FTA Report No. 0232

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Research Report and Findings: Emergency Egress in Rail Transit Tunnels

PREPARED BY

Stephen Wilk
MaryClara Jones
Devin Sammon
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 Michael Brown

Research Report and Findings: Emergency Egress in Rail Transit Tunnels

OCTOBER 2022

FTA Report No. 0232

PREPARED BY

Stephen Wilk
MaryClara Jones
Devin Sammon
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
55500 DOT Road
Pueblo, CO 81001

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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE October 2022	2. REPORT TYPE Final	3. DATES COVERED September 2018–March 2019
4. TITLE AND SUBTITLE Research Report and Findings: Emergency Egress in Rail Transit Tunnels		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Stephen Wilk, MaryClara Jones, Devin Sammon		5d. PROGRAM NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) 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. 0232
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/10.21949/1527645] Suggested citation: Federal Transit Administration. Research Report and Findings: Emergency Egress in Rail Transit Tunnels. Washington, D.C.: United States Department of Transportation, 2022. https://doi.org/10.21949/1527645.

14. ABSTRACT
The objective of this study was to address National Transportation Safety Board (NTSB) recommendation R-16-02, "Issue regulatory safety standards for emergency egress in tunnel environments." All relevant standards and specifications related to emergency egress, including egress from rail transit vehicles, were included in the literature search. After completion of literature review, relevant elements were documented, and gaps identified to be incorporated into a voluntary standard.

15. SUBJECT TERMS
NTSB rail evacuation, tunnel evacuation, rail emergency evacuations, rail vehicle evacuations

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	25	19b. TELEPHONE NUMBER

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

TABLE OF CONTENTS

LIST OF TABLES

Abstract

The objective of this study was to address National Transportation Safety Board (NTSB) recommendation R-16-02, "Issue regulatory safety standards for emergency egress in tunnel environments." All relevant standards and specifications related to emergency egress, including egress from rail transit vehicles, were included in the literature search. After completion of literature review, relevant elements were documented, and gaps identified to be incorporated into a voluntary standard.

Executive Summary

Under a Federal Transit Administration (FTA) Cooperative Agreement, the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) contracted with the Transportation Technology Center, Inc. (TTCI) to support the development of voluntary standards for emergency rail transit tunnel egress.

The objective of this study was to address National Transportation Safety Board (NTSB) recommendation R-16-02—"Issue regulatory safety standards for emergency egress in tunnel environments." All relevant standards and specifications related to emergency egress, including egress from rail transit vehicles, were included in the literature search. After completion of literature review, relevant elements were documented, and gaps identified to be incorporated into a voluntary standard.

The literature review identified eight relevant sources to tunnel egress, and a detailed comparison was performed on three of the sources, which have topics specifically dedicated to tunnel egress; the other five sources focused on vehicle egress or ventilation practices and were not a part of the comparison. Two of the compared sources were published by the National Fire Protection Association (NFPA) and focus on fire prevention for railways (NFPA 130, Fixed Guideway Transit and Passenger Rail Systems) and highways (NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways). The third compared source is a European Union (EU) publication, "Safety Railroad Tunnels Technical Specification for Interoperability (SRT TSI)" that provides a minimum standard for all EU rail tunnels.

The review showed that NFPA 130 is the most comprehensive standard that could be used in the development of a tunnel egress standard and covers most necessary topics. However, NFPA 130d focuses primarily on design; a comprehensive document would include the information from NFPA 130 for tunnel design as well as specific information for maintenance and reliability.

Findings from the review are the following.

Finding 1: A voluntary standard or recommended practice for new tunnel design would include the following elements, most of which can be addressed through incorporation of NFPA 130 by reference:

- Emergency lighting
- Emergency signage
- Number of egress points
- Walkway design
- Door design

- Traction power design
- Safe areas
- Communication
- Emergency ventilation

Finding 2: Whereas NFPA 130 is comprehensive, there are some potential gaps, including:

- Self-closing doors
- Fire protection ratings for emergency door design
- Emergency signage to direct emergency responders
- Supplementing emergency ventilation with white papers on procedures

Finding 3: APTA may want to review and update its white paper on emergency ventilation to reflect progress in ventilation methods and detection methods.

