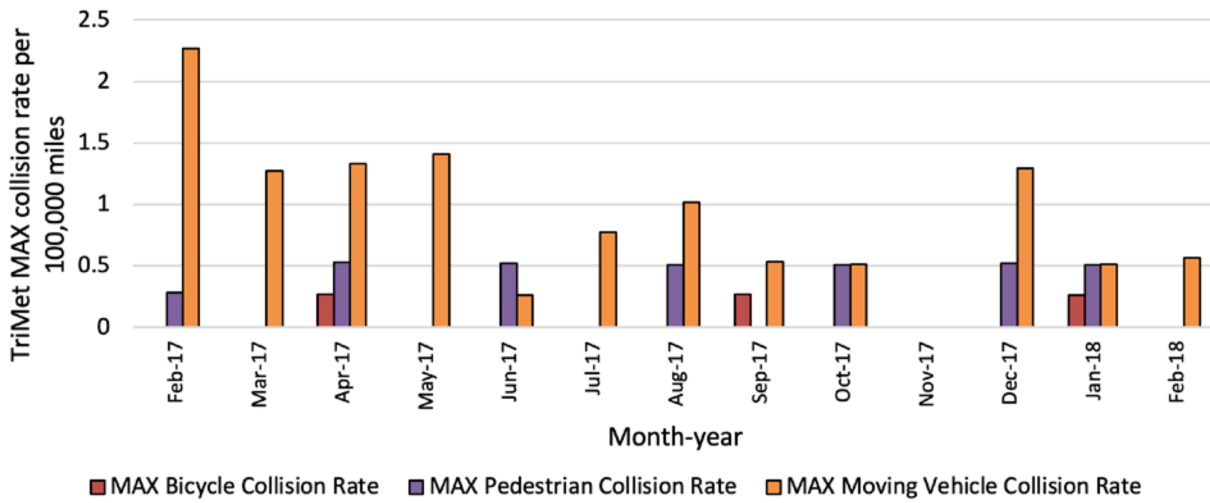


Figure 3-80 *TriMet MAX improved collision rate per 100,000 miles by type, 2017–2018*

TriMet is using root cause analysis to investigate the correlation of increased accidents, incidents, and rule violations that may be influenced by the reduction of available operators and the potential for fatigue or other factors associated with longer work hours and stress. Understanding the benefits of proactive hazard identification, TriMet is implementing a close-call program, customer service complaint analysis, and upgrading the camera systems on-board and at the platforms. Close-call and evasive action reporting is limited to hard stops, and the agency recognizes that there is room for improvement of the reporting mechanism for these incidents. TriMet's customer service department is mature and well-developed, and each complaint is thoroughly investigated. TriMet does not employ operator-facing cameras in the leading train cab but is negotiating the issue of inward-facing cameras with union representatives.

TriMet has implemented a comprehensive color-coded document that describes the types of events and the thresholds to trigger the reporting requirements for each external agency that must be contacted (NTSB, OSHA, FRA, SSO). The color-coded document, along with a heat map, are key components of the procedural actions taken by TriMet to lower event rates.

Areas of Concern

TriMet's diverse operating environment contributes to several types of incidents rather than one typical type. However, most light rail collisions involve a motor vehicle. As noted, TriMet uses a root cause analysis approach to investigate all collisions, with an emphasis on mitigating contributing factors, improving the agency's safety culture, and improving public safety. The MAX has many unique situations that create specific problems and vary from one location to the next. Additionally, TriMet representatives reported a significant trespasser issue. Areas with potential safety challenges are listed below.

Along the Blue Line, one intersection in particular tracks transition from the middle of the street to the edge of the roadway and run parallel to traffic, there is potential risk due to reduced line of sight for vehicles (Figures 3-81 and Figure 3-82).

Photo credit: TTCI

Figure 3-81 *Intersection with tracks in middle*

Photo credit: TTCI

Figure 3-82 *Intersection with tracks to side*

SW Moody and Tilikum Crossing is a very busy intersection, with high volumes of cyclists and pedestrians during certain times of the day. Given the track alignment and multiple crossings, the risk of collision appears to be high in this area (Figure 3-83). To combat this increased risk, many innovative solutions are in place at this intersection, such as bicycle signals and pavement markings to clarify the exclusive intended use of light rail vehicles, as shown in Figure 3-85. There is an additional challenge with the multimodal configuration at this intersection as the streetcar runs in mixed-use traffic, while the light rail runs on exclusive right-of-way, adding to the necessity of pavement markings.

The intersection configuration shown in Figure 3-86 highlights the width of the dedicated light rail lane and poor marking visibility, both of which appear to exacerbate the risk of collision with turning personal vehicles, although the number of collisions at this location have been minimal.

Photo credit: TTCI

Figure 3-83 *Moody Avenue and Tilikum Crossing*

Photo credit: TTCI

Figure 3-84 *Bicycle signal*

Photo credit: TTCI

Figure 3-85 *LRT-only lane markings*

Photo credit: TTCI

Figure 3-86 *Wide rail right-of-way with hazard*

Although it does not necessarily occur in similar configurations, the risk of collisions with personal vehicles due to poor line of sight is a hazard at TriMet. Two examples can be seen under Portland bridges where the line of sight is blocked due to an overpass column (Figure 3-87) or due to nearby buildings (Figure 3-88).

Photo credit: TTCI

Figure 3-87 *Overpass column*

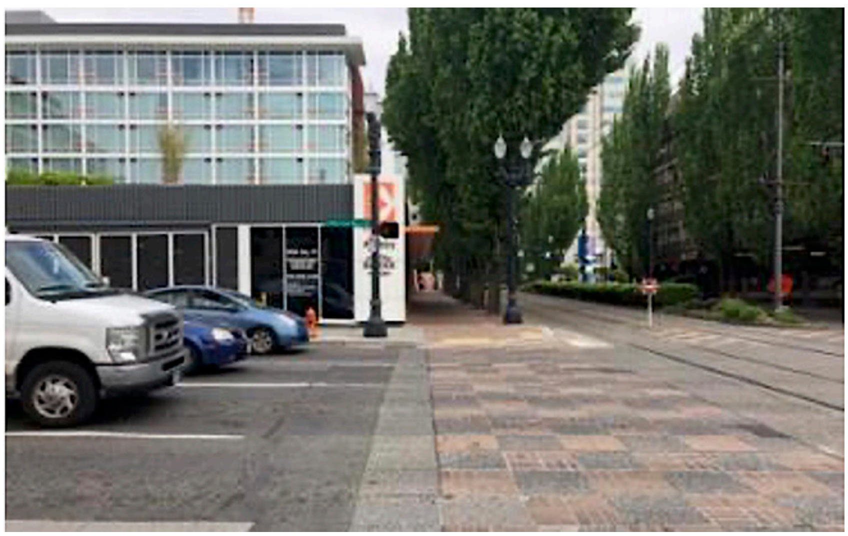


Photo credit: TTCI

Figure 3-88 *Building and vegetation*

Portland's downtown area poses a unique challenge, with light rail operating adjacent to personal vehicles. Like most downtown areas, there are many one-way streets, and the light rail tracks are located to one side of the street in a dedicated lane. The light rail right-of-way is separated using turtleback delineators; however, the delineating turtlebacks are difficult to maintain, resulting in many missing or degraded delineators. The street lanes are narrow, and if vehicles stop in the street blocking traffic, the blocked traffic will occasionally proceed around the parked car using the light rail lane to the left, causing the potential for collisions with a light rail vehicle. Additionally, inconsistencies in the signage and signals used along the routes and at intersections have the potential to add to unfamiliar road user confusion.

Although traffic signals are timed and all turning movements for automobile traffic are held on red while trains advance through intersections, some traffic signals are not always as well synchronized as possible. For example, upon successful preempt through the intersection at 10th Avenue, an operator advancing east at the appropriate speed may subsequently encounter a red auto signal at Broadway (Figure 3-89).

Photo credit: TTCI

Figure 3-89 *Downtown Portland*

Technologies and Other Safety Applications

TriMet does not employ PTC on its trains; due to the nature of its service, it does not anticipate potential for train-on-train events. However, TriMet trains are equipped with ATC, which intervenes to stop a train in case of signal overruns or speeding when they are operating in the Automatic Block Signal System (ABS). In such cases, a violation causes the train's service brake to engage. In non-ABS areas, trains are separated by an operating rule requiring a minimum of one block separation between trains.

TriMet's camera system is being upgraded, with the possible installation of operator-facing cameras, as noted. All Type 4 and newer cars and a few older cars have in-cabin forward-facing cameras. There are also cameras installed on each platform and within all passenger compartments.

TriMet employs a variety of signs and lighting at intersections to ensure public awareness of train traffic. Despite the diversity of the operating environment, signage remains mostly consistent throughout the system (Figures 3-90 and 3-91).

TriMet recently improved more of its pedestrian crossings using channelization (Figure 3-92) and one-way swing gates (Figure 3-93). The agency has employed these types of treatments at higher collision risk intersections since the late

1990s. It also installed a newly-designed pedestrian warning pole equipped with an audible warning bell, flashing red lights, and a passive “Look Both Ways” warning sign (Figure 3-94).

Where the space for installation is available, many of TriMet’s crossings are protected by gates (Figure 3-95). Additionally, it is important to note that the MAX service traverses through several different municipalities, each of which is responsible for signage and traffic signaling. TriMet, however, maintains the crossing gates. The agency uses coordinated communication to ensure that all signage and gating are regularly maintained.

Photo credit: TTCI

Figure 3-90 *Downtown signage and lighting*

Photo credit: TTCI

Figure 3-91 *Signage and lighting*

Photo credit: TTCI

Figure 3-92 *Channelized pedestrian crossing*

Photo credit: TTCI

Figure 3-93 *Swing gate*

Photo credit: TTCI

Figure 3-94 *Pedestrian warning poler*

Photo credit: TTCI

Figure 3-95 *Gated crossing*

Other Modifications or Procedural Actions

TriMet's fleet is composed of five types of trains (Figure 3-96). The leading edge of Type 1, Type 2 and Type 3 light rail trains is open with exposed couplers without bumpers or guards; Type 4 and 5 trains incorporate design elements to protect pedestrians and motor vehicles in collisions, reducing the risk of being pulled under the train in the case of a collision. TriMet trains employ event data recorders that record brake application, speed and stopping distances, and other systems data.

Type 1 **Type 2** **Type 3** **Type 4** **Type 5**

Photo credit: TriMet

Figure 3-96 *TriMet light rail vehicles*

Successes

TriMet has a comprehensive outreach program focused on public safety campaigns developed around a seasonal approach. During the darker winter months, TriMet works with City and County partners to distribute flashing strobe lights to the public to emphasize the importance of deliberately remaining visible when it is dark outside. As the spring season begins, safety campaign messaging shifts to address distracted walking, the use of mobile devices while waiting for a train, and safety distances around TriMet vehicles. TriMet personnel work with schools and student groups to distribute safety materials to students, teaching them how to be safe while riding TriMet buses and trains. Employees volunteer to speak to classes before they embark on field trips via mass transit. This student outreach program is being revamped, focusing on the distribution of safety materials to youths. TriMet uses a fun approach with modern graphics to fully engage the school children.

Another important success is *ExpressLine*, a weekly newsletter available on the employee website. It focuses on educating employees on safety, security, and environmental topics that benefit work-life and private-life. TriMet also produces *Trainline*, a rail-specific publication released as needed to highlight emerging safety concerns.

Through an internal employee website, personnel can report hazards and request a safety assessment. The Safety Department follows up on each hazard reported. TriMet employees also have a hotline on which they can directly report safety issues and concerns. TriMet considers the website and hazard hotline excellent tools to reduce accidents through calculated risk mitigation while also improving employee retention rate and employee satisfaction through feedback and considerate risk mitigation. Frontline personnel are especially appreciative when their mitigation ideas are considered and implemented. Listening to employee ideas for risk mitigation is mutually beneficial and increases employee pride and ownership.

In early 2018 TriMet equipped its rail supervisors with radar to check train speeds. Random train speed checks ultimately lowered the number of speed violations.

TriMet's comprehensive approach to training operators using reduced class sizes and focused curriculum, combined with clearly-defined policies and procedures for hours of service and incident investigation, position TriMet as a model transit agency. Innovative solutions such as channelized pedestrian ways and one-way pedestrian swing gates with signage warning pedestrians to look both ways and remain aware are risk mitigation solutions that could be implemented at other agencies experiencing similar risks. Employee reporting and the reduction of operating violations have also contributed to improved safety on the MAX and throughout the TriMet system.

Section 4

Conclusions and Findings

Light rail and streetcar rail transit present transit safety risks, specifically transit collisions with pedestrians/bicyclists and motor vehicles. The operations of these systems, often within shared corridors, establish a high probability of vehicle and/or pedestrian bicycle collision events, as detailed in the NTD data presented in the Background section of this report.

The research team performed extensive background research and relevant literature reviews to identify the effective measures that have proven successful in improving the safety of light rail operations. Through this research, the team identified systems reported as successful at reducing collision or other incidents or those being tested that show promise.

Innovative collision avoidance technologies are being tested or piloted at agencies, including Protran's Blind Spot Awareness System©, Mobileye Shield+ Collision Avoidance System©, and TCT's Train Intelligent Detection System (TIDS). The literature review identified products and systems being testing in Europe that show potential, including SIL4, Bombardier's DAS with 3D Stereovision, Bombardier's BodyGuard, Alstom's Pegasus 101, Bosch's Tram Forward Collision Warning System, and the multilayer laser scanner collision avoidance system applied to Durmazlar Machine's Silkworm tram.

From the case studies, the research team identified onboard technologies that agencies deployed that resulted in improved safety. In addition, innovative solutions such as left-turn gates, parking lot-style gates, pedestrian gates and channelized crossings, and quad gates at vehicular intersections were all successful in their respective agencies in reducing risk and improving system safety. Fencing placed along the rail line was described as effective in deterring unwanted pedestrian crossings. Successful modifications to operational practices and public outreach campaigns that improved safety on light rail systems are also reflected in the case study summaries as follows:

- **Greater Cleveland Regional Transit Authority** – To combat left-turning personal vehicle challenges, GCRTA uses a combination of static and active blank-out signage to warn drivers of an approaching train, prohibiting left turns into the path of light rail vehicles. GCRTA employs crossing gate protection at rail crossing signals on the Waterfront Line, and fencing is also frequently used to deter pedestrians from crossing the tracks in prohibited areas.
- **Hillsborough Area Regional Transit** – HART employs the use of passive and active signage at grade crossings to warn vehicle operators of a streetcar. In one location, a parking lot-style gate is used at the exit of a parking lot to prevent vehicles from encroaching onto the tracks when a

train is approaching. HART is part of the Tampa Connected Vehicle Pilot Program, which installed 40 wireless communication roadside units, ten on-board units on HART buses, ten on-board units on HART's streetcar trolley cars, and 1,500 units on privately-owned vehicles that travel the study area regularly. Streetcars equipped with on-board units can communicate with connected personal vehicles to relay information about vehicles crossing the tracks, thus reducing the risk of collisions. HART's partnership with the connected vehicle pilot project will help leverage newly advancing technologies, such as collision avoidance warnings and alerts when vulnerable road users are on or near the rail line.

