FTA

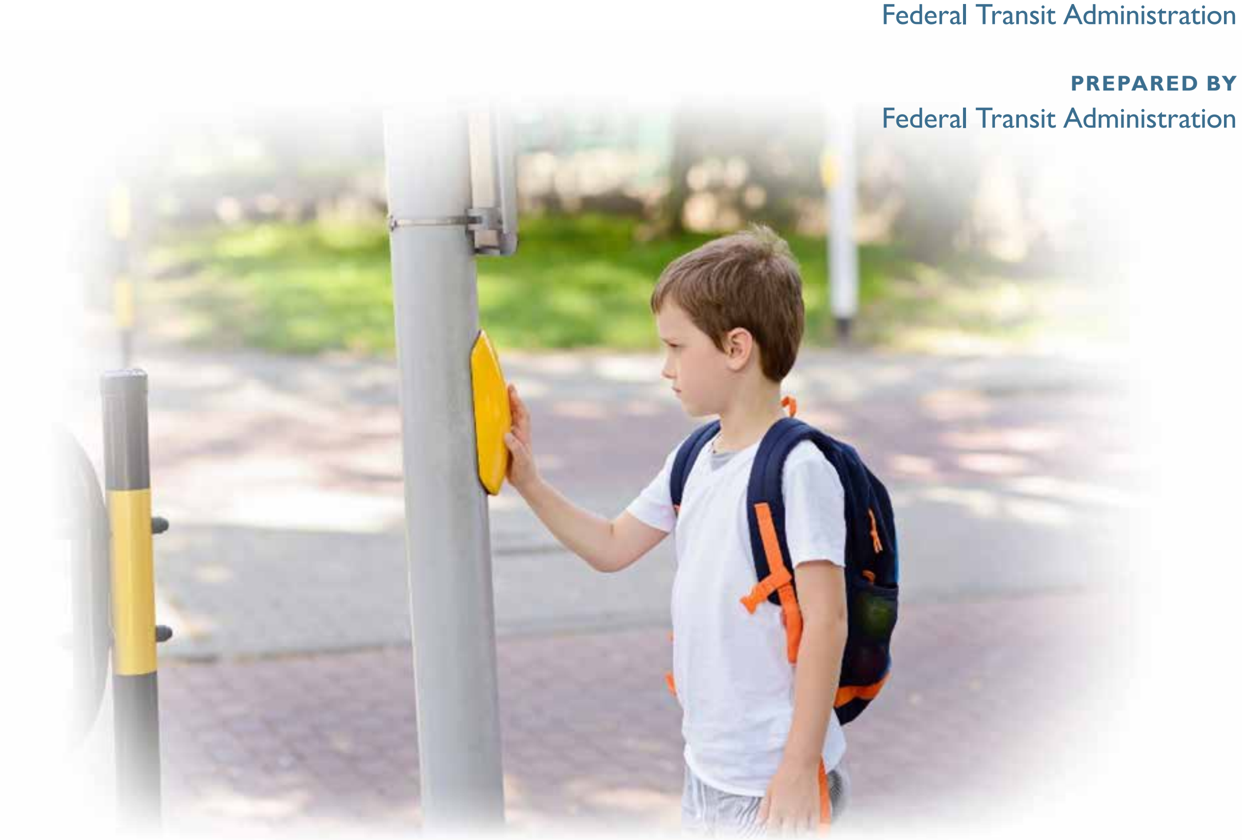
FEDERAL TRANSIT ADMINISTRATION

Report to Congress on Innovative Safety and Security Technology Solutions for Alternative Transportation Facilities

MAY 2017

FTA Report No. 0108
Federal Transit Administration

PREPARED BY
Federal Transit Administration



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U.S. Department of Transportation
1200 New Jersey Avenue, SE
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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

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13. ABSTRACT
This research collected information on the frequency and impact of safety and security incidents (threats) at selected facilities and identified priority incidents at each facility. A customized "all hazards" approach was used to determine the hazards that could impact the facilities to determine which assets (people, property, and materials) were vulnerable to man-made or natural threats at the facilities. The threats were sub-divided into safety and security dimensions and then broken out into incident categories. Once the priority issues were identified, additional research focused on finding innovative technologies that could address these issues.

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ACRONYMS AND ABBREVIATIONS

ACS	Access Control Systems
AS	Active Shooter
BART	Bay Area Rapid Transit
CBRN	Chemical, Biological, Radiological, Nuclear
CCTV	Closed Circuit Television
DSRC	Dedicated Short Range Communications
ECP	Entry Control Points
FAA	Federal Aviation Administration
FARS	NHTSA's Fatality Analysis Reporting System
FEMA	Federal Emergency Management Agency
FTA	Federal Transit Administration
GPS	Global Positioning Systems
LE	Law Enforcement
LED	Light-Emitting Diode
MAP-21	Moving Ahead for Progress in the 21st Century Act
MARTA	Metropolitan Atlanta Rapid Transit Authority
MBTA	Massachusetts Bay Transit Authority
MTA	Maryland Transit Administration or Metropolitan Transportation Authority (NY)
NCVS	National Crime Victimization Survey
NHTSA	National Highway Traffic Safety Administration
NiTS	NHTSA's Not-in-Traffic Surveillance System
NTD	FTA's National Transit Database
PTC	Positive Train Control
PTIDS	Platform Track Intrusion Detection System
PTZ	Pan-Tilt-Zoom
RFID	Radio Frequency Identification
SBIR	USDOT's Small Business Innovation Research Program
SRD	FTA's Safety Research and Demonstration Program
SRER	Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Demonstration
TCRP	Transportation Research Board's Transit Cooperative Research Program
TSA	Transportation Security Administration
UAS	Unmanned Aircraft Systems
UCR	Federal Bureau of Investigation's Uniform Crime Reporting Program
USDOT	United States Department of Transportation
VA	Video Analytics
WMATA	Washington Metropolitan Area Transit Authority
WMD	Weapons of Mass Destruction