Finding 4: Public transit agencies should consider the use of new voluntary standards or recommended practices for tunnel design improvements of their existing tunnels; however, not all existing tunnels could meet NFPA 130 criteria due to their original design.

Section 1 Introduction

Transportation Technology Center, Inc. (TTCI), contracted by the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF), was tasked by the Federal Transit Administration (FTA) to research and develop specifications and guidelines for rail transit tunnel emergency egress. This includes identifying areas of transit safety risk within the industry, developing an inventory of existing transit safety standards (or those within other transportation industries that could be modified to address transit safety-related risks), and establishing focus areas for further research.

To effectively meet the research needs for this project, TTCI is performing research to determine and improve the state of design, inspection, and maintenance practices for railway transit tunnels in the U.S. A previous study involved a broad literature review of all aspects of railway transit tunnel design, inspection, maintenance, and remediation.[1] To expand on that study, FTA sponsored a more detailed study into tunnel emergency egress to aid the identification and modification or development of voluntary standards or recommended practices through the American Public Transportation Association (APTA) Standards Program. The necessary research and background studies conducted under this project also inform evidence-based safety policy and decision-making (regulations, directives, advisories, etc.) for FTA's Office of Transit Safety and Oversight (TSO), as appropriate.

The objective of the study was to address National Transportation Safety Board (NTSB) recommendation R 16-02, "Issue regulatory safety standards for emergency egress in tunnel environments." This involved a literature review and documentation of all relevant elements of standards related to emergency egress.

[1] Rakoczy, A., S. Wilk, and M. Jones, "Review of Specifications and Guidelines for Rail Tunnel Design, Construction, Maintenance, and Rehabilitation," P-18-018, Washington, DC, 2018.

Section 2

Tunnel Egress Literature

A literature review of relevant tunnel egress standards and white papers identified eight potential sources that a new voluntary standard or recommended practice can reference. The sources cover three main topics—vehicle egress, tunnel egress, and ventilation. The project scope focuses on tunnel egress, so those standards receive the most emphasis in this report, but both the vehicle standards and ventilation white paper are included because of their relevancy to tunnel egress.

A summary of the eight standards used in the literature review is provided in Table 2-1.

Table 2-1 *General Information on Relevant Tunnel Egress Standards*

Publisher	Standard	Year Published	Vehicle/Tunnel	Reference Type
APTA	Emergency Lighting	2017	Vehicle	Design/maintenance standard
APTA	Emergency Signage	2017	Vehicle	Design/maintenance standard
APTA	Low-Location Exit Path	2017	Vehicle	Design/maintenance standard
APTA	Emergency Egress/Access	2012	Vehicle	Design/maintenance standard
NFPA	130	2017	Railway tunnel	Design standard
NFPA	502	2017	Roadway tunnel	Design standard
EU	SRT TSI	2014	Railway tunnel	Design standard
APTA	Emergency Ventilation	2010	Railway/roadway tunnel	White paper

Vehicle Egress in a Tunnel

APTA has four existing vehicle egress standards that already have been adopted industry-wide. A previous study by TTCI on emergency lighting and signage goes into more detail and can be reviewed if more background is required.[2] These existing standards will satisfy the vehicle egress component of R-16-02 because the first step of tunnel egress is evacuating passengers from the transit vehicle. The four APTA standards are as follows:

- APTA RT-VIM-S-020-10 Rev 1: Emergency Lighting System Design for Rail Transit Vehicles[3]
- APTA RT-VIM-S-021-10 Rev 1: Emergency Signage for Rail Transit Vehicles[4]
- APTA RT-VIM-S-022-10 Rev 1: Low-Location Exit Path Marking[5]

[2] Jones, M., "Research and Analysis on Emergency Lighting and Signage for Rail Transit Passenger Vehicles," P-17-024, Washington, DC, 2018.
[3] American Transportation Association (APTA), Emergency Lighting System Design for Rail Transit Vehicles, APTA RT-VIM-S-020 Rev 1, 2017.
[4] APTA, Emergency Signage for Rail Transit Vehicles, APTA RT-VIM-S-021 Rev 1, 2017.
[5] APTA, Low-Location Exit Path Marking, APTA RT-VIM-S-022 Rev 1, 2017.