- **Massachusetts Bay Transportation Authority** – MBTA is installing Green Line Train Protection (GLTP), which is designed to improve train-on-train protection requirements, signal enforcement (block, interlocking, speed, and distance), train-on-train enforcement (signal and separation), over-speed derailment protection at high-risk locations, work zone protection, switch enforcement, and the roadway worker alert system. This system is intended to decrease braking time and braking distance while improving operational safety. The agency has installed fencing that divides the tracks in opposite directions, preventing pedestrians from crossing the tracks in unintended areas, which has lowered the pedestrian close-call rate and eliminated all train-pedestrian collisions since its implementation. Signage encouraging pedestrians to look for trains at pedestrian crossings has been installed, and most pedestrian crossings are painted yellow to increase their visibility, especially at night. MBTA has developed public informational campaigns delivered at schools and churches to educate the public on how to safely use the system. In 2014, MBTA released the "Eyes Up, Phone Down" campaign to encourage individuals to remain vigilant around Green Line tracks. MBTA's outreach program is recognized as contributing to lower accident rates between trains and pedestrians and increased customer satisfaction.
- **Metropolitan Transit Authority of Harris County (Houston METRO)** – METRO deployed a Bluetooth Proximity Alert System (BPAS) technology to alert pedestrians when a train is approaching. The system is activated by a Bluetooth beacon on the train when it approaches and begins an audible message in both English and Spanish warning pedestrians of an approaching train with an intermittent bell sound. The agency uses various high-visibility signage, lighting, and blank-out signs to alert motorists and pedestrians of train traffic. METRO also is installing fencing all along the midtown corridor at all rail stations and around all adjacent parks to deter pedestrians from crossing in undesirable areas. In 2009, METRO started an initiative to add an LED red backplate lighting to the outer frame of the signaling for red traffic signals. This initiative was put in place to combat red-light signal violation collisions by personal vehicles with the light rail. The initiative has proven to be successful enough to allow METRO

to procure additional LED back-plate traffic signals in 2018. The agency implemented an extraordinary public safety campaign that highlights the nationally-acclaimed “Think Rail” program. METRO remains very active in its community with safety representatives spreading its message to think, look, and listen around rail at schools, community meetings, neighborhood events, such as YMCA Healthy Kids Day and the Cesar Chavez Parade, and at the public library and the Children’s Museum Free Family Night. METRO also partners with Girl and Boy Scouts, providing the opportunity to earn light-rail safety patches and railroad merit badges.

- **Los Angeles County Metropolitan Transportation Authority** – LA Metro representatives identified major safety trends on their light rail system – vehicles colliding with oncoming trains, pedestrian collisions, and suicides. Accidents between personal vehicles and trains are mostly attributable to illegal left turns across the track. The agency is piloting left-turn gates to prevent personal vehicles from entering the track when the train is approaching. Metro representatives indicated that due to the success of the gates, their use will be reflected as the standard for the Crenshaw Line. LA Metro established design standards for signalized grade crossings that include additional crossing elements such as ringing bells, alternately flashing LED railroad signals warning of an approaching train and indicating the prohibition of left turn movements, and photo enforcement cameras. “Motorman” lights are also installed to warn operators if the gates are not operating properly. Metro uses internally-illuminated raised pavement markers (IIRPM) at certain crossings along the Gold and Blue lines as another pilot project to mitigate illegal left-hand turns. Active LED “Look Both Ways” signs have been installed to remind pedestrians to look both ways before crossing the tracks, and trains are equipped with Protran© worker protection technology. This secondary warning system alerts operators if workers are present on the track and alerts workers on the track when a train is approaching. Metro’s Community Education developed numerous safety campaigns, including the production of Safetyville videos that tackle issues such as running to catch a train, lack of attention while driving a car near tracks, and failure to follow posted safety instructions. The videos have been effective and well-received, reaching over 4 million people on YouTube since their launch.
- **Southeastern Pennsylvania Transportation Authority** – SEPTA uses various signage and common traffic signaling to help maintain public awareness and prevent collisions. The agency is in the process of investigating some onboard collision avoidance technologies originally designed for buses to detect potential collisions and exploring the possibility of adapting them to their light rail vehicles and trolleys. Systems being investigated include Protran’s Blind Spot Awareness System©, the Mobileye Shield+ Collision Avoidance System©, and TCT’s Train Intelligent Detection System (TIDS). Crossings negotiated by SEPTA trolley routes

are multimodal street intersections; as such, SEPTA's main mitigation actions include operator training (initial and annual refresher), ongoing rules and compliance testing focused on street operations, and signage on the rear of the trolleys alerting drivers to not pass on the right. SEPTA is considering linking signaling systems to traffic signals to provide right-of-way to light rail vehicles approaching intersections. Other modifications under include street delineators to protect island platforms in mid-street dedicated right-of-way, signage at portals where light rail vehicles transition from mixed street to tunnel, "No Left Turn" signs, and at least one flashing sign from a private driveway warning that a light rail vehicle is approaching. SEPTA developed its outreach program to educate the public and employees on a wide range of safety topics. The Safety Department manages and disseminates safety messages throughout the entire system. Station "Safety Blitzes" promote safety across the system, with blitzes held throughout the year at various rail and transit stations to remind customers to make safe choices and avoid distractions while walking near SEPTA vehicles or riding on them.

- **Tri-County Metropolitan Transportation District of Oregon** – TriMet uses a variety of signs and lighting at intersections to ensure public awareness of train traffic. Despite the diversity of the operating environment, signage remains mostly consistent throughout the system. In areas where track alignment and multiple crossings activity occurs, the agency has initiated innovative solutions such as bicycle signals and pavement markings to clarify the exclusive intended use of light rail vehicles. The Portland Streetcar operates in shared use lanes with the public, while TriMet's light rail does not permit personal vehicles to operate on their right of way. To combat confusion, extensive lane markings and signage is used. TriMet recently improved more of its pedestrian crossings using channelization and one-way swing gates and installed a newly-designed pedestrian warning pole equipped with an audible warning bell, flashing red lights, and a passive "Look Both Ways" warning sign. The agency has a comprehensive outreach program focused on public safety campaigns developed around a seasonal approach. During the darker winter months, TriMet works with City and County partners to distribute flashing strobe lights to the public to emphasize the importance of deliberately remaining visible when it is dark outside. As the spring season begins, the safety campaign messaging shifts to address distracted walking, the use of mobile devices while waiting for the train, and safety distances around TriMet vehicles. TriMet personnel work with schools and student groups to distribute safety materials to students, teaching them how to be safe while riding TriMet buses and trains.

Beyond the case studies, the following findings are presented based on the literature review and background research.

Finding 1: The literature review and the case study visits demonstrate the need for technical support to transit agencies considering the implementation of light rail services in their communities or those expanding existing services. The industry would benefit from a series of recommended practices or guidance documents for implementing light rail service that includes lessons learned from agencies operating these services. Areas of technical support could include:

- Signaling and signage
- Intersection and line design elements
- Pedestrian treatments
- Vehicle design options
- Use of collision avoidance technologies

Finding 2: The literature review and case studies identified technologies reported as successful in reducing safety risk by those performing pilots or demonstrations. In future demonstration funding opportunities, FTA may want to encourage deployments that include active collision avoidance system technologies reflected in products such as:

- Bombardier – Optical Driver Assistance System “Flexity Vehicle” – (3D Stereovision using vehicle envelop in real-time)
- Bosch – Collision Avoidance Warning System (camera w/radar)
- “Silkworm” – Collision Avoidance System (Lidar)
- SIL4
- Protran

Appendix A Site Visit Questionnaire

System Information

Number of vehicles operated in maximum service (VOMS)	
Number of trains operated in maximum service	
Number of operators	
Number of operators with less than 3 years' seniority	
Number of operators with more than 3 years' seniority	
Vehicle revenue miles	
Total miles of track	
Number of light rail passenger trips	
Number of miles shared with public streets	
Number of routes	
Number of vehicles on each route (peak time)	
Frequency of arrivals on each route:	
Weekday	
Saturday	
Sunday	
Number of access points	
Number of stops on route	
Number of crossings	

Documentation

	Received?	
1. Accident investigation policies and procedures (last 5 years)	Yes	No
2. Accident reports (last 5 years) a. Operator report b. Supervisor report c. Police report (if applicable)	Yes	No
3. Records of events (last 5 years) a. Fatalities b. Injuries c. Property damage	Yes	No
4. Documents of corrective action (last 5 years) a. Identification of contributory factors b. Operator discipline c. Re-training (remedial) d. Re-route (if any) e. Identification of maintenance issues f. Follow-up system to ensure effectiveness of CAP	Yes	No
5. System Safety Program Plan (SSPP) (should contain accident investigation procedures)	Yes	No
6. Training curriculum a. Initial b. Refresher c. Remedial	Yes	No
7. Wireless Communication Policy	Yes	No
8. Procedures to track driving hours/ hours of service (check if use extra board)	Yes	No
9. Procedures to prevent fatigue (sleep apnea)	Yes	No
10. Procedure for operator selection	Yes	No
11. Operational policies and procedures (operator handbook)	Yes	No
12. Do you have an agreement with City/County/State for route modification (crossings, intersections, etc.)?	Yes	No
13. Track of close call a. Identification b. Analysis c. Action item	Yes	No
14. Does an independent body collect near-miss data?	Yes	No
15. What is done when close calls are reported?		
16. Is there a process for mitigation of identified hazards?	Yes	No
17. Do you have any collision-related statistics you can provide?		
18. Is there a specific incident that occurs more or less than others?	Yes	No

19. Minutes of safety meetings	Yes	No
20. Documents of trend identification (incidents/accidents/ close calls)	Yes	No
21. Policies and procedures for track maintenance and track inspections	Yes	No
22. What is your definition of accident?		
23. What is your definition of incident?		
24. What is your definition of preventability? (note if addresses system preventability or only operator preventability)		
25. Which guidelines are you using to determine preventability?		
26. Does the transit system have a method in place to review accidents/incidents?		
27. Do you have an accident/incident review committee?	Yes	No
a. Does review determine if accident/incident was organizational issue?	Yes	No
b. Who are members of the accident/ incident review committee? (generally, supervisor, safety personnel, operator of the year, maintenance personnel, union representative)		
c. How often does committee meet?		
d. Does committee address security issues? (if yes, ask to review SPP)		
e. Does the committee determine preventability?		
28. If accident/incident is organizational issue, how is that documented and addressed? (ask for documents, if any)		
29. What elements are in use at intersection? (traffic lights, alarms, barriers, etc.)		
30. Which elements/signals are in use at grade crossings?		
31. What is threshold that triggers property damage investigation? (generally $25,000, but agencies can decide to lower it)		
32. Do you test for medical fitness for duty?	Yes	No
33. Are you involved when another jurisdiction (County) makes modifications to intersections?	Yes	No
34. Does your state have a State Grade Crossing Action Plan as required under 49 CFR 534.11? (https://safety.fhwa.dot.gov/hsip/xings/) I think they mean 49CFR 234.11)	Yes	No
35. Are grade crossings hazard-ranked on regular basis (annually?)	Yes	No
36. What methods or mitigation strategies has your agency identified as impactful?		
37. Are there locations more prone to collisions (i.e., see more incidents)?	Yes	No
a. Are there any particular differences in street design, traffic lights, gating, etc. in those particular areas?	Yes	No
38. Have you implemented any form(s) of alternative notification of entering transit rail line (flashing lights, rumble strip, etc.)?	Yes	No
39. Any rail vehicle technologies implemented (i.e., collision avoidance, autonomous braking such as Bosch system used on trams in Germany)?	Yes	No
40. Any agency-wide standards for grade crossings specifically for areas with no grade separation (for example, UTA has uniform standards for grade crossings)?	Yes	No

Appendix B

Light Rail Technology Scan and Case Studies (TTCI Technical Report)

MITIGATION MEASURES FOR REDUCING LIGHT RAIL COLLISIONS: CASE STUDY RESEARCH,TECHNOLOGY SCAN, AND DEPLOYMENT RECOMMENDATIONS

P-18-047

Prepared for:

Federal Transit Administration and
Center for Urban Transportation Research (CUTR)

Prepared by

Kane Sutton

Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, CO USA

November 2018

Table of Contents

List of Figures

Executive Summary

The Federal Transit Administration (FTA) entered into a cooperative agreement with the University of South Florida and its Center for Urban Transportation Research (CUTR) to develop a Safety Standards Strategic Plan to identify areas of transit safety risk within the industry, inventory existing transit safety standards (or those within other transportation industries that could be modified to address transit safety-related risks), and establish focus areas for further research to support FTA's Standards Development Program (SDP). Light rail safety has been identified as one of those risks due to evidence supporting an increase in frequency and severity of collisions with the public. CUTR partnered with Transportation Technology Center, Inc. (TTCI) to investigate. This report focuses on TTCI's role in this investigation.

Case studies of seven transit authorities across the United States were conducted to learn more about the nature of the collisions they are experiencing, along with any mitigation practices they currently have in place. The case studies revealed that collisions with motor vehicles occur more than any other type of collision, typically in shared lane environments with no grade separation. In several cases these collisions occurred more than twice as often as those with pedestrians and cyclists combined. The mitigation measures deployed by the authorities in the case studies varied significantly. Some appeared to put more emphasis on technology, and others relied more upon policy and best practices.

TTCI also was tasked to conduct a technology scan with an emphasis on existing and emerging technologies with the potential of reducing light rail collisions. Several onboard collision avoidance systems were discovered. The capabilities of these systems ranged from simple video camera systems providing blind spot awareness to others capable of detecting potential collisions and taking control of the light rail vehicle in an attempt to prevent the collision. Given the typical stopping distances of light rail vehicles, line-of-sight sensing systems are well-suited for this application. Many wayside technologies also were investigated. Some of them focused on increasing the awareness of the public of an approaching train while others take the approach of preventing access of the public to the right of way when a train is present or approaching. Not all of the technologies found are specific to light rail but may be applicable.

All of the technologies presented are recommended for further investigation. As noted, some are light rail-specific and ready for pilot testing and evaluation and others will require further development to be adapted to the light rail environment. A pragmatic approach should be taken when considering technologies to deploy for collision mitigation. The deployment of any technology should be done after thorough testing that meets well-defined system requirements. A balance between enhancing awareness and limiting access to the right-of-way needs to be considered as well.

Introduction

The Federal Transit Administration (FTA) entered into a cooperative agreement with the University of South Florida and its Center for Urban Transportation Research (CUTR) to develop a Safety Standards Strategic Plan to identify areas of transit safety risk within the industry, inventory existing transit safety standards (or those within other transportation industries that could be modified to address transit safety-related risks), and establish focus areas for further research to support FTA's Standards Development Program (SDP). Through the SDP, research and background studies are being performed on safety-critical emphasis areas to collect the information necessary to support the identification and modification or development of voluntary standards or recommended practices for the public transit industry. In addition, it provides the support of the CUTR research team, CUTR, and Transportation Technology Center, Inc. (TTCI) to the American Public Transportation Association (APTA), the transit industry's standard development organization, to perform the research and background studies necessary to support APTA's standards process.

Previous work in support of FTA's Safety Standards Strategic Plan suggested that the frequency and severity of collisions of light rail vehicles with the public were increasing. Therefore, this mode of transportation was selected to be investigated with several goals in mind. The first was to gain a better understanding of the problem itself and identify some common factors across transit authorities, if any. Another goal was to identify current collision mitigation measures that have proven to be effective. The final goal was to research any technologies that may help prevent light rail collisions.

With these goals in mind, TTCI was tasked to do the following:

- Conduct case study research on the seven transit authorities listed below to determine any trends and correlations in both the collisions they are experiencing and the mitigation measures they are practicing:
  - Metropolitan Transit Authority of Harris County, Texas (Houston, TX)
  - Hillsborough Area Regional Transit Authority (Tampa, FL)
  - Tri-County Metropolitan Transportation District of Oregon (Portland, OR)
  - Los Angeles County Metropolitan Transportation Authority (Los Angeles, CA)
  - Massachusetts Bay Transportation Authority (Boston, MA)
  - Southeastern Pennsylvania Transportation Authority (Philadelphia, PA)
  - Greater Cleveland Regional Transit Authority (Cleveland, OH)
- Conduct a high-level scan of any existing or emerging technologies that could potentially improve light rail safety as it pertains to collisions with the public.
- Present the findings of the previous tasks and provide deployment recommendations for practices and technologies identified as potential mitigation measures for reducing light rail collisions.

Case Studies

The case studies of each transit authority initially involved gathering information about their light rail systems. The information provided was used to gain insight into the general operating environments of each system and to determine the types and frequency of collisions they are experiencing. This information also helped to identify mitigation measures that are currently in place and assess their effectiveness. A site visit to each transit authority also was conducted to gather additional information as needed. The site visits also provided the opportunity to selectively document and investigate any locations where the majority of collisions are occurring.

Metropolitan Transit Authority of Harris County, Texas

Operating Environment

The Metropolitan Transit Authority of Harris County, Texas, operates in the greater metropolitan area of Houston. The light rail service, known as METRORail, is approximately a 23-mile system comprising three lines of service—Red, Green, and Purple. The system is constructed almost entirely at-grade with street level, having both dedicated and shared lanes with vehicular traffic in densely populated areas. Allowable maximum speeds vary depending upon location. In most areas where there is high pedestrian traffic and vehicular traffic, this speed is 25 mph. In other locations where they have exclusive right-of-way with gated crossings maximum speeds can reach 45 mph. Figure 1 illustrates a common track configuration, particularly along the Red Line, consisting of two parallel tracks located along the street median with platforms intermittently placed between the tracks in the median for patron access.

Figure 1: Common track configuration

Areas of Significant Vehicle and Pedestrian Interaction

The majority of collisions METRORail experiences with the public are with personal vehicles. Among these collisions, the majority can be categorized into two types of events. The most common involves vehicles turning into the path of the train. More specifically, these turning incidents are usually left-hand turns. Given the common track configuration of having the tracks in the middle of the street, vehicles making left-hand turns need to cross the track to do so. In locations where it is legal to do so, the left-hand turn lane is sometimes shared with the train. See Figure 2. In this configuration, personal vehicles will attempt to enter the left-turn lane while a train is approaching from behind, likely in the vehicle’s blind spot, and get struck by the train despite signage warning vehicles of approaching trains.

Figure 2: Shared left turn lane

The other common occurrence involving left turns is in situations where there is no shared left-turn lane. In this configuration, vehicles will attempt to make a left turn from the adjacent lane and get struck by the train. This occurs at intersections where it is both legal (when signaled to do so) and illegal (always) to turn left at the intersection. Figures 3 and 4 are examples of both situations. The second most common type of collision event involves vehicles running red lights at cross street intersections. Some of the higher-incident cross streets appear to have relatively higher volumes of traffic that lead to highway access points.

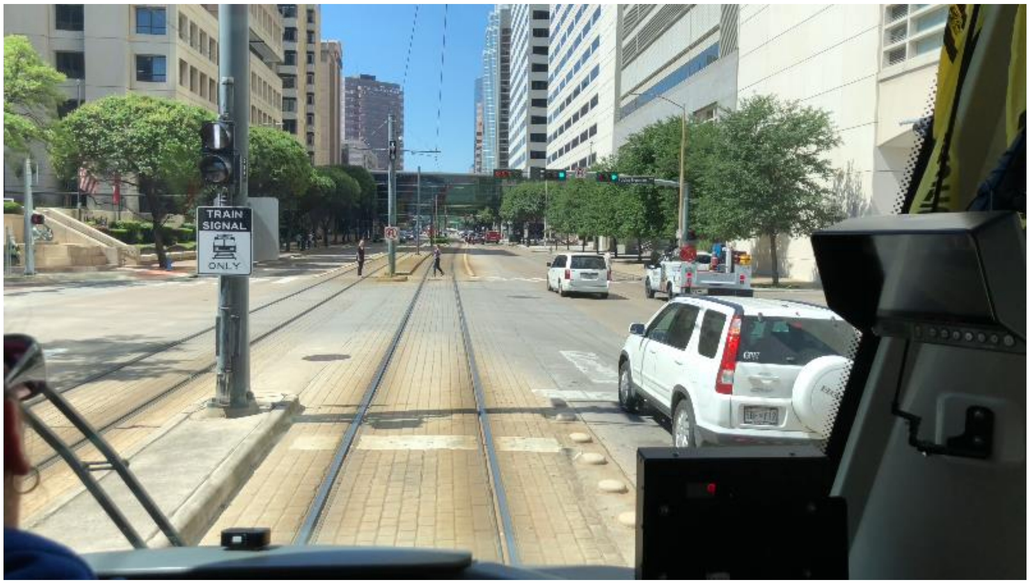


Figure 3: Legal left turn from adjacent lane

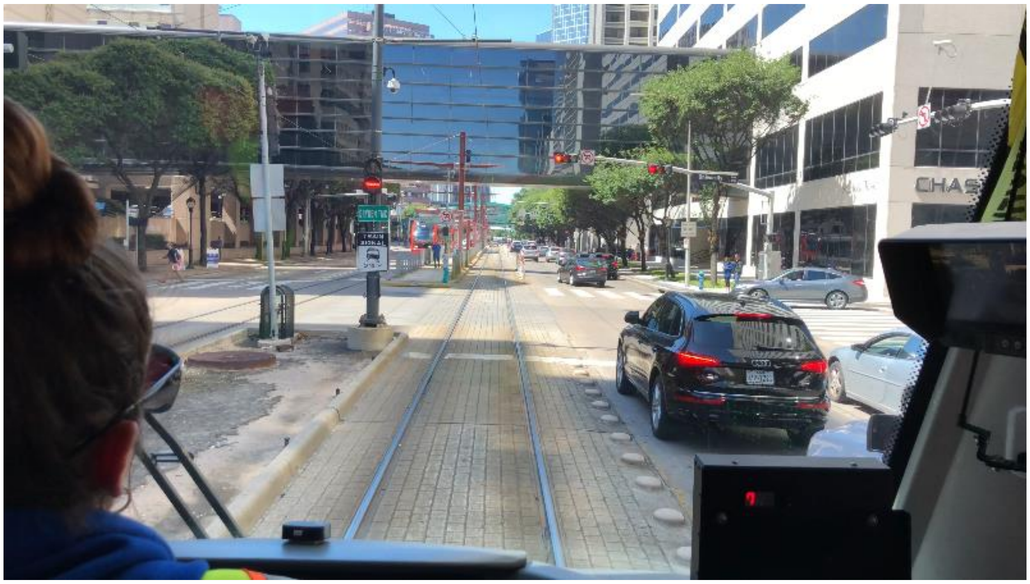


Figure 4: Illegal left turn from adjacent lane

It is important to note that after an accident occurs, it is reviewed by a board to determine, among other things, if it was preventable. The board determines if the operator did all they could to prevent the accident. The vast majority of accidents that METRORail experiences have been found to be non-preventable by the operator.

Notable Mitigation Measures

Houston Metro employs the use of various high visibility signage, lighting, and blank out signs to alert motorists and pedestrians of train traffic. See Figures 5 and 6 as well as previous figures for examples.

Figure 5: Traffic signaling

Figure 6: Traffic signaling

Traditional gated crossings tend to be used when there is enough space to employ them (Figure 7). Physical barriers also are employed to delineate and separate dedicated lanes. In some areas where dedicated lanes become shared left-turn lanes, plastic delineators are used (Figure 8). "Turtlebacks" also are used as deterrents to prevent cars from encroaching into a dedicated rail lane (Figure 9). Finally, fencing appears to be used where there is less cross traffic (Figure 10).

Figure 7: Gated crossing

Figure 8: Plastic delineators

Figure 9: Turtlebacks used to separate lanes

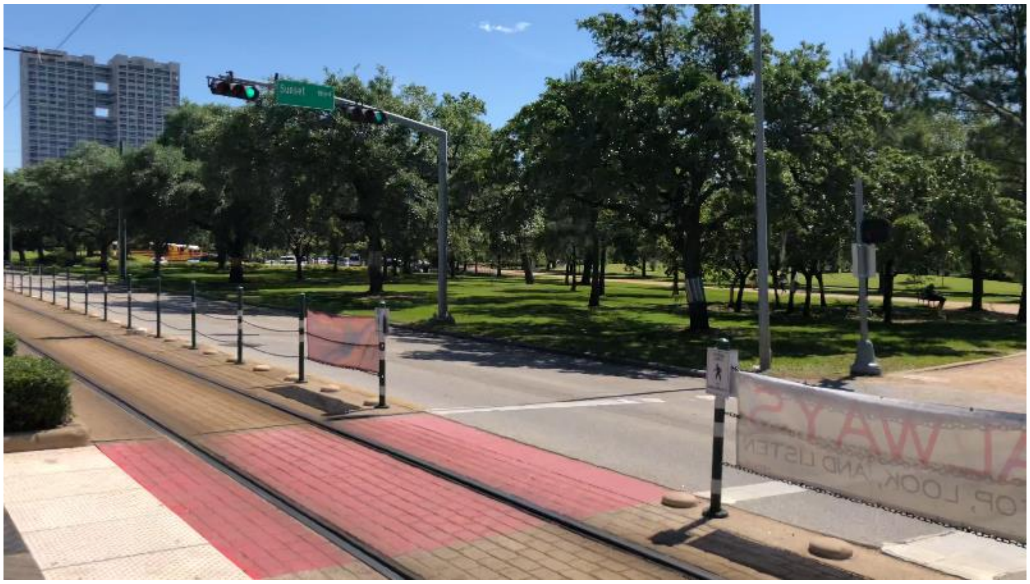


Figure 10: Fencing

Pedestrian crossings usually have well-defined crosswalks providing areas of refuge where needed. In one particular area where a high-profile fatality occurred with a cyclist, an experimental audible system is employed for approaching trains. This system is activated by a Bluetooth beacon on the train when it approaches and begins an audible message in both English and Spanish warning pedestrians of an approaching train with an intermittent bell sound. See Figure 11. Unfortunately, it also was activated as the train left due to the fact that there is a Bluetooth beacon at both ends of the train. This caused some confusion about whether or not a train was coming or going at times.

Figure 11: Bluetooth-enabled audio warning device

METRORail also employs what is referred to as a magnetic trip stop. This device is placed at intersections to send a magnetic signal to the train that causes it to stop if it enters an intersection during a stop signal.

Summary

Personal vehicles turning left and running red lights are the most prominent collision problems facing METRORail. Eliminating these types of collisions would reduce their collision rate by more than half. Houston Metro has employed various mitigation measures as noted above. It has a strong desire to reduce shared lanes with vehicular traffic as much as possible to help reduce collisions due to left turns. This could be improved with more consistent and effective delineation. "Turtlebacks" appear to be somewhat ineffective, and the plastic delineators known as "candlesticks" could be better maintained. Many candlesticks are missing or broken. For vehicles running red lights, Houston Metro would like to improve traffic signaling to make it more effective and consistent. Unfortunately, this requires coordination with the City of Houston, which has proven to be difficult to accomplish. Traffic signal preemption systems also could be improved to prevent all vehicular traffic from entering an intersection; however, this also requires close coordination with the City of Houston. There may be locations where crossing gates could be installed if the City would allow.

Hillsborough Area Regional Transit Authority

Operating Environment

Hillsborough Area Regional Transit, also known as HART, services the area of Tampa, Florida. HART has a small streetcar system on a single line that is about 2.7 miles long servicing the downtown and some of the surrounding areas of Tampa Bay. It operates at street grade in its own separated lane; occasionally, it operates on ballasted track in an exclusive right-of-way. The maximum operating speed is approximately 20 mph. A typical track configuration has the track off to one side of the road using a small concrete median to separate the streetcar lane from vehicular traffic. See Figure 12.

Figure 12: Typical track configuration

Areas of Significant Vehicle and Pedestrian Interaction

HART experiences one specific type of collision more than any other. Due to the given track configuration being off to one side of the street, vehicles approach from a cross street on the side where the track is often encroached while attempting to turn and get struck by an oncoming streetcar that has no time to stop. The problem some motorists encounter is a lack of visibility of traffic on the street where the tracks are when coming to a stop at the designated point. Having the streetcar tracks and a crosswalk in front of them when stopped at a stop sign often puts them in a position where there is not a clear line of sight to the left and or right to see oncoming traffic. See Figure 13 for an example of this situation.

Figure 13: Poor line of sight from cross street

If a vehicle wanted to turn left in the example given in Figure 13, it has to move forward onto the tracks to see traffic approaching from the right. Meanwhile, a streetcar could be approaching from the left with no time to stop before colliding with the vehicle on the tracks. This situation also occurs from parking areas located on the track side of the street.

Another potential hazard given this configuration could arise from vehicles traveling in the same direction as the streetcar. In this situation, a vehicle may not notice the streetcar in their blind spot and turn right into the path of a streetcar. See Figure 14 for an example of an intersection where this could occur.

Figure 14: Potential right-turn conflict

Notable Mitigation Measures

HART employs the use of signage and lights at crossings like those shown in Figure 15. There is one location where a parking lot-style gate is used at the exit of a parking lot to prevent vehicles from encroaching onto the tracks when a train is approaching (Figure 16).

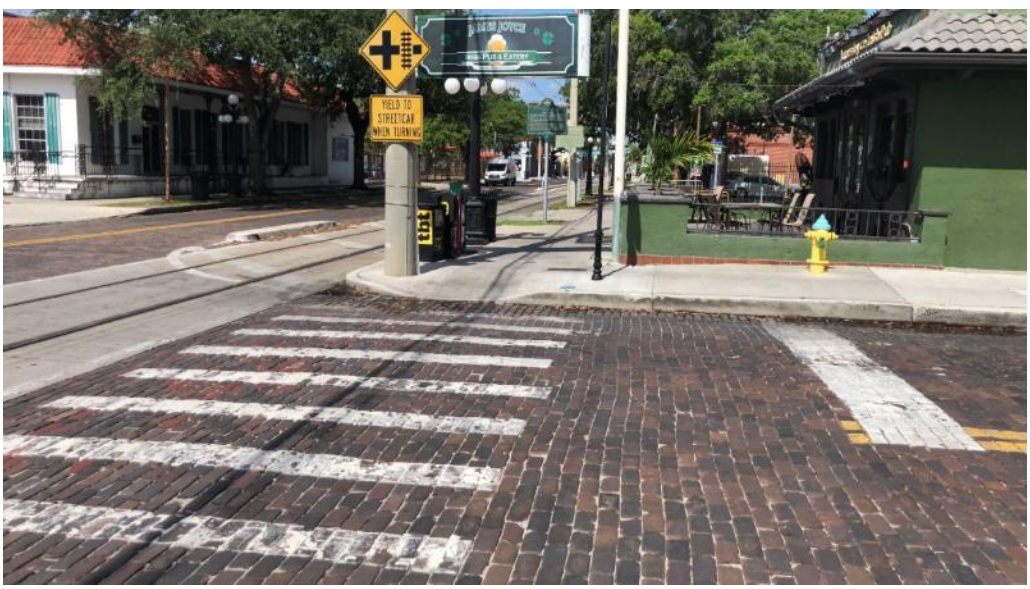


Figure 15: Warning signs

Figure 16: Parking lot exit gate

The City of Tampa and HART are currently involved in a connected vehicle pilot program using vehicle-to-vehicle communication technology meant to improve safety and traffic in downtown Tampa. In this pilot program, approximately 1,600 personally owned vehicles, 10 HART buses, and 10 street cars will be equipped with this technology. An application also will be available for pedestrians to download. This technology has the potential to alert motorists and pedestrians of approaching streetcars. It also could enhance the awareness of streetcar operators of possible collisions ahead. In this pilot program, operators will receive a warning when a connected vehicle or pedestrian is about to cross the tracks, reducing the risk of collision. This pilot program is being conducted in several cities and is currently in a data collection phase.