- APTA RT-VIM-S-023-12: Emergency Egress/Access for Rail Transit Vehicles[6]

The first three standards originally were published in 2010 and were revised in 2017. APTA-RT-VIM-S-023-12 was published in 2012 without any revision. All four standards include recommendations for design, maintenance, and reliability.

Tunnel Egress

Three standards were identified as relevant to tunnel egress, two of which are published by the National Fire Protection Association (NFPA) and the third (SRT TSI) by the European Union (EU):

- NFPA 130: Fixed Guideway Transit and Passenger Rail Systems[7]
- NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways[8]
- Safety Railroad Tunnels Technical Specification for Interoperability (SRT TSI)[9]

NFPA 130 focuses on fire protection for railways in general and has a chapter specifically dedicated to railway tunnels. The most recent version of NFPA 130 was published in 2017 and emphasizes supporting system design standards for railways. The sections in NFPA 130 regarding tunnel egress (Section 6) and emergency ventilation (Section 7) are comprehensive, but the standard has an overall focus on fire protection and prevention and not tunnel egress. However, a previous literature review of tunnel design, maintenance, and rehabilitation[10] conducted by TTCI found that NFPA 130 is a common standard used by transit agencies for tunnel supporting system design, which includes tunnel egress. That source can be reviewed for additional details of NFPA 130 with non-tunnel egress supporting systems.

The NFPA 502 standard focuses on fire protection for limited access highways, including tunnels. Whereas NFPA 502 is highway-focused and NFPA 130 covers railway tunnels, NFPA 502 is included for completeness. The most recent version of NFPA 502 was published in 2017 and emphasizes design of components related to fire protection.

The Safety Railroad Tunnels Technical Specification for Interoperability (SRT TSI) is a design standard set by the EU in 2014 to be applied to all transit railways in the EU. The motivation for this standard was to ensure that all EU countries

[6] APTA, Emergency Egress/Access for Rail Transit Vehicles, APTA RT-VIM-S-023, 2012.
[7] National Fire Protection Association (NFPA), NFPA 130, Standards for Fixed Guideway Transit and Passenger Rail Systems, 2017 edition.
[8] NFPA, NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways, 2017 edition.
[9] European Union, Safety in Railway Tunnels SRT – Technical Specification for Interoperability, TSI. No. 1303/2014, Brussels, Belgium, 2014 edition.
[10] Rakoczy, A., S. Wilk, and M. Jones, *op. cit*.

adopted the same minimum standards for passenger rail. SRT TSI includes many important components of tunnel egress but often differs from the U.S. in details.

Emergency Ventilation

Emergency ventilation because of improper ventilation presents a significant safety hazard to passengers during evacuation. Although emergency ventilation design is covered in NFPA 130 and 502, an APTA white paper (APTA SS-SEM-WP-013-10, “Operational Strategies for Emergency Smoke Ventilation in Tunnels”[11]) focuses on ventilation strategies. This white paper was current in 2010 at the time of publishing; however, review of this paper for additional ventilation capabilities and practices is suggested prior to incorporation in a new standard.

[11] American Transportation Association, Operational Strategies for Emergency Smoke Ventilation in Tunnels, APTA SS-SEM-WP-013-10. 2010.

Section 3

Comparison of Relevant Tunnel Egress Standards

The purpose of the literature review was to review existing standards and identify topics and specifications that could be recommended for a new tunnel egress standard. The literature review first compiled tunnel egress topics within each relevant existing standard, which provided a general overview of topics in the standards. Second, the literature review compared each source by topics that could be included in a tunnel egress standard and identified gaps, differences between standards, and level of detail within each standard. The comparison also identified NFPA 130 as the most expansive standard and recommended template for any newly adopted tunnel egress standard. Third, gaps relevant to tunnel egress within NFPA 130 were identified.

Topics Covered by Relevant Standards

The first step of the literature review was to compile tunnel egress topics within each relevant existing standard. These topics are combined and categorized in the next sections to compare how each relevant standard addresses tunnel egress topics that could be adopted by a new voluntary standard or recommended practice. The standards are categorized into three groups—vehicle standards, tunnel egress, and emergency ventilation. Whereas tunnel egress has the primary relevancy, aspects of vehicle egress and emergency ventilation are important and should be considered.

Table 3-1 lists the topics covered by the vehicle egress standards.

Table 3-1 *General Topics Covered by Relevant Vehicle Egress Standards*

Publisher	Standard	General Topics Covered
APTA	Emergency Lighting	• Types of lighting • Location • Amount of light • Power sources
APTA	Emergency Signage	• Visual identification and recognition • Multilingual • Locations of signs • Letter/sign size • Color and contrast • Illuminance/luminance criteria • Component material
APTA	Low-Location Exit Path	• Locations • Materials / charging light
APTA	Emergency Egress/ Access	• Number of access/egress points (doors) • Emergency access/egress (ability to exit) • Emergency releases (ability to manually open doors)

Table 3-2 lists the topics covered by each relevant tunnel egress source.

Table 3-2 *General Topics Covered by Relevant Tunnel Egress Standards*

Publisher	Standard	General Topics Covered
NFPA	130	• Location of egress routes • Size of egress routes • Egress components (walkway design) • Traction power protection • Signage, illumination, and emergency egress
NFPA	502	• Tenable environment • Walking surfaces • Emergency exit doors • Emergency exits (pathways)
EU	SRT TSI	• Safe areas • Access • Communication • Lighting • Signage • Walkways

Table 3-3 lists the topics covered by emergency ventilation.

Table 3-3 *General Topics Covered by Relevant Emergency Ventilation Source*

Publisher	Standard	General Topics Covered
APTA	Emergency Ventilation	• Ventilation types and objectives • Ventilation strategies

Comparison of Sources by Topic Category

The second step of the literature review compared each source by topics that could be included in a tunnel egress standard and identified any gaps, differences between standards, and the level of detail within each standard. This comparison includes only tunnel egress component design and not inspection or maintenance of these components. The comparison also identified NFPA 130 as the most expansive standard and recommended template for any newly adopted tunnel egress standard.

Table 3-4 lists the relevant topics to tunnel egress and which standards address those topics. The three tunnel egress standards (NFPA 130, NFPA 502, and SRT TSI) and are included along with the APTA source (APTA SS-SEM-WP-013-10) which is a white paper that only discusses emergency ventilation.

Table 3-4 *Relevant Topics Covered and Identified by Multiple Sources on Tunnel Egress*

Relevant Topic	APTA	NFPA 130	NFPA 502	SRT TSI
Emergency lighting		✓		✓
Emergency signage		✓		✓
Number of egress points		✓	✓	✓
Walkway design		✓	✓	✓
Door design		✓	✓	✓
Track power protection		✓		
Safe area				✓
Communication		✓		✓
Ventilation	✓	✓	✓	✓

In-depth comparisons of each of the relevant topics in Table 3-4 are provided below. Due to the different scopes of the standards, differences are expected when comparing the standards. NFPA 130 applies to railway tunnel design with an emphasis on fire protection, NFPA 502 applies to highway tunnel design with an emphasis on fire protection, and SRT TSI applies to European railway tunnel design.

Emergency Lighting

Emergency lighting is typically a backup lighting system that provides enough light for passengers to safely egress from vehicles and tunnels.

Emergency lighting in tunnels is covered in both NFPA 130 and SRT TSI. Details in NFPA 130 are found in Section 6.3.5, and details in SRT TSI are found in Section 4.2.1.5.4. The comparison is shown in Table 3-5. NFPA 130 covers topics related to emergency lighting and provides different guidance on how to appropriately implement the standards. For example, NFPA 130 states that all walking areas should be illuminated to 2.7 lux, whereas SRT TSI states that lighting should be built into the handrail.

Table 3-5 *Emergency Lighting Standard Comparison*

Topic	NFPA 130	SRT TSI
Illumination	2.7 lux	1 lux
Illuminated areas	All walking areas	Above walkway Built into handrail
Uniformity ratio	10:1	Not included
Electrical details	Separate wiring	From alternative power supply
Other references	NFPA 101[12] (Installation) NFPA 70[13] (Installation)	Not included

[12] NFPA, NFPA 101: Life Safety Code, 2018 edition.
[13] NFPA, NFPA 70: National Electrical Code, 2017 edition.

Emergency Signage

Clear and concise signage is important for quick and safe evacuation of passengers from vehicles and tunnels. The purpose of signage is to direct passengers in the correct direction of egress and prevent them from accidentally egressing into a dangerous area. Emergency signage is also to provide details to emergency responders on how to find specific areas/rail lines. Details such as how many feet to the next exit or the next station also are beneficial to passengers.