Summary

Although HART has a relatively small rail transportation system, it still has some challenges. Vehicles turning into the path of a streetcar are its primary collision-related problem. Having higher visibility signage and lighting may assist the public's awareness. It was also noted that pavement markings are severely worn and faded at several intersections (perhaps due to the extreme exposure typical in this climate). Innovative mitigation measures such as a parking lot exit gate show promise where standard railroad gates cannot be installed due to lack of space. Finally, the connected vehicle technology appears to have significant potential preventing collisions with pedestrians and vehicles, enhancing the awareness of both the public and the streetcar operators.

Tri-County Metropolitan Transportation District of Oregon

Operating Environment

The Tri-County Metropolitan Transportation District of Oregon, also known as TriMet, services the greater metropolitan area of Portland. The light rail service, known as MAX Light Rail, has approximately 122 miles of track with 5 lines of service. The Willamette River runs directly through the downtown area of Portland. Of the many bridges that cross the river, all five lines of service use only two. One line in particular, the Blue Line, is more than 30 miles long, operating in both urban and suburban environments. Given the diversity of the areas of operation, maximum operating speeds vary from 20 to 55 mph. The MAX Light Rail is generally at street grade with a mixture of shared and dedicated lanes as well as areas with exclusive right-of-way. Track alignment varies significantly from one area to the next. In some locations, the tracks are off to one side of the street and in others they are located in the middle.

Areas of Interest

Given the diverse operating environment, there does not appear to be a consistent type of collision with the public that occurs other than those with personal vehicles. The MAX light rail has many distinct situations that create specific problems that vary from one locale to the next. The following is a sample of some of the situations.

The 10th Avenue and Washington Street intersection in the Hillsboro Area, along the Blue Line, is where the tracks transition from the middle of the street on one side of the intersection to the side of the street on the other side of the intersection. This causes line of sight issues for vehicles coming from one direction. See Figures 17 and 18.

Figure 17: West side of intersection (tracks in middle)

Figure 18: East side of intersection (tracks to side)

At another intersection, 12th Avenue and Washington Street (also Hillsboro), Washington Street runs parallel with the tracks that comes to a gated cross street, 12th Avenue. The gate controls traffic only on 12th Avenue, making it easy for traffic to potentially make a left turn onto the tracks from Washington Street. See Figures 19 and 20.

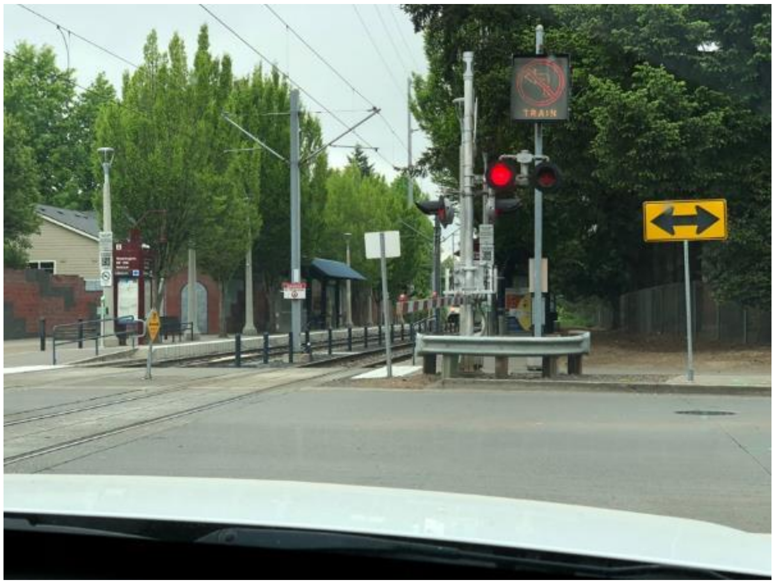


Figure 19: Parallel street at gated crossing

Figure 20: Parallel street at gated crossing

Near one of many of Portland's bridges there is an extremely busy intersection, SW Moody and Tilikum Crossing, where a high volume of cyclists and pedestrians can flow during certain times of the day. Given the track alignment and multiple crossings, the risk of collision appears to be high in this area. See Figure 21.

Figure 21: Moody Avenue and Tilikum Crossing

At Holladay and 11th Avenue, MAX light rail experiences a high risk of collisions with personal vehicles turning into the path of the train. Given the configuration, this could occur from multiple directions. The width of the dedicated light rail lane with poor markings appears to exacerbate the situation. See Figure 22.

Figure 22: Holladay and 11th turning hazard

Not far from Holladay and 11th is a location where an exit ramp from a highway, I-84, unloads at a location next to the tracks. See Figure 23. In the figure, the exit ramp is to the right. Vehicles exiting the highway are traveling at relatively high speeds and come around a blind curve that deposits them right at a crossing. This is a potentially dangerous situation that requires better traffic control of personal vehicles on the exit ramp.

Figure 23: Exit ramp hazard

Although they do not necessarily occur in similar configurations, collisions with personal vehicles due to poor line of site is an occurrence of note in Portland. Figure 24 illustrates an example where line of sight is blocked due to an overpass column. Figure 25 shows an example of poor line of sight due to nearby buildings.

Figure 24: Overpass column

Figure 25: Buildings and vegetation

The downtown area poses a special situation that causes collisions with personal vehicles as well. Like most downtown areas, there are many one-way streets, and the tracks are located to one side of the street in a dedicated lane. However, the only thing delineating the two lanes is turtlebacks, many of which are either missing or degraded. The street lanes are narrow, and it is common for a vehicle to stop in the street, blocking traffic behind. The blocked traffic will then proceed to go around the parked car using the light rail lane to the left. Sometimes when doing so, they go directly into an approaching train's path. See Figure 26.

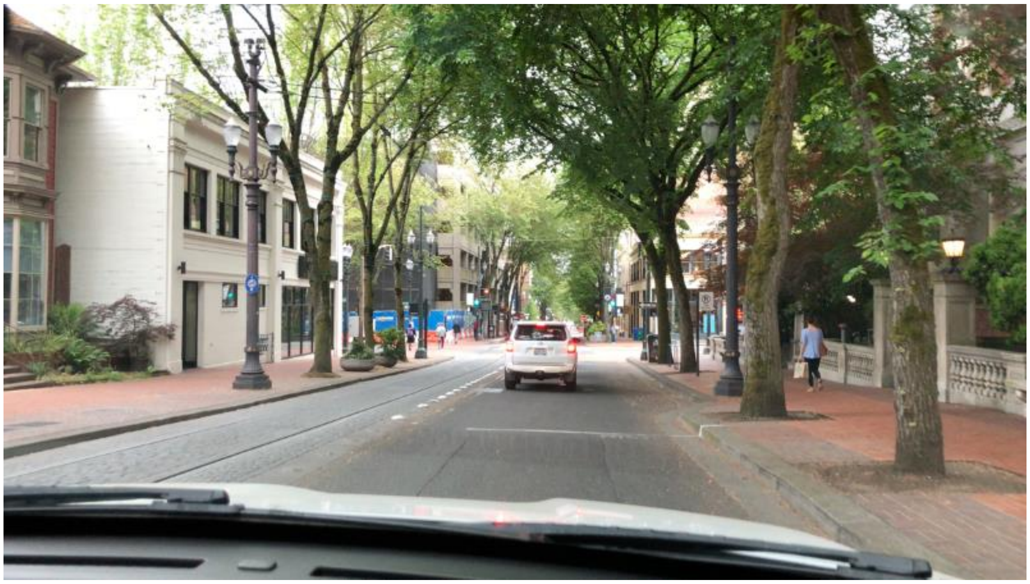


Figure 26: Downtown Portland

Notable Mitigation Measures

TriMet employs a variety of signs and lighting at intersections to make the public more aware of train traffic. Despite the diversity of the operating environment, it appears to be somewhat consistent. See Figures 27 and 28 for examples.

Figure 27: Signage and lighting

Figure 28: Signage and lighting

TriMet recently improved some of its pedestrian crossing treatments by making them more channelized and installing one way swing gates. See Figures 29 and 30. It also installed a newly designed pedestrian warning pole equipped with an audible warning bell, flashing red lights, and a passive “Look Both Ways” warning sign. See Figure 31.

.

Figure 29: Channelized pedestrian crossing

Figure 30: Swing gate

Figure 31: Pedestrian warning pole

Many of TriMet's crossings are protected by gates in some of the less densely populated areas such as those seen at the ends of the Blue Line. This likely is due to the fact that there is more space available to install them. Additionally, it is important to note that the MAX light rail service traverses through several different municipalities, each of which is responsible for signage, traffic signaling, and crossing gates. Therefore, depending upon the municipality, some crossings may be better protected than others. For instance, the City of Portland has been reported to be reluctant to install some treatments such as gated crossings or more effective lane delineators for aesthetic reasons, whereas another region may be more inclined to do so.

Summary

MAX light rail operates in a diverse environment, which presents some different interactions with the public. There appears to be more collisions with vehicles than pedestrians. However, the nature of these collisions and hazards differs according to the area that MAX light rail services, which ranges from different urban and suburban environments. Additionally, the presence of the Willamette River, effectively dividing the service area in half, has an effect on track alignment and, subsequently, how it services the public, which, in turn, presents challenges like those present at Moody Avenue and Tilikum Crossing. TriMet is dependent upon the different municipalities it services for much of the crossing treatments and traffic signaling needed to maintain safety. Fortunately, it has a good working relationship with these municipalities. TriMet appears to have put a significant amount work into improving its pedestrian crossings through channelizing and implementing a new warning pole.

Los Angeles County Metropolitan Transportation Authority

Operating Environment

The Los Angeles County Metropolitan Transportation Authority services the greater metropolitan area of Los Angeles. This is a densely populated urban environment. The rail service, known as LA Metro Rail, has approximately 105 miles of track. It comprises six lines—four light rail and two heavy rail. The light rail service has a variety of installations ranging from elevated at street grade with dedicated lanes and at street grade with exclusive right-of-way to underground. Operating speeds vary significantly due to the different operating environments.

Areas of Significant Vehicle and Pedestrian Interaction

LA Metro Rail experiences the majority of its collisions with the public along its Blue Line of service. This line extends from the Metro Center (downtown Los Angeles) to Long Beach. The majority of this line is at street grade, and most collisions are with personal vehicles. The primary hazard is from vehicles turning left across the tracks. See Figures 32, 33, and 34.

Figure 32: Left turn

Figure 33: Left turn

Figure 34: Illegal left turn

Notable Mitigation Measures

LA Metro has implemented significant mitigation measures in areas where it has experienced more collisions. There is a section of the Blue Line where the train has exclusive right-of-way that has recently received attention to control access to intersections. This area begins with having substantial fencing to prevent trespassing. See Figure 35.

Figure 35: Fencing

The intersections appear to be effectively controlled with the use of gated crossings for both the vehicles and pedestrians. See Figures 36 and 37.

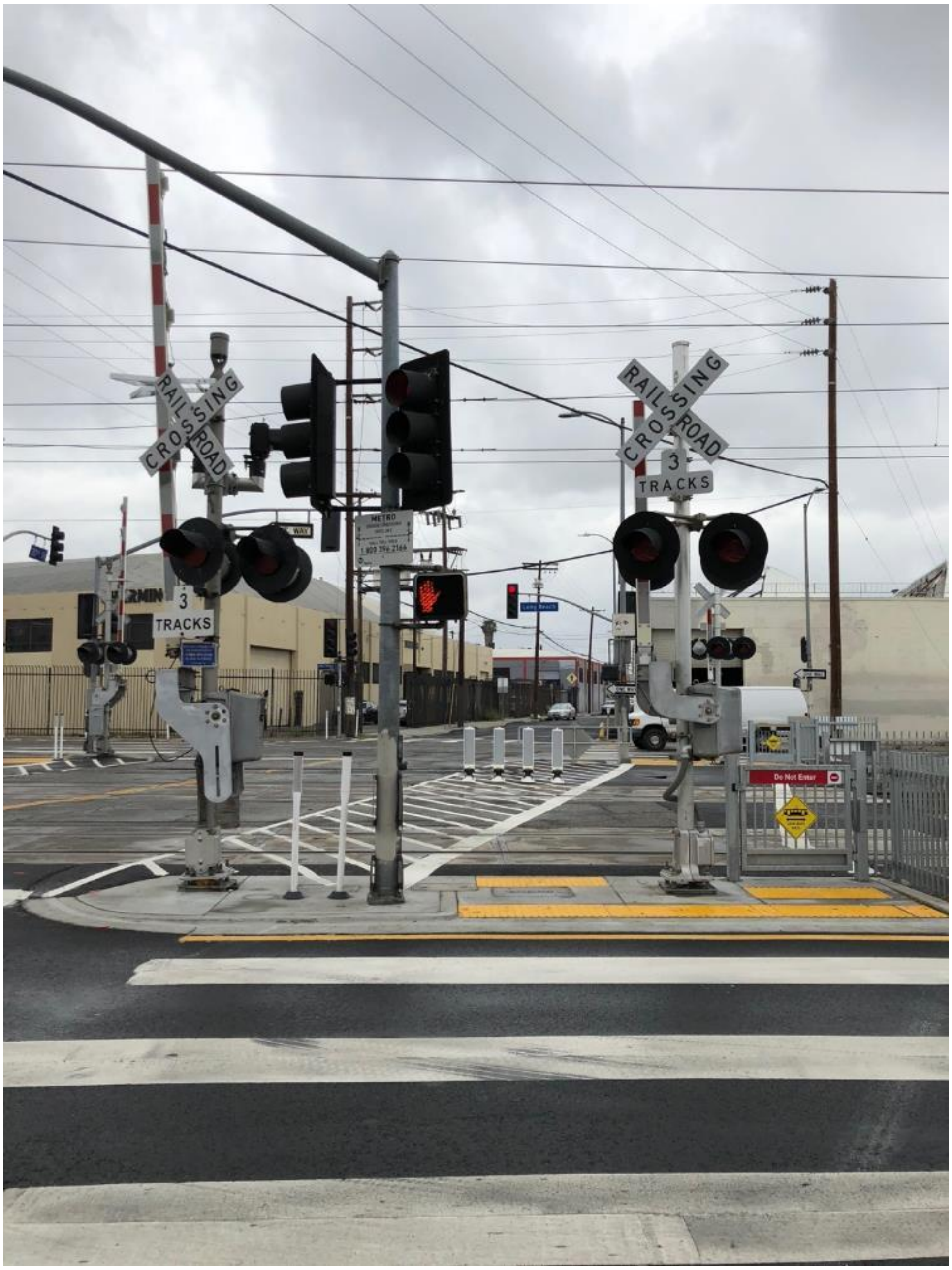


Figure 36: Gated crossings

Figure 37: Gated crossings

Note that the pedestrian crossings are equipped with swing gates (Figure 38) designed to open in a manner that will allow pedestrians to exit the crossing if they find themselves in the crossings with the other crossings gates down.

Figure 38: Pedestrian swing gates

In addition to the use of gates, these crossings have a substantial amount of signage, lighting, and audible warnings, so much that it may be more than what the public can digest at once. See Figures 39 and 40.

Figure 39: Signage and lighting

Figure 40: Signage and lighting

The Blue Line has some issues with vehicles turning left in front of the train. In many of these locations, there is no room to implement gated crossings as in other areas. Therefore, LA Metro has implemented a pilot project for a parking garage-style gate in one location that has a history of collisions. Figures 41 and 42 illustrate a location where vehicles turn left onto a freeway entrance ramp controlled by one of these gates.