Emergency signage is covered by NFPA 130 and SRT TSI. Details in NFPA 130 are found in Section 6.3.5, and details in SRT TSI are found in Section 4.2.1.5.5. Details comparing the standards are provided in Table 3-6. Both the NFPA and SRT TSI are general and reference other sources. NFPA 130 references NFPA 70 and Occupational Safety and Health Administration (OSHA), and SRT TSI code references Directive 92/58/EEC[14] regarding sign details.

Table 3-6 *Emergency Signage Standard Comparison*

Topic	NFPA 130	SRT TSI
Signage warnings	Hazards (e.g., voltage) Directional egress signs Egress points Exit facilities	Exit direction and length Position of emergency equipment
Font/Size	NFPA 70 and OSHA	Not included
Maximum Sign Distance	82 ft	50 m (165 ft)

Number of Egress Points

An appropriate number of egress points is necessary to ensure passenger evacuation from tunnels in a timely manner no matter where the vehicle stops within the tunnel. For transit tunnels, this includes exits and cross-passages if they are installed instead of an exit.

The number of egress points is covered in NFPA 130, NFPA 502, and SRT TSI. Details in NFPA 130 are found in Section 6.3.1, details in NFPA 502 are found in Section 7.16.6, and details in SRT TSI are found in Section 4.2.1.5. Details comparing the standards are listed in Table 3-7. NFPA 130 and SRT TSI standards are similar but have slight variations. NFPA 130 appears to cover the topic for U.S. specifications.

Table 3-7 *Number of Egress Points Standard Comparison*

Topic	NFPA 130	NFPA 502	SRT TSI
Exits	2,500 ft	1,000 ft	1,000 m (3,300 ft)
Cross passage	800 ft (if used instead of exit)	Not included	500 m (1,650 ft)

[14] European Union, Safety and/or Health Signs, Directive 92/58/EEC, June 1992.

Walkway Design

Safe walkways are necessary to reduce the number of injuries that can occur during the passenger egress process. This generally includes the width and clearance of the walkway, surface of the walkway, and any guard or handrails to prevent slippage or falling from walkways that are above grade.

Walkway design is covered in NFPA 130, NFPA 502, and SRT TSI. Details on walkway design are found in Section 6.3.3 of NFPA 130, Section 7.16.4 in NFPA 502, and Section 4.2.1.6 in SRT TSI. Comparison of all walkway design details are listed in Table 3-8.

Each standard has similarities with NFPA 130 and SRT TSI being the most specific as noted within this report. NFPA 130 appears to cover the necessary topics for walkway design.

Table 3-8 *Emergency Signage Standard Comparison*

Topic	NFPA 130	NFPA 502	SRT TSI
Walkway width	3.75 ft	3.7 ft	2.6 ft
Walkway height	7 ft	Not included	7.4 ft
Surface	Uniform, slip-resistant design	Not included	Not included
Guards	2.5 ft above grade	Not included	2.6–3.6 ft above walkways
Exit stairs	NFPA 101	Not included	
Other	No obstructions	Lead to exit Be protected from traffic	Height top of rail or higher No obstructions

Door Design

Appropriate door design for passenger egress is to ensure safe evacuations and reduce injuries and confusion. This includes the direction a door opens, how much force is required to open a door, whether a door is self-closing, and whether emergency releases are included.

The number of egress points is covered in NFPA 130, NFPA 502, and SRT TSI. Details in NFPA 130 are found in Section 6.3.1, details in NFPA 502 are found in Section 7.16.5, and details in SRT TSI are found in Section 4.2.1.5. Details comparing the standards are listed in Table 3-9.

NFPA 130 appears to cover the necessary topics for door design in addition to ensuring a door is self-closing, which is important to prevent smoke from entering egress tunnels. SRT TSI requires wording on doors but includes few specific details compared to NFPA standards.

Table 3-9 *Emergency Door Design Standard Comparison*

Topic	NFPA 130	NFPA 502	SRT TSI
Door open direction	Exit	Exit	Not included
Open force	50 lb Must withstand positive and negative pressures from train	50 lb Must withstand positive and negative pressures from vehicles	Not included
Self-closing	Not included	Yes	Not included
Emergency releases	Hatches	Not included	Not included
Fire protection	Not included	1.5-hr rating	Not included

Traction Power Protection

Traction Power protection is to ensure that passengers avoid accidental contact with traction power during emergency egress. NFPA 130 Section 6.3.4 is the only standard that appears to address this and generally states that traction power must be designed to avoid accidental contact when near walkways.