Figure 41: Parking lot-style gate

Figure 42: Parking lot-style gate

On the Gold Line, LA Metro has installed embedded lighting in the road to act like a virtual barrier in an effort to prevent vehicles from turning left into a train's path. See Figures 43 and 44.

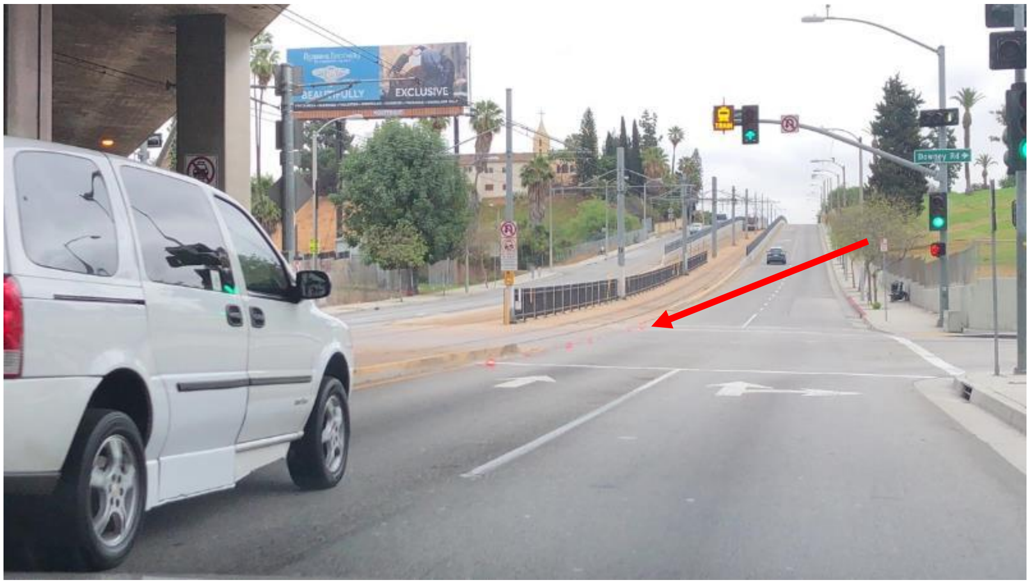


Figure 43: Embedded lighting

Figure 44: Embedded lighting

For some crossings where vehicles tend to violate traffic signaling and enter the crossing, LA Metro has implemented a camera system that detects when personal vehicles commit dangerous traffic violations and takes a picture of the offending vehicle. The license plate number of the personal vehicle is recorded, and the registered owner of the vehicle is fined $400. Figures 45 and 46 show one of these systems installed on the Blue Line.

Figure 45: Photo enforcement


Figure 46: Photo enforcement

Finally, there are some crossings where four-quadrant crossings have been installed in an effort to reduce the possibility of personal vehicles going around crossing gates. See Figures 47 and 48.

Figure 47: Four-quadrant gated crossing

Figure 48: Four-quadrant gated crossing

LA Metro has installed a system on some crossings that detects if a personal vehicle is inside the crossing via mass detection when a train is approaching and signals the train in an effort to alert the operator. Figure 49 shows one of these aspects directed towards the direction of the train, which lights up if a vehicle is detected in the crossing.

Figure 49: Vehicle detection warning system

Summary

LA Metro's service area includes densely-populated regions in both pedestrian and vehicular traffic. Like many other light rail services in the country that are at street grade, there is a significant challenge preventing collisions with personal vehicles. LA Metro has a significant issue with personal vehicles turning left into the path of a train. Also, given the dense population, it also has a need to control high volumes of pedestrian traffic. LA Metro has implemented a number of mitigation systems in an effort to reduce collisions with the public, including robust and innovative physical controls where possible to limit access to intersections and effective lighting embedded in the street to act as a virtual barrier where physical gates are not possible. Photo-enforced fines act as deterrents against intentional traffic violations that could lead to a collision. LA Metro is not without problems in terms of collisions with the public. However, the measures it takes to control them are impressive and could be helpful to other transit agencies.

Massachusetts Bay Transportation Authority

Operating Environment

The Massachusetts Bay Transportation Authority (MBTA) services eastern Massachusetts as well as some parts of Rhode Island. It has two light rail lines that service the Boston area – the Green Line and the Mattapan Line. These two lines combined are approximately 126 revenue miles in length, the majority of which belongs to the Green Line. The installations are primarily a combination of exclusive right-of-way in the median with frequent level crossings and imbedded at street grade sharing the right-of-way with vehicles. Due to the congested nature of the Boston area, operating speeds tend to be 20 mph or less. However, in a few areas where the surrounding population is less dense, operating speeds can reach 40 mph.

Areas of Significant Vehicle and Pedestrian Interaction

The majority of the collisions experienced by MBTA are with vehicles. According to data provided by MBTA, the frequency of collisions with vehicles is approximately 3 to 4 times that of collisions with pedestrians and cyclists. This can be attributed to the congested nature of the operating environments, with frequent crossings and shared lanes with motor vehicles. See Figures 50 and 51 for examples of typical operating environments.

Figure 50: Typical level crossing

Figure 51: Shared-lane environment

One area of particular concern at crossings is the inclination for the public to turn in front of a train, both legally and illegally. In either case, the train operator has little to no time to react. Figure 52 illustrates several cars making both left and right turns onto a crossing, and Figure 53 shows an illegal left turn, which is a common occurrence, according to MBTA personnel.

Figure 52: Turning vehicles

Figure 53: Illegal left turn

In shared-lane environments, clearance is another issue. There is little room for trains to operate in this environment, which can result in track fouling and "sideswipe" incidents. Figure 54 shows a clearance situation where the rear-view mirror of a school bus comes close to making contact with a passing train. In this instance, the bus driver realized the potential collision and stopped to allow the train to pass before proceeding.

Figure 54: Clearance example

Notable Mitigation Measures

There appear to be minimal physical mitigation implementations for collision avoidance in high-risk locations like crossings, aside from typical traffic and pedestrian signaling and signage. Some signage encourages pedestrians to look for trains at pedestrian crossings. Fencing also is placed in many locations to prevent pedestrians from crossing the tracks, and most pedestrian crossings were also painted yellow. See Figures 55 and 56 for examples.


Figure 5: Typical pedestrian crossing

Figure 6: Pedestrian signage

The most notable collision mitigation measure practiced by MBTA is train speed. They have a rigorous speed enforcement program and frequently spot-check train speed. By keeping speeds lower, operator reaction time and train stopping distances are reduced.

Summary

MBTA's light rail system is one of the oldest in the country, with sections that have been in place since before 1900. It also is one of the most heavily used light rail systems in the country. Since its inception, the surrounding communities have changed and grown significantly and have also become dependent upon light rail transportation. The combination of age and communal dependency has resulted in a population that is familiar with the system. Given the challenges MBTA faces with its light rail service, its approach to collision mitigation with the public is a pragmatic one that relies on public common knowledge and a strict speed enforcement policy rather than technological implementations.

Southeastern Pennsylvania Transportation Authority

Operating Environment

The Southeastern Pennsylvania Transportation Authority, widely known as SEPTA, services the city of Philadelphia and four other surrounding counties. The light rail service operates within the western Philadelphia metropolitan area and has approximately 73.6 miles of track. This region is a densely-populated urban environment. The service operates almost entirely at street grade on embedded track with dedicated and shared lanes with motor vehicles. The maximum operating speed is 45 mph; however, it generally operates at 25 mph. SEPTA's light rail service is a trolley service where the vehicles generally operate as a single car.

Areas of Significant Vehicle and Pedestrian Interaction

Given its operating environment, the majority of collisions that occur are with motor vehicles on shared streets. During a site visit, several hazards with motor vehicles were identified and noted by SEPTA personnel. The first is from vehicles either unexpectedly turning or switching lanes in front of an oncoming trolley. It is common for the trolley to merge into a shared lane from a dedicated lane, which also facilitates the hazard. The potential for this hazard presents itself where there is a shared lane on a street of multiple lanes and at intersections with turn lanes. See Figures 57 through 60 for examples.

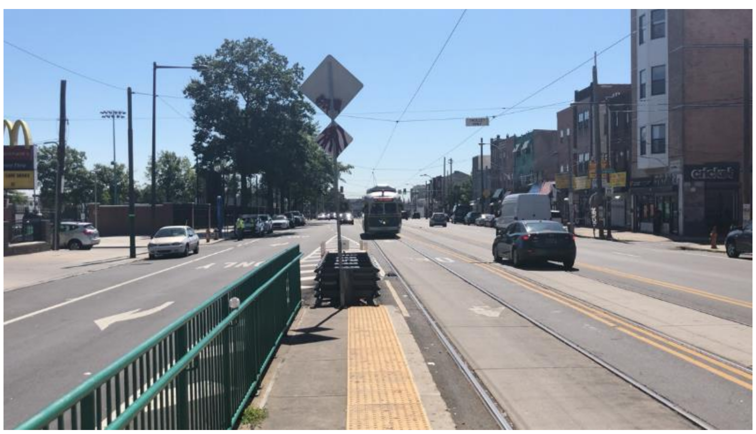


Figure 57: Trolley emerging from dedicated lane to shared turn lane

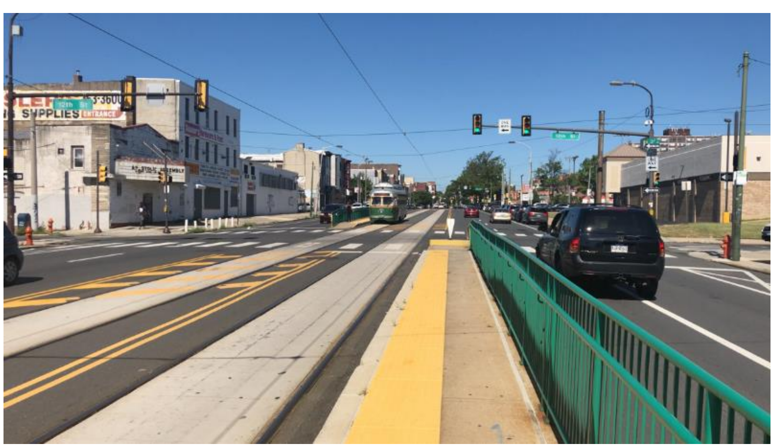


Figure 58: Turning scenario at an intersection

Figure 59: Turning scenario

Figure 60: Traffic merging into a dedicated lane

The other common type of collision with vehicles occurs from clearance issues and track fouling. There are many single-lane streets where there is little clearance between the trolley and parked cars. Occasionally, a trolley will come into contact with a parked vehicle. Usually, the operator will recognize the situation and will stop service and have the vehicle moved. See Figure 61 for an example of this situation.

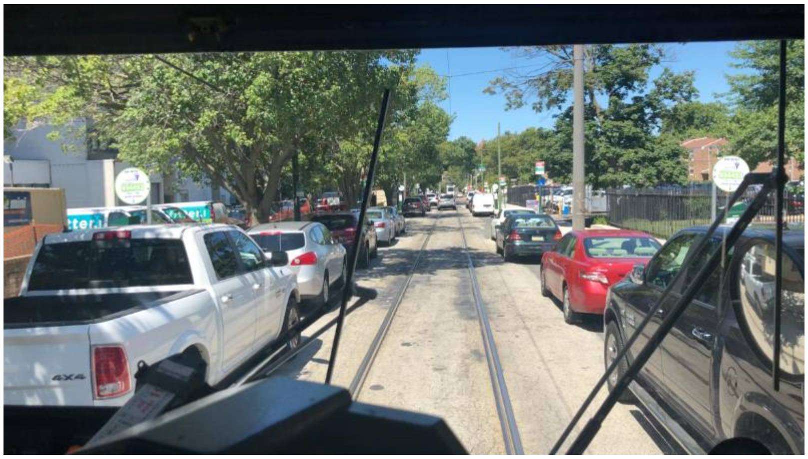


Figure 61: Parked cars

Related to clearance and track fouling, one of the most common collisions occurs due to the front and rear of the trolley swinging out into adjacent traffic lanes in a curve. Also, due to the length of the trolley, its center will encroach into an adjacent lane on the inside of a curve. Some motorists are not cognizant of these situations and do not maintain proper distance from the trolley and its tracks, resulting in collisions. See Figures 62 and 63.

Figure 62: Corner of trolley swinging out in curve

Figure 63: Center of trolley encroaching inside lane

Notable Mitigation Measures

SEPTA relies upon various signage and common traffic signaling to help maintain public awareness and prevent collisions. Figures 64 and 65 illustrate some of the trolley specific signage used.

Figure 64: Trolley-only sign for dedicated lane

Figure 65: Sign illustrating clearance in turn zone

SEPTA is in the process of investigating some onboard technologies originally designed for buses to detect potential collisions and exploring the possibility of adapting them to its trolleys. These technologies are meant to increase operator awareness, particularly in blind spots, and alert them of potential collisions. Two of the technologies being investigated are the Protran Blind Spot Awareness System and Mobileye Shield+ Collision Avoidance System.

Summary

Philadelphia is a densely-populated urban environment with congested traffic conditions that make it challenging to operate light rail service. Collisions with vehicles are, by far, the most common type of collision with the public. Collisions from vehicles turning and switching lanes in the path of trolleys might be mitigated better with more effective traffic signaling and signage. Having more prominent delineation and perhaps physical barriers for dedicated lanes and, if possible, reducing the number of shared lanes could help mitigate collisions as well. For clearance-related accidents, there also could be better signage to keep the public aware of the trolley's turning clearances. In addition, SEPTA's investigation of adapting blind spot alert technology in buses to its trolleys could prove to make a significant improvement in its collision rate with vehicles.

Greater Cleveland Regional Transit Authority

Operating Environment

The Greater Cleveland Regional Transit Authority (GCRTA) services the city of Cleveland, Ohio, and the surrounding suburbs of Cuyahoga County. The light rail service totals approximately 15.3 miles of revenue track with three lines—Blue, Green and Waterfront. Sections of the light rail service date back to the early 1900s. These lines operate in an exclusive right-of-way with frequent level crossings in urban and suburban environments. Maximum operating speeds can reach 45 mph, although generally they operate at around 25 mph. See Figures 66 and 67 for some examples of typical operating environments.

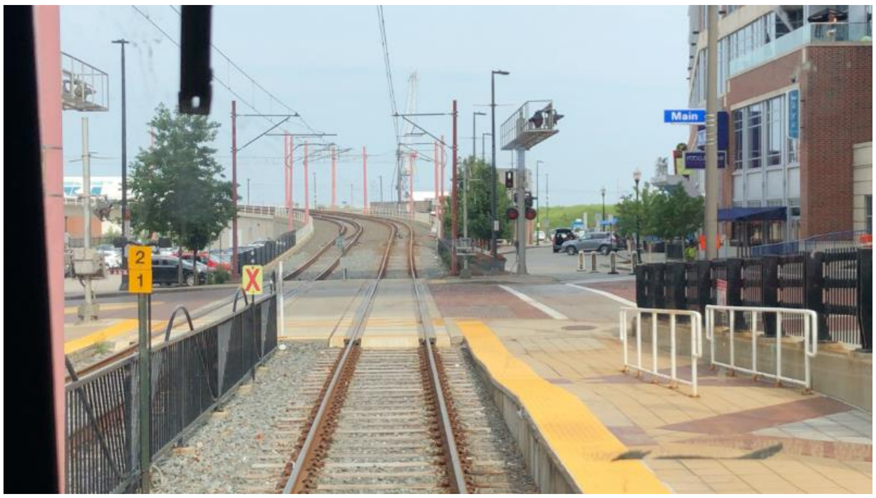


Figure 66: Downtown Cleveland approaching Lake Erie

Figure 67: Green Line, Shaker Heights

Areas of Significant Vehicle and Pedestrian Interaction

Of the few collisions the GCRTA light rail service experiences, the majority occur at grade crossings with vehicles making left turns despite the clear signaling and signage prohibiting traffic to do so when a train is approaching and in a crossing. In these instances, the tracks are generally located in a wide median, with vehicular traffic traveling one way on either side. See Figures 68, 69, and 70.

Figure 68: Left turn situation

Figure 69: Left turn situation

Figure 70: Left turn situation where Blue and Green lines meet

Notable Mitigation Measures

The GCRT uses a combination of static and blank out signs to warn drivers of an approaching train prohibiting them from making a left turn onto its path. See Figures 71, and 72.

Figure 71: No left turn static sign

Figure 72: No left turn blank out sign

When permitted to do so, GCRTA also employs the use of gated crossings. There are several locations where it would like to do so; however, they are not permitted by the local municipality due to aesthetic reasons according to GCRTA personnel. Figure 73 illustrates a location where they are in place.

Figure 73: Double gated crossing

Fencing is also frequently used to deter pedestrians from crossing the tracks, as shown in Figure 74.

Figure 74: Fencing

Summary

Although most of GCRTA's collisions are with vehicles, the frequency is relatively low. This may be attributed to a number of factors. One possible factor could be its size and the population density in which it operates compared to other transit agencies. Another may be that its light rail service generally operates in an exclusive right-of-way with significant space and barriers that control its exposure to the public, limiting it to platforms and crossings. Finally, for the most part, it employs effective and consistent signaling at crossings warning the public of approaching trains. Many of these crossings could still be improved upon if they were gated in some way which would help to reduce their collision rate even further.

Case Study Summary

The case studies revealed that collisions with motor vehicles occur more frequently than any other type of collision. This was consistent across all transit authorities studied. This comes as no surprise given the fact that light rail operations typically operate on or near streets with frequent grade crossings in urban environments with congested traffic conditions. Collisions with vehicles typically occur at crossings where parallel traffic attempts to turn into the path of an oncoming light rail vehicle. It also was evident that operating environments with more shared lanes and no grade separation experienced more collisions while those with exclusive right-of-way had less. However, not all transit authorities are the same; comparing one authority to another needs to take into account many factors such as the population densities they serve and the size of their light rail networks.

Collision mitigation methods varied across transit authorities. Some authorities clearly focused more on physical implementations, such a gated crossings and high-visibility signage, and others focused more on operating policy such as reduced speed. Some authorities also are experimenting with innovative implementations such as parking lot-style gates and embedded street lighting at crossings. These implementations have not been in place long enough to determine their efficacy. It also is important to note that another factor that appears to highly influence each transit authority's ability to mitigate collisions is the traffic signaling systems used to govern the surrounding vehicular and pedestrian traffic. Often, these signaling systems are not managed by the transit authorities; rather, they are managed by the local municipality in which they operate. Well-coordinated traffic signaling systems can greatly improve collision mitigation methods implemented by the transit authorities.

Technology Scan

The technology scan yielded a variety of results. Several onboard collision avoidance systems are in existence today. Some are designed specifically for light rail vehicles and others may be designed for buses, semi-trailer trucks, or any other large motor vehicles but could possibly be applied to light rail vehicles. There also are wayside technologies with the potential to improve light rail safety. Both onboard and wayside applications have varying degrees of complexity with both active and passive systems. This section summarizes these findings providing examples. It is not meant to be all-inclusive or exhaustive; it is merely an overview of the types of technologies that were discovered.

Collision Avoidance Systems

The collision avoidance systems identified in this scan were categorized as follows:

1. Passive
2. Active with No Control
3. Active with Control

Passive Systems

Passive systems are akin to video surveillance. The simplest are video camera systems with cameras strategically placed around the vehicle and a display near the vehicle control stand that allows the operator to see all around the vehicle and take action if necessary to avoid a collision. Forms of this technology have been available for decades. Manufacturers of these types of systems are numerous, with various types of applications that could easily be applied to light rail vehicles in both new and retrofit installations. Light rail vehicles are large vehicles with numerous blind spots. Having 360-degree vision around the vehicle would enhance operator awareness and potentially improve reaction times.

Systems of this nature have been extensively evaluated for use in buses in the past, suggesting that they are effective at reducing side collisions.[1] An example of this technology is provided by a company called SEON. In a bus application, four cameras are strategically placed on each side of the vehicle. Images from these cameras are then blended together and displayed to the driver as a single image on a dash-mounted monitor. See Figure 75.

Figure 75: SEON's inView 360 Collision Avoidance System[2]

Active Systems with No Control

The next type of collision avoidance system is one that is capable of sensing its surroundings and providing an alert to the operator of a potential collision. It is then up to the operator to make a decision and take the appropriate action. The purpose behind these types of systems is to enhance

[1] Lin, P.-S., Lee, C., Kourtellis, A., & Saxena, M. (2010), "Evaluation of Camera-Based Systems to Reduce Transit Bus Side Collisions," University of South Florida, Center for Urban Transportation Research.

[2] Around Vehicle Monitoring System inView 360, (October 11, 2018), retrieved from www.seon.com/products/collision-avoidance-systems/inview-360.

the operator's senses so that they can react more quickly, just like in the case of the video surveillance systems described earlier. However, in this case, the system is analyzing and reacting to its surroundings by providing alerts to the operator and bringing a potential collision to their attention. Systems of this nature can sense their surroundings in a variety ways using video cameras, radar, lidar, thermal imaging, etc. These different sensors provide data for analysis by a central processing unit that then sends alerts as necessary. Alerts are typically either visual and or audible.

There are applications of this technology for large vehicles such as buses and semi-trailer trucks. Two examples of this technology already were noted in the case study for SEPTA. Protran's Blind Spot Awareness System uses radar to detect objects in the blind spot of the vehicle and then provides an audible and visual warning to the operator. The visual warning comes in the form of an LED indicating light. Figure 76 illustrates this application on a bus.[3]

Figure 1: Protran blind spot awareness

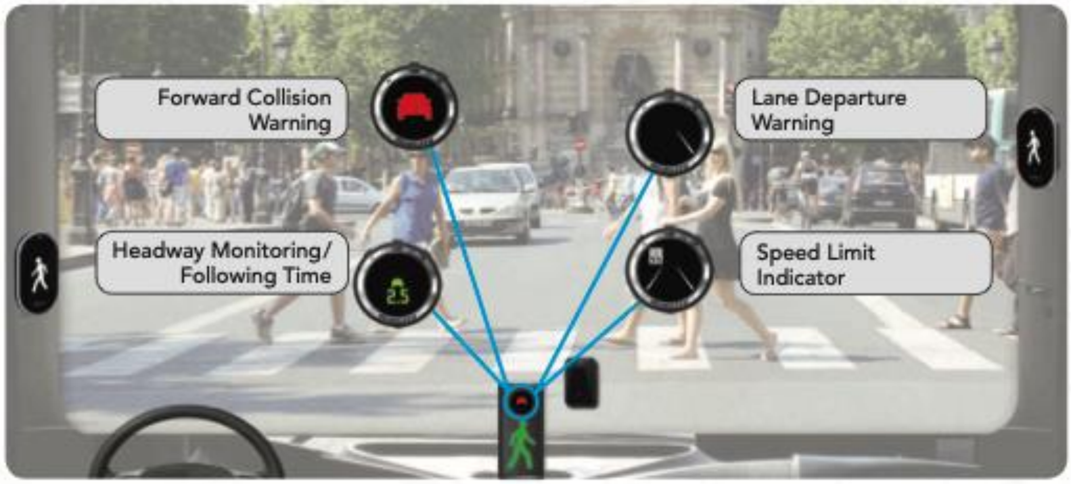
The Mobileye Shield+ Collision Avoidance System by Rosco Vision Systems is another system of this nature. It uses an artificial vision sensor capable of detecting other vehicles, pedestrians, and cyclists. The system continually measures the distance and relative speed of the vehicle to vulnerable road users (VRU), providing both visual and audible alerts and notifying the operator of the presence of VRUs and potential collisions. Figure 77 illustrates a typical bus installation, and Figure 78 illustrates the alert display readouts for the operator in a typical bus installation.[4]

---

[3] Blind Spot Awareness (October 11, 2018), retrieved from www.protrantechnology.com/bus-safety/blind-spot-awareness.
[4] VQS4560 (October 11, 2018), retrieved from www.roscovision.com/our-products/view/VQS4560.

Figure 77: Typical bus installation of Mobileye Shield+ Collision Avoidance System

SMART SENSOR AND DRIVER DISPLAY LOCATIONS



The Shield+ System for commercial vehicles includes three (3) display modules that alert the driver, visually and audibly, when the bus is in motion, and a pedestrian and/or cyclist is in one of the danger zones around the bus.

DRIVER ALERT DISPLAY READOUTS

	FEATURE	DESCRIPTION
Center Display Only	**Lane Departure Warning**	Alerts when vehicle departs from driving lane without turn signals. Right/left lane icon as appropriate. Active above 34 MPH.
	Speed Limit Indicator	Alerts when the vehicle exceeds the posted speed limit. Notes the amount exceeding the posted limit. Active at any speed.
	Headway Monitoring /Following	Displays the amount of time in seconds, to the vehicle in front when that time becomes 2.5 seconds or less. Green vehicle icon signifies safe headway; red icon unsafe. Active above 19 MPH.
	Forward Collision Warning	Red vehicle icon warns of up to 2.7 seconds before an imminent rear-end collision. Active at any speed. Same red vehicle icon warns of a possible low speed collision, under 19 MPH.
	Solid Green	Solid green display indicates all the functions of the Shield+ System are operational. If the green center display is off, the pedestrian and cyclist detection is not operational.
	Solid Amber	Solid amber display alerts the driver that a pedestrian or cyclist is detected around the truck, but is in a safe area. The driver may continue operating the truck with caution. Active under 31mph.
	Blinking Red Alert	Blinking red display and audible beeping alerts the driver of a pedestrian or cyclist that is in the bus collision trajectory. Driver should stop the truck immediately. Active under 31mph.

Figure 78: Display locations and readouts of Mobileye Shield+ System

Bombardier and the Austrian Institute of Technology (AIT) developed a Driver Assistance System specifically for light rail vehicles. This system uses stereo cameras focused on the area in front of the vehicle. Software algorithms evaluate the vehicle envelope in real time along the track for obstacles and the related collision risk. The driver is alerted visually and acoustically when a collision risk is detected. The system can be applied as a new or a retrofit installation. This system was deployed in Frankfurt, Germany, in 2015.[5] See Figures 79 and 80 for illustrations of the Driver Assistance System.[6]

Figure 79: Bombardier Driver Assistance System

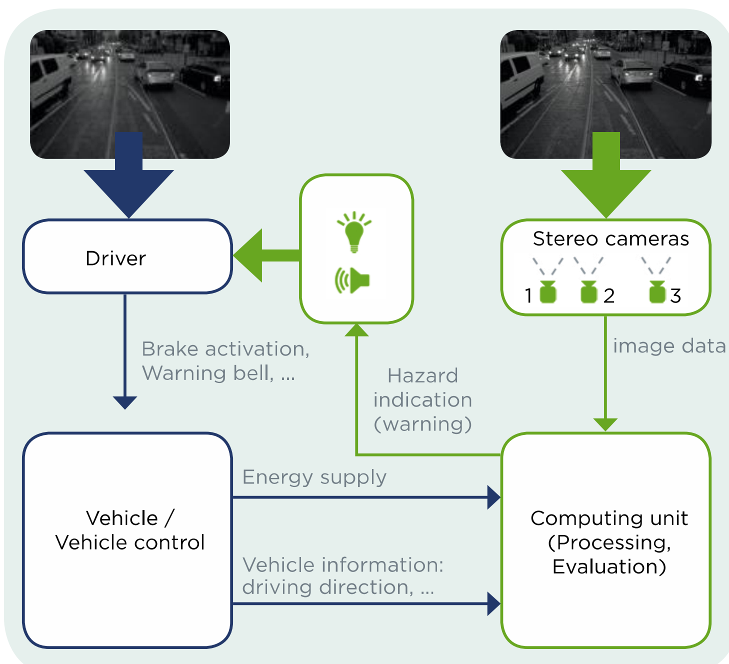


Figure 80: Bombardier Driver Assistance System flow chart

[5] "Bombardier gets approval from VFG for drivers assistance system for trams"(July 23, 2015), retrieved from https://www.railway-technology.com/news/newsbombardier-gets-approval-from-vfg-for-drivers-assistance-system-for-trams-4630769/.
[6] Driver Assistance System (October 11, 2018), retrieved from www.bombardier.com.

Active Systems with Control

The third type of collision avoidance system identified in this scan also senses its surroundings and provides an alert to the operator of a potential collision. However, if the operator does not take action in time, these systems are capable of taking control of the vehicle in an attempt to avoid a collision. These are active systems with some degree of control over the vehicle. Two systems of this nature were found.

The Tram Forward Collision Warning System by Bosch Engineering consists of a multipurpose camera, radar sensor, and control unit designed specifically for light rail vehicles. This system monitors the track ahead and if it detects a potential collision, it sends a visual and or acoustic warning to the operator. The Type 1 version of this system requires action from the operator; the Type 2 version can initiate automatic braking if the operator fails to respond in time. Figures 81 and 82 illustrate this system.[7]

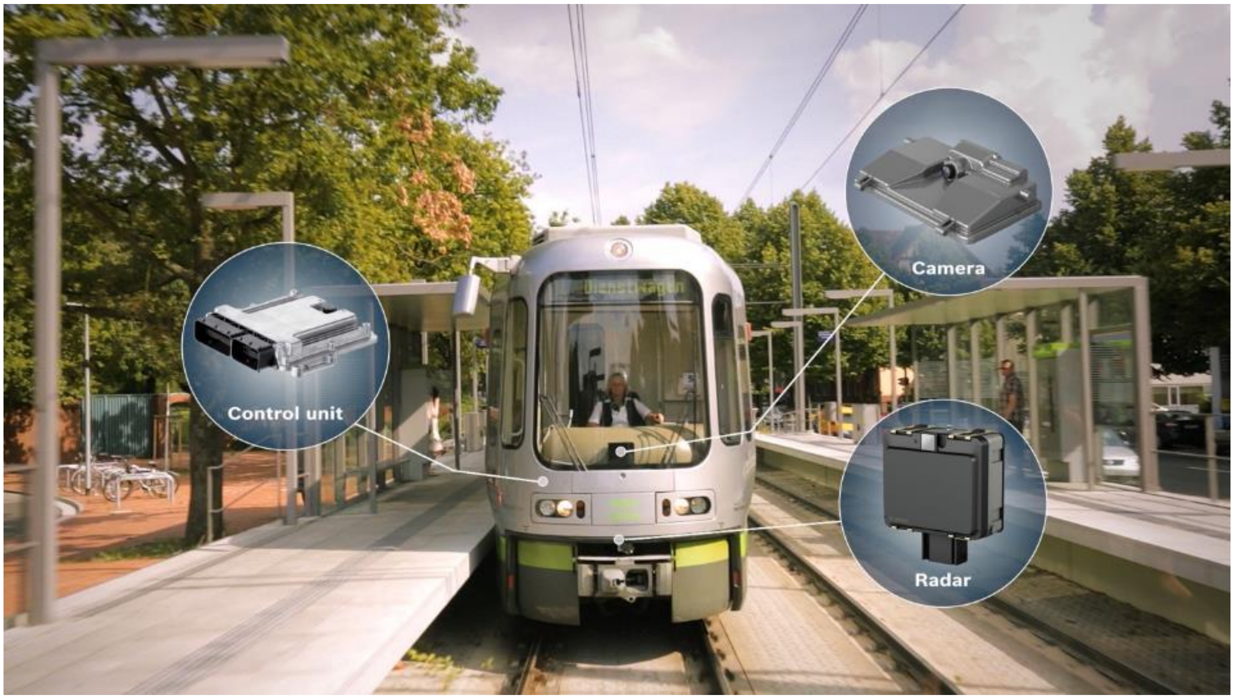


Figure 2: Bosch Engineering Tram forward collision warning system

[7] Tram forward collision warning system (October 11, 2018), retrieved from https://www.bosch-engineering.us/en/us/einsatzgebiete_3/schienenfahrzeuge_3/kollisionswarnung_2/kollisionswarnung_3.html.