Safe Areas

SRT TSI includes a discussion on “safe areas” in which passengers can stay during evacuation or where employees and equipment can be temporarily housed if they need to avoid train operations. This could be included in new tunnel builds but is not necessarily feasible for existing tunnels.

Communication

SRT TSI includes a discussion on communication related to passengers or employees contacting control centers during egress with either a mobile phone or fixed connection. NFPA 130 requires that enclosed trainways have emergency communications.

Emergency Ventilation

Emergency ventilation is an important feature during passenger egress because smoke inhalation is a prevalent cause of injuries and fatalities in tunnel accidents.[15] The appropriate emergency ventilation strategy depends on the specific circumstances, so different methods should be ready to be used in a tunnel fire situation to effectively direct smoke away from evacuating passengers. This means that appropriate ventilation strategies must include location of the fire, location of the stopped vehicle and passengers, and location of the nearest egress location, among other tunnel specific details.

[15] NTSB, WMATA L’Enfant Plaza Station Electrical Arcing and Smoke Accident, RAR-16/01, Washington, DC, 2016.

NFPA 130 Section 7 covers emergency ventilation systems and includes design, emergency ventilation fans, airflow control devices, testing, shafts, emergency ventilation system operations, and power supply. NFPA 502 addresses emergency ventilation in Section 11; details of design are beyond the scope of this project, so they are not compared in this report.

APTA SS-SEM-WP-013-10, “Operational Strategies for Emergency Smoke Ventilation in Tunnels,” discusses the different types of ventilation and strategies for properly ventilating a tunnel to reduce passenger injury. Topics discussed include the following:

- *Types of ventilation systems*—There are three main types of ventilation system — longitudinal, transverse, and semi-transverse. The most common in rail tunnels is longitudinal ventilation, in which vents are used to push smoke away from passengers (air is pushed from one side and sucked from the other). This commonly assumes that only one group of passengers is in the tunnel and that the location of the fire and passengers are known.
- *Strategies for smoke management*—To optimize the effectiveness of ventilation, the sequence of events, objectives for smoke control, and design features of tunnel and ventilation system must be considered. For example, it may be beneficial to preserve smoke stratification (near-zero air velocity) in some situations, whereas in other situations it may be beneficial to push all the smoke in one direction (above critical velocity). The first option may be better in a situation in which passengers are on both sides of the fire, and the second may be better in a situation in which all passengers are on one side of the fire. Other factors to consider are direction of traffic, congestion, and tunnel elevations.
- *Ventilation control*—Ventilation can be controlled automatically, semi-automatically, or from a manual system. Automatic modes may be more beneficial in complex situations but may not be appropriate in all evacuation scenarios.
- *Sequence of events*—A step-by-step order is important to follow during fire events. This includes verifying fire or smoke condition, determining cause and location, determine evacuation direction, determine ventilation strategy, monitor situation, and change strategies if needed.
- *Fire detection*—The first step for the ventilation process is detecting and verifying if a fire or smoke condition exists in a tunnel. Fire detection systems can be automatic or manually triggered.
- *Other operational strategies*—In rail tunnels, there are additional other factors to consider such as stopping all other trains in the tunnel is important to avoid air flow from an adjacent train overpowering any ventilation strategy, ensuring a clear command structure, proper communication and training with first responders, and de-energizing traction power.

NFPA 130 and 502 also reference NCHRP Report 836,[16] which specifically mentions that the best practices documented therein do not necessarily apply to railway tunnels because of distinct differences in highway and railway tunnel egress. However, NFPA 130 and NCHRP 836 could serve as foundations for ventilation strategies in railway tunnels; although there are differences, there also is much overlap between the two transportation modes.

Gaps in NFPA 130 for Tunnel Egress

The literature review showed that NFPA 130 is the most expansive standard that could be incorporated into a new rail-specific standard and covers most necessary topics; however, NFPA 130 appears to be missing some details and information covered in other standards.

It should be emphasized that only topics included in tunnel egress standards (see Table 1-1) other than NFPA 130 are included; this is not a recommendation of topics to include or exclude from a future voluntary standard or recommended practice. Table 3-10 shows general design topics that are or are not gaps found in NFPA 130.

Table 3-10 *Gaps in NFPA 130 Standards for Emergency Tunnel Egress Design*

Design Topic	NFPA 130	Gaps
Emergency lighting	6.3.5	No gaps
Emergency signage	6.3.5	Signage to direct emergency responders at diversion points Supplement with NCHRP reports and ISO 7010[17]
Number of egress points	6.3.1	No gaps
Walkway design	6.3.3	Minor language details
Door design	6.3.1	Self-closing Fire protection rating
Traction power protection	6.3.4	No gaps
Safe area		Not included
Communication		Not included
Ventilation	7.0	Supplement with APTA and NCHRP reports

To expand on a few aspects of Table 3-10, emergency signage should be installed to aid first responders navigating the rail system, including entrance points for first responders, safe areas, and diverging routes on the system. Walkway design could consider Americans with Disabilities Act (ADA)[18] recommendations to aid in the egress of persons with disabilities. Currently,

[16] NCHRP, Report 836, "Recommended ASSHTO Guidelines for Emergency Ventilation Smoke Control in Roadway Tunnels," NCHRP 20-07 Task 363, May 2016.

[17] International Organization for Standardization, Report 7010, "Graphical Symbols – Safety Colours and Safety Signs – Registered Safety Signs," May 2011

[18] 101st US Congress, Americans with Disabilities Act, 1989.

NFPA 130 does not comply with ADA recommendations but that could be by design, as a person with disabilities may require other passengers or emergency responders for assistance. One area in which NFPA 130 does not comply is handrail height, and walkway recommendations could be difficult or even impossible to meet in areas with tight clearances such as curves, so procedures could be developed to identify these locations and plan egress routes so passengers or first responders could avoid these locations.

NFPA 130 is a fire protection design standard and, therefore, does not include information on inspection, maintenance, reliability, and non-fire protection design. Most reviewed APTA standards (see Table 1-1) include information on inspection, maintenance, and reliability, which are additional gaps in NFPA 130.

Section 4 Conclusions

This study reviewed available standards and white papers to help accumulate potential specifications that could be used by a standards development organization such as APTA to assist in development of a voluntary standard or recommended practice that addresses NTSB Recommendation R-16-02 to FTA on emergency tunnel egress.

The literature review showed that NFPA 130 is the most expansive standard that could be adopted by or incorporated by reference into a voluntary standard and covers most necessary topics. However, NFPA 130 appears to be missing some details related to inspection, maintenance, and reliability. A future comprehensive voluntary standard or recommended practice could incorporate much of the wording of NFPA 130 as well as some details not included.

Findings from the literature review are as follows.

Finding 1: A voluntary standard or recommended practice for new tunnel design could consider including the following elements, most of which can be addressed through the incorporation of NFPA 130 by reference:

- Emergency lighting
- Emergency signage
- Number of egress points
- Walkway design, door design
- Traction power design
- Safe areas
- Communication
- Emergency ventilation

Finding 2: Whereas NFPA 130 is comprehensive, there are some potential gaps, as referenced in Table 4-1.

Table 4-1 *Summary of NFPA 130 Tunnel Egress Topics*

Design Topic	NFPA 130	Gaps
Emergency lighting	6.3.5	No gaps
Emergency signage	6.3.5	Signage to direct emergency responders at diversion points Supplement with NCHRP reports and ISO 7010[19]
Number of egress points	6.3.1	No gaps
Walkway design	6.3.3	Minor language details
Door design	6.3.1	Self-closing Fire protection rating
Traction power protection	6.3.4	No gaps
Safe area		Not included
Communication	6.4.3	No gaps
Ventilation	7.0	Supplement with APTA and NCHRP reports

Finding 3: APTA may want to update its white paper on emergency ventilation to reflect progress in ventilation methods and detection methods.

Finding 4: Public transit agencies should consider the use of new voluntary standards or recommended practices for tunnel design improvements of their existing tunnels; however, not all existing tunnels could meet NFPA 130 criteria due to their original design.

[19] International Organization for Standardization, Report 7010, *op. cit.*

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