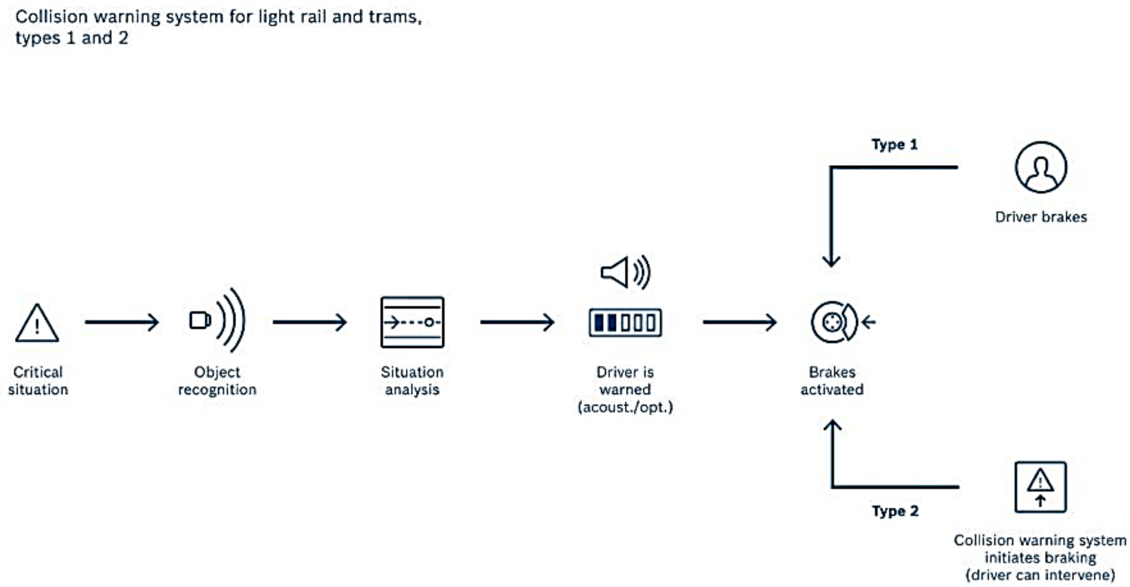


Figure 3: Bosch Engineering Tram forward collision warning system flow chart

Another example of a collision avoidance system that active scans for potential collisions and is capable of controlling the vehicle if necessary to avoid the collision was recently developed and tested on a tram known as the "Silkworm," manufactured by Durmazalar Machine, Inc., in Bursa, Turkey.[8] See Figure 4. The testing was performed in a controlled environment at the Durmazalar facilities. The system architecture, as shown in Figure 5, is composed of three parts—a sensor module, an object recognition and tracking module, and a collision avoidance module. The sensor module is a Lidar Digital-Multilayer Range Scanner by Sick, Inc., that is positioned on the nose of the vehicle. It is used to detect obstacles in front of the tram up to 50 meters away with an accuracy of ± 5 centimeters. Once detected, the object recognition and tracking module uses algorithms to classify the object and track it; then the collision avoidance module assesses the risk. If necessary, it will alert the operator and apply the brakes depending upon the collision probability. Testing results were positive overall, and there are plans for future work in real-world environments and developing a system incorporating both radar and lidar or camera and lidar.

[8] Lüy, M., Çam, E., Ulamış, F., Uzun, İ., & Akın, S. İ. (2018) "Initial Results of Testing a Multilayer Laser Scanner in a Collision Avoidance System for Light Rail Vehicles," *Applied Sciences, 8* (475).

Figure 4: "Silkworm" with collision avoidance system

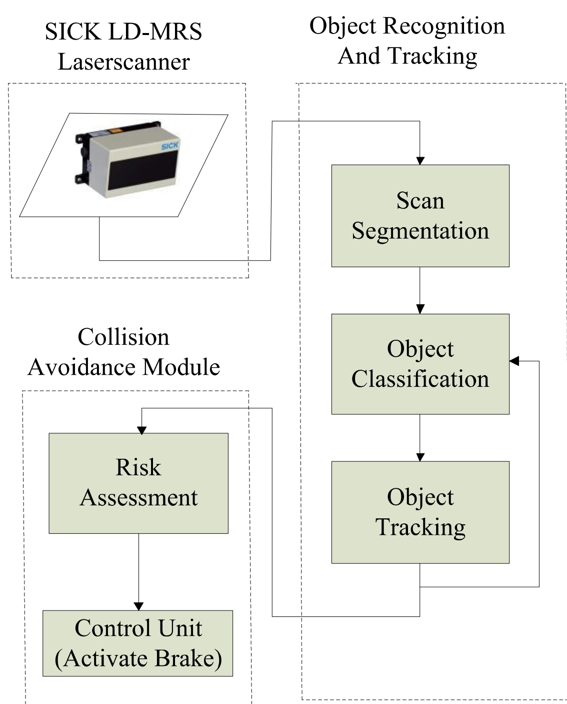


Figure 5: "Silkworm" collision avoidance system architecture

All collision avoidance systems described above use line-of-sight sensing in some form; the stopping distances of most light rail vehicles are typically well within that range. This is critical for any type of collision avoidance system. The sensing capabilities need to exceed the stopping distance of the equipped vehicle in a given situation. The speed and weight of the vehicle along with the environmental conditions are important factors that need to be considered.

Wayside/Right of Way Systems

There are numerous vendors of products and technologies designed to improve light rail safety. Many of these products are designed to either make the public more aware of a possible approaching train or establish some kind of barrier or separation that either hinders or prevents public access to hazardous areas. Many of these products use well-known and established technologies such as fencing, blank out signs, guard rails, lighting, etc. However, some technologies were found during the course of the technology scan that were considered to be innovative in their application that should be pointed out. Note that some of these technologies are not necessarily rail-specific but might be worth considering.

Preventing access to hazardous areas is an effective way to prevent collisions with the public. Hence, the use of traditional railroad gates at crossings, such as those pictured in Figure 48, and fencing, as pictured in Figure 35, are examples. Unfortunately, this is not always possible for a variety of reasons, one of which is space limitations. Traditional railroad crossings require a large amount of space. An alternative to this is the use of parking lot-style gates like those used by HART and LA Metro Rail (Figure 16Figure 45). These gates were placed in specific locations identified as problem areas with limited space. Sometimes, there may not be enough space for a gate of this nature. In those circumstances, having some kind of barrier that deploys from the ground could be considered. Retractable bollards may be one of those options. Another possibility is wedge barriers that are frequently used at security gates; wedge barriers are used at some railroad crossings in Europe. See Figure 6Figure 7 for examples.

Figure 6: Automatic bollard by Bullyboy LTD[9]

[9] Bullyboy Automated Retractable Bollards (October 12, 2018), retrieved from http://www.bullyboy.co.nz.

Figure 7: Wedge barricade by Delta Scientific[10]

If a physical barrier is not practical, street lighting can be used in a virtual barrier. LA Metro Rail has implemented something like this, as shown in Figures 43 and 44. There also are other forms of this technology meant for rail. Figure 8Figure 9 are two examples.

Figure 8: Hanning & Kahl's Guidelight System[11]

[10] Delta Scientific Product Gallery (October 12, 2018), retrieved from https://deltascientific.com/gallery/.
[11] GuideLight for Signalling at Crossings (October 15, 2018), retrieved from https://www.hanning-kahl.com/products/intelligent-guiding-systems/guidelight-for-signalling-at-crossings.html.

***Figure 9: Trax Alert by Light Guard Systems*[12]**

Deployment Recommendations

All the technologies discussed vary in their readiness for deployment in a light rail environment. Some are ready-made products for light rail. The two collision avoidance systems produced by Bosch and Bombardier are examples of systems that are currently being deployed in Europe. Embedded street lighting, wedge barriers, and parking lot-style gates are examples of wayside systems also in use in railroad environments in the US and abroad. These technologies could be considered immediately for a pilot program at selected transit authorities. A program of this nature would be used to gather data about the performance of the technology over an appropriate period of time to determine its effectiveness and viability. Given what was learned from the case studies, one particular area of focus for active collision avoidance systems would be on false alerts. Some operating environments are densely-populated, causing congested traffic conditions around light rail operations. Environments like this may be challenging for these types of collision avoidance systems.

Several technologies mentioned are not necessarily light rail ready but are recommended for consideration. These include collision avoidance systems currently in use by transit authorities on their buses and retractable bollards. These technologies will need further development, testing, and evaluation before being deployed in a light rail operational environment. Further development would involve coordination with manufacturers. However, it is important to specify what the requirements of the potential system are beforehand. These requirements can then be distributed to vendors along with a Request for Proposal on how they would implement them. Acceptable proposals could be selected for development. Once a system has been developed and meets the specified requirements, it will need to be tested in a controlled environment. Pending the results of this testing, the next phase would be a pilot in a suitable operational environment. The key step in this entire process, however, is the development and documentation of the system requirements.

[12] TraxAlert™ Advanced Grade Crossing IRWL Warning Light System (October 15, 2018), retrieved from https://www.lightguardsystems.com/traxalert-grade-crossing-irwl-warning-light-system/.

The case studies revealed several technologies that overlapped with the technology scan, which reinforced the findings. However, one technology that was distinct to the case study and has already been deployed in a pilot program is the connected vehicle pilot program being conducted in Tampa. This program is part of a larger one sponsored by the U. S. Department of Transportation Intelligent Transportation Systems Joint Program Office.[13] Similar pilots are also being conducted in Wyoming and New York City. This technology has potential in transportation safety in general. The world is becoming more and more connected, which means technology of this nature is becoming more prevalent and accessible. Although wide-scale implementation appears to be some time away, this program should be monitored and evaluated for ways in which light rail vehicles could become more integrated to improve their safety by preventing collisions with the public.

Conclusion

Light rail transportation has a long history in the US. Some systems have been in place in one form or another since the late 19th century and others are less than 20 years old. Despite how long they have been in place, when operating in urban environments, all face similar challenges while striving to serve the public in a meaningful manner. In an effort to be accessible to the public, they are often located in or near a street, which presents a conflict with motor vehicles. This is evident from the information about collisions with the public gathered from the transportation authorities in the case studies. Every agency experienced more collisions with motor vehicles than any other type of collision. Of the sites visited, it is estimated that vehicle collisions account for approximately half of all collisions with the public. Of these collisions, many are due to motor vehicles turning in front of light rail vehicles, especially in a shared-lane environment.

Many technologies are available that may help mitigate collisions. This was evident from the technology scan as well as the case studies. The technologies range from complex onboard systems capable of taking autonomous corrective action to more simple yet effective and innovative use of lighting to make the public more aware of an approaching train. Choosing a technology to implement is not a simple task. Rather than just trying different technologies to see what works, one should take a pragmatic approach by defining what is required of the system first, followed by selecting and/or developing systems designed to meet these requirements for thorough testing and evaluation. After this process, decision can be made about implementation.

Overall, there are two approaches to collision mitigation between the public and light rail vehicles. One is by enhancing awareness of both the public and the light rail service. The expectation is that this enhanced awareness allows for preventive or corrective action to take place before a collision. It can even be taken a step further in some cases, wherein the technology actually takes control, such as some collision avoidance systems. The other approach is limiting access of the public to the right-of-way of the light rail service. If access is controlled effectively, the possibility of a collision is greatly reduced because the two are being separated as much as possible. When comparing the two approaches, it can be concluded that enhanced awareness is

[13] Connected Vehicle Pilot Deployment Program (October 15, 2018), retrieved from https://www.its.dot.gov/pilots/index.htm.

not as effective as access control for collision mitigation given the momentum of light rail vehicles. There comes a point when there is simply no time to react to avoid a collision. On the other hand, limiting access is arguably much more effective for collision mitigation; however, it is not always a practical application for a transportation service meant to serve the public in densely-populated urban environments. When looking for technologies and implementations meant to reduce light rail collisions with the public, there must be a balance of pragmatism and effectiveness when managing the risks involved.

Bibliography

Bombardier. www.bombardier.com.

Bombardier. Driver Assistance System. www.bombardier.com,

Bombardier gets approval from VFG for drivers assistance system for trams. *Railway Technology*, https://www.railway-technology.com/news/newsbombardier-gets-approval-from-vfg-for-drivers-assistance-system-for-trams-4630769/.

Bosch Engineering. Tram Forward Collision Warning System. https://www.bosch-engineering.us/en/us/einsatzgebiete_3/schienenfahrzeuge_3/kollisionswarnung_2/kollisionswarnung_3.html.

Bullyboy Automated Retractable Bollards. http://www.bullyboy.co.nz.Seon, Around Vehicle Monitoring System inView 360. www.seon.com/products/collision-avoidance-systems/inview-360.

Delta Scientific Corporation. Delta Scientific Product Gallery. https://deltascientific.com/gallery/.

Hanning & Kahl. GuideLight for Signalling at Crossings. https://www.hanning-kahl.com/products/intelligent-guiding-systems/guidelight-for-signalling-at-crossings.html.

Lin, P.-S., Lee, C., Kourtellis, A., & Saxena, M. (2010). Evaluation of Camera-Based Systems to Reduce Transit Bus Side Collisions. University of South Florida, Center for Urban Transportation Research.

Lightguard Systems. TraxAlert™ Advanced Grade Crossing IRWL Warning Light System. https://www.lightguardsystems.com/traxalert-grade-crossing-irwl-warning-light-system/.

Lüy, M., Çam, E., Ulamış, F., Uzun, İ., & Akın, S. İ. (2018). Initial Results of Testing a Multilayer Laser Scanner in a Collision Avoidance System for Light Rail Vehicles. *Applied Sciences*, 8(475).

Protran Technology. Blind Spot Awareness. www.protrantechnology.com/bus-safety/blind-spot-awareness.

Rosco Vision Systems. VQS4560. www.roscovision.com/our-products/view/VQS4560.

US Department of Transportation. Connected Vehicle Pilot Deployment Program. https://www.its.dot.gov/pilots/index.htm.

Appendix C Transit Agency Policies and Procedures

TRI-COUNTY METROPOLITAN
TRANSPORTATION DISTRICT OF OREGON

SYSTEM SAFETY POLICY	REVISED – JULY 2010
TITLE – ACCIDENT REVIEW AND APPEAL POLICY	

1. PURPOSE

This policy outlines the process for reviewing accidents involving TriMet vehicles equipment and property and accidents involving vehicles, equipment or property operated by TriMet employees acting in the course of employment.

2. SCOPE

This policy applies to all TriMet employees.

3. PREVENTABLE ACCIDENT POLICY

Accidents occurring during the operation of TriMet vehicles and/or in the performance of assigned duties jeopardize the safety of TriMet employees and the public, and impacts TriMet resources.

Therefore, any accident or incident, which causes injury or property damage as a result of failure to observe defensive driving principles or established SOPs, may be judged "preventable." The circumstances of each accident or incident will be reviewed to determine whether an employee's action or failure to act fell below performance expectations of the National Safety Council and thereby contributed to the accident or incident.

Each preventable accident/incident will become a part of the employee's personnel record for twenty four (24) consecutive months for the purpose of the implementation of this policy.

4. SCHEDULE of DISCIPLINARY ACTION for PREVENTABLE ACCIDENTS/INCIDENTS

IMPORTANT NOTE – Not withstanding this schedule, serious, fatal and/or multiple-person injury accidents, or accidents involving extensive property damage, or gross disregard for TriMet property and/or public safety, and/or gross negligence may result in immediate suspension or discharge.

IMPORTANT NOTE – LRV Operators are subject to applicable rule violations, which will be addressed in a manner consistent with the practice at Light Rail and therefore the following schedule may not apply.

First Occurrence

Operator will have a meeting with a member of the Station Management Team and will receive training as warranted.

Note – Station Management's conversation with the Operator must include a review of the preventable incidents/actions that occurred during the accident, an outline of performance expectations, and forewarning of probable consequences if the Operator's conduct continues. A follow-up with letter to document discussion with the Operator is also expected.

Second Occurrence

Operator will have a meeting with a member of the Station Management Team and will receive training.

Note – Station Management's conversation with the Operator must include a review of the preventable incidents/actions that occurred during the accident, an outline of performance expectations, and forewarning of probable consequences if the Operator's conduct continues. A follow-up with letter to document discussion with the Operator is also expected.

Third Occurrence

Operator will have a meeting with a member of Station Management team, will complete recertification training, and may be subject to discipline.

Note – Station Management's conversation with the Operator must include a review of the preventable incidents/actions that occurred during the accident, an outline of performance expectations, and forewarning of probable consequences if the Operator's conduct continues. A follow-up with letter to document discussion with the Operator is also expected.

Fourth Occurrence

Discharge

BUS

5. INITIAL REVIEW

Accidents/Incidents will be reviewed a minimum of once a week by:

- Assistant station manager or
- Operator trainer assigned to a garage

6. ACCIDENT/INCIDENT FILES

Accident reports (Supervisor and Operator) may be found in digital sender.

1. OCC personnel advise Operator and Supervisor to complete State and TriMet accident reports as applicable.
2. OCC advises Road Supervisor of accident.
3. Operator and Supervisor shall turn Accident/Incident report into Station Agents at end of shift or within twenty four (24) hours of notifying dispatch of the accident/Incident. If report is not received within twenty four (24) hours, Assistant Station Manager or Station Agent will follow up with Operator and apply SOR policy as necessary.
4. Station Agent reviews accident reports to ensure they are complete. Station Agent makes necessary copies, enters report into digital sender, forwards original report to Claims, and copies respective Station Management.
5. Assistant Station Manager receives copies and reviews for clarity and completeness then requests supplemental information if necessary.
6. Bus Trainer assigned to garage reviews each accident/incident occurring from a particular garage and places it one of two categories:

   Incident – Incident will be closed out in the ACID (Accident and Incident Data Base) and no further action is required.

   Ready for Review – Accident/incident will be marked in ACID as "ready to review".

IMPORTANT NOTE – Any incident or accident involving property damage or personal injury shall be sent for review.

7. ACCIDENT REVIEW COMMITTEE and APPEALS BOARD SELECTION

Operator Representatives designated to serve on the Accident Review Committee and Appeals Board will be selected by the System Safety Representative and Executive Director of Operations or their management designee, and ATU subject to their sole discretion. Eligible employees must minimally:

- Have taken the Defensive Driving Course within the last two years
- Have not had any preventable accidents in the last two years
- Be able to attend the hearings on a regular basis, and are currently serving in their regular assignment.

<u>Term</u> – Selected employees will serve a minimum term of two years.
<u>Training</u> – Each member will receive accident determination training as outlined in the National Safety Council's "A Guide to Determine Motor Vehicle Accident Preventability,"

8. ACCIDENT REVIEW COMMITTEE

The Accident Review Committee will review all vehicle accidents from all facilities, assigned as requiring further review by the first stage process. This committee will be comprised of the following:

- Two bus trainers
- Two bus Operators
- Chairperson (Safety Department or designee)
- Union representative

Review committee will review the following types of accidents/incidents:

- Revenue vehicles
- Non-revenue vehicles
- MOW vehicles
- Pool cars
- Hi-Rail equipment – not on track

VOTING MEMBERS –

- Two Bus trainers
- Two Bus Operators

NON-VOTING MEMBERS –

- Chairperson (Safety Department or designee)
- Union representative

IMPORTANT NOTE – In the event of a tie vote the Chairperson will become a voting member and will cast the vote to decide the matter.

9. ACCIDENT REVIEW COMMITTEE FINDINGS

Accident Review Committee shall base its findings on the National Safety Council Guidelines, outlined in the "Guide to Determine Motor Vehicle Accident Preventability".

The Accident Review Committee will review accidents/incidents and assign one of the following:

- Non-Preventable
- Preventable (PA)
- Not enough Information
- Incident
- ONC, Operator no Control
- Safety Related Incident (SRI) – A situation in which an incident occurs that does not result in a claim of property damage or personal injury; however, the potential for injury or damage was present due to the actions taken by the Operator of the vehicle.
- The Safety Incident category will be used as a catalyst for training, follow-up and establishing District expectations for performance. Appropriate training and actions will be taken to minimize the potential for re-occurrence of the behavior that created the hazardous situation.

At the time of the decision, the Accident Review Committee shall provide a brief summary of their findings and the reasons for assigning the judgement.

10. NOTIFICATION OF FINDINGS

Following the decision of the Accident Review Committee, the employee will be informed in writing of the committee's decision.

Committee findings are placed in ACID by the Chairperson or designee.

Letters of Review Determination are generated by ACID and include the appeal form and information on filing an appeal. They will also include an explanation of what could have been done to prevent the accident as outlined in the National Safety Council's "A Guide to Determine Motor Vehicle Accident Preventability."

Form 501 – This form shall be attached to any correspondence involving decisions. On receipt of the 501 the employee shall sign, return to the station agent, who signs and date stamps the 501. Following this, the 501 is returned to the Training Department.

11. APPEALS

Enclosed with the Review Determination letter is information outlining the appeal rights of the individual.

Employee has sixty (60) calendar days from the date of the receipt of the notice in which to schedule and attend an appeal of the Review Committee findings.
Request for appeal is entered into ACID.

12. APPEALS BOARD

The Appeals Board will review vehicle accidents from all facilities determined to be Preventable accidents by the Accident Review Committee when an appeal is requested by the Operator. This includes all non-revenue vehicle accidents. The Appeals Board will be comprised of the following participants, who have not previously addressed the matter in accident reviews:

- Two Bus trainers
- Two Bus Operators
- System Safety representative
- Union representative

VOTING MEMBERS:

- Two Bus trainers
- Two Bus Operators

NON-VOTING MEMBERS:

- Chairperson (Safety Department or designee)
- Union representative

IMPORTANT NOTE – In the event of a tie vote the Chairperson will become a voting member and will cast the vote to decide the matter.

UNION REPRESENTATIVE:
The union representative attends the Appeals Board meeting to monitor the process on behalf of the employee and to request that any pertinent questions are addressed.

13. APPEALS BOARD FINDINGS
The Appeals Board shall base its findings on the guidelines outlined in the National Safety Council's "A Guide to Determine Motor Vehicle Accident Preventability".

The Appeals Board will review the accident file and question the Operator/driver concerning the event.

At the time of the decision, the Appeals Board shall provide a brief summary of their findings and decision to add to the file outlining the reasons for overturning a decision made by the Accident Review Committee.

The decisions are entered into ACID and the appeals determination letters sent to Operators. If the appeal determination was a PA, the Operator has seven days to request an external appeal. This period begins from date of the employee receipt of notification as indicated on the 501.

14. EXTERNAL TriMet ACCIDENT APPEALS
Following the Appeals Board decision, the Operator/driver may exercise a further option as the final opportunity to appeal this accident review determination. A Final Appeal may be submitted when the Appeals Board confirms the review determination as Preventable (PA).

A completed External TriMet Accident Appeal form shall be returned to the Safety Department within seven (7) calendar days of receipt of the Appeals Boards decision letter informing them of the decision to uphold the Accident Review Committee decision. An independent Third Party will conduct a review of the accident/incident

15. EXTERNAL TriMet ACCIDENT APPEAL FINDINGS
Bus Transportation receives notification, in writing, of the Third Party review decision and enters the decision into ACID. They then send out a determination letter to the Operator and close out the accident.

RAIL and Hi-Rail EQUIPMENT on TRACK

16. INITIAL REVIEW

Rail Administration will access ACID, daily to review entries and assign the following:

- Incident – No further action required
- Accident /Incident – Ready for review

17. RAIL REVIEW COMMITTEE

The Rail Review Committee meets on an as needed basis. The Rail Review Committee will be comprised of the following:

- Two Rail Operators
- Two Assistant Managers or Trainers
- Safety Representative
- Union Representative

The Rail Review Committee will review the following type of accidents/incidents:

- Revenue vehicles
- Hi-Rail equipment on track incidents

VOTING MEMBERS

- Two Rail Operators
- Two Assistant Managers or Trainers

NON-VOTING MEMBERS

- Safety Representative
- Union representative

IMPORTANT NOTE – In the event of a tie vote the Safety Representative will become a voting member and will cast the vote to decide the matter.

18. RAIL REVIEW COMMITTEE FINDINGS

Rail Review Committee shall base its findings on the National Safety Council Guidelines, outlined in the "Guide to Determine Motor Vehicle Accident Preventability." The Rail Review Committee shall assign accidents/incidents as one of the following:

- Non-Preventable
- Preventable (PA)
- Not Enough Information
- Incident
- ONC, Operator No Control
- Safety Related Incident (SRI) – A situation in which an incident occurs that does not result in a claim of property damage or personal injury; however, the potential for injury or damage was present due to the actions taken by the Operator of the vehicle.
- The Safety Incident category will be used as a catalyst for training, follow-up and establishing District expectations for performance. Appropriate training and actions will be taken to minimize the potential for re-occurrence of the behavior that created the hazardous situation.

Once the meeting is completed and findings are assigned, Rail Administration enters the findings of the Rail Review Committee in ACID.

Rail Transportation informs the Operators of the findings and of their appeal rights by letter.

Form 501 – This form shall be attached to any correspondence involving decisions. On receipt of the 501 the employee shall sign, return to the station agent, who signs and date stamps the 501. Following this, the 501 is returned to Rail Transportation.

19. APPEALS

Employee has ten (10) calendar days from the date of the receipt of the notice in which to request an Appeal.

Request for appeal is entered into ACID.

Enclosed with the Review Determination letter is information outlining the appeal rights of the individual.

The Manager, System Safety is responsible for the scheduling of the Rail Appeals Board hearings. Rail Appeals Board meets on an as needed basis. The Rail Appeals Board will review all rail vehicle accidents from all facilities, determined to be Preventable accidents by the Rail Review Committee if requested by the Operator. The Rail Appeals Board will be comprised of the following:

- Two Rail Operators
- Two Assistant Managers or Trainers
- Safety Representative
- Union Representative

VOTING MEMBERS:

- Two Rail Operators
- Two Assistant Managers or Trainers

NON-VOTING MEMBERS:

- Safety Representative
- Union representative

IMPORTANT NOTE – In the event of a tie vote the Safety Representative will become a voting member and will cast the vote to decide the matter.

UNION REPRESENTATIVE:

The Union Representative attends the Rail Appeals Board meeting to ensure the interests of the employee are met and that any pertinent questions are addressed.

20. RAIL APPEALS BOARD FINDINGS

The Rail Appeals Board will review the accident file and question the Operator/driver concerning the event.

21. EXTERNAL TriMet ACCIDENT APPEALS

Following the Rail Appeals Board, the Operator/driver may exercise a further option. A Final Appeal may be submitted when the Rail Appeals Board confirms the review determination as Preventable. A completed External TriMet Accident Appeal form shall be returned to Rail Transportation within seven (7) calendar days of receipt of the Rail Appeals Board's decision letter informing them of the decision to uphold the Rail Review Committee decision. The independent Third Party will review the accident and either uphold, reverse or change the decision.

22. EXTERNAL TriMet ACCIDENT APPEAL FINDINGS

Operator will be informed in writing of the Third Party review decision.

23. ACCIDENTS/INCIDENTS INVOLVING MAINTENANCE EQUIPMENT/PLANT

Accidents/incidents that do not involve revenue or non-revenue vehicles will be handled in the following manner. Examples of the type of incidents this process will handle are:

- Forklift accidents
- Overhead cranes
- Maintenance equipment and tools

The Garage Manager of the facility where the incident occurred will conduct a review of the event and assign a finding.

- Non-preventable
- Preventable
- Safety Related Incident (SRI) – A situation in which an incident occurs that does not result in a claim of property damage or personal injury; however, the potential for injury or damage was present due to the actions taken by the Operator of the vehicle. The Safety Incident category will be used as a catalyst for training, follow-up and establishing District expectations for performance. Appropriate training and actions will be taken to minimize the potential for re-occurrence of the behavior that created the hazardous situation.
- The Garage Manager will inform the maintenance employee in writing of the decision.

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ANSI	American National Standards Institute
APTA	American Public Transportation Association
ARA	Applied Research Associates, Inc.
AREMA	American Railway Engineering and Maintenance of Way Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ATD	Anthropomorphic Test Devices
BEA	Bureau of Economic Analysis
BRT	Bus Rapid Transit
CBTC	Communications Based Train Control
CEM	Crash Energy Management
CEREMA	Center for Studies and Expertise on Risks, Environment, Mobility and Development
CFR	Code of Federal Regulations
COST	European Cooperation in Science and Technology
CPUC	California Public Utilities Commission
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAST Act	Fixing America's Surface Transportation Act
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GCRTA	Greater Cleveland Regional Transit Authority
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
HART	Hillsborough Area Regional Transit Authority
HOS	Hours of Service
IDEA	Innovations Deserving Exploratory Analysis
IEEE	Institute of Electrical and Electronics Engineers
LA METRO	Los Angeles County Metropolitan Transportation Authority
LRT	Light Rail Transit
LRV	Light Rail Vehicle
MAP–21	Moving Ahead for Progress in the 21st Century
MBTA	Massachusetts Bay Transportation Authority
METRO	Metropolitan Transit Authority of Harris County
MTA	Maryland Transit Administration
MUTCD	Manual on Uniform Traffic Control Devices

NIOSH	National Institute for Occupational Safety and Health
NHTSA	National Highway Traffic Safety Administration
NHTS	National Household Travel Survey
NTD	National Transit Database
NTSB	National Transportation Safety Board
OCC	Operations Control Center
POV	Personally Operated Vehicle
PTASP	Public Transportation Agency Safety Plan
PTC	Positive Train Control
SAC RT	Sacramento Regional Transit
SAE	Society of Automotive Engineering
SEPTA	Southeastern Pennsylvania Transportation Authority
SGR	State of Good Repair
SMS	Safety Management Systems
STRMTG	Le Service Technique des Remontées Mécaniques et des Transports (France)
SUV	Sport Utility Vehicle
SSO	State Safety Oversight
TCRP	Transit Cooperative Research Program
TRACS	Transit Advisory Committee for Safety
TRB	Transportation Research Board
TRI	FTA Office of Research, Demonstration and Innovation
TriMet	Tri-County Metropolitan Transportation District of Oregon
TRID	Transport Research International Documentation
TSO	FTA Office of Transit Safety and Oversight
UNECE	United National Economic Commission for Europe
USC	United States Code
USDOT	United States Department of Transportation

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
https://www.transit.dot.gov/about/research-innovation