EXECUTIVE SUMMARY

Section 3025 of the Fixing America's Surface Transportation (FAST) Act, Pub. L. 114-94, requires that the U.S. Department of Transportation (USDOT), Federal Transit Administration (FTA), research safety incidents at transportation facilities that encourage the use of alternative transportation (i.e., modes other than private motor vehicle). These facilities include 1) local, state, and regional rail and bus stations/stops/terminals; 2) parking lots associated with public transportation, lots at colleges/universities, and carpool lots; 3) rest stops; 4) bike paths and walking trails; and 5) sidewalks, streets, and bike lanes used for alternative transportation. The purpose of the research was to collect information on the frequency and impact of safety and security incidents at selected facilities and identify priority incidents at each facility. Once the priority issues were identified, additional research focused on finding innovative technologies that could address these issues.

A customized "all hazards" approach was used to determine the hazards that could impact the facilities. This approach determined which assets (people, property, and materials) were vulnerable to man-made or natural threats at the facilities. The hazards were sub-divided into safety and security dimensions and then broken out into categories. The types of hazards covered in this report are listed in the table below.

Incident Categories		
Hazard	**Category**	**Incident Type**
Man-Made Hazards	**Security**	Mass-casualty crime
		Violent crime (personal)
		Non-violent crime (personal)
		Property crime (including trespassing and nuisance issues)
	Safety	Vehicular crashes
		Non-vehicular crashes
		Catastrophic crashes
Natural Hazards	**Safety**	Advance notice weather or geological hazards
		No advance notice weather or geological hazards

Methodology

The research team used a comprehensive approach to identify high-priority safety and security incidents within the identified categories. Methods included conducting a traditional literature search as well as using web search engines to identify sources of data and trends related to incident frequency and impact. Anecdotes from articles, news stories, and reports were used to supplement more quantitative sources and to gather information on incidents at facilities at which data are not regularly collected. Interviews with FTA and Transportation Security Administration (TSA) staff also helped with identifying and confirming safety and security priorities at facilities.

Innovative technology solutions were researched using similar methods. A web search identified safety and security technology research published in academic journals, on government websites, or in other transportation-related media sources. Technologies that progressed beyond the research stage were identified through a web search of commercially-available safety and security solutions. Interviews with FTA and TSA staff also were used to identify potential safety and security technologies.

Findings

The research team populated a facility-incident matrix with high-priority safety and security incidents (see Table 3: Priority Incident Matrix). Selected facilities were included based on the frequency and severity of criminal and safety-related incidents. When statistics were not available, qualitative information from reports, news stories, and interviews was used. The innovative technology research focused on the priority incidents identified in this matrix.

Security

Notably, the TSA, an agency of the U.S. Department of Homeland Security (DHS), has the lead responsibility for the federal government's activities related to transportation security. However, a person's perception of personal safety often is based, in whole or in part, on crime rates. Therefore, this report discusses security issues as well as safety issues.

Security Priorities:

- Crowded public spaces such as streets, sidewalks, and rail and bus stations are attractive targets for **mass-casualty crimes** such as bombings or mass shootings. The high impact of such crimes, including loss of life, injury, and fear of using public facilities, elevates these rare events to priority status.
- **Violent personal crime** is present in all facilities to some degree. Assaults are a problem across all facilities, whereas other violent crimes are reported most often on streets and sidewalks. Robberies occur with relatively high frequency at rest stops and transit stations. On bike and pedestrian trails, homicide and rape, although rare, are listed as high-impact incidents due to the fear they elicit in users, leading to lower facility use.
- **Non-violent personal crime** in the form of theft is present at all facilities. Crowded spaces attract pickpockets and purse-snatchers, and parking lots are home to theft of and from motor vehicles.
- **Non-violent property crime** tends to show up as vandalism or property destruction and is a challenge across all facilities.
- **Nuisance issues** were brought up by FTA staff members when identifying priority incidents for all transit-related facilities. Homeless persons or

trespassers who sleep or linger in rail and bus stations make users feel unsafe, and unruly passengers also can incite fear or instigate confrontations.

Safety Priorities:

- **Suicides** at rail facilities, although relatively rare, were identified as a priority concern in several FTA regions.
- **Crashes involving public transportation vehicles** also rose to the top as a priority concern. Bus collisions with pedestrians and bicyclists on streets, at intersections, and in bike lanes are the most common incidents. Heavy, light, and commuter rail collisions with bicycles and pedestrians on streets, at intersections, and at stations also were a concern.
- **Pedestrian and bicycle collisions with motor vehicles** at intersections of bike/pedestrian trails and streets were cited as a priority by those trying to keep trails and walking paths safe.
- **Backward pedestrian collisions** are problematic across all types of parking lots.
- Although rare, **commuter or passenger train derailments and collisions** have become a higher priority due to recent collision incidents in New Jersey and Pennsylvania.
- The **natural hazards** category as a whole is included in the list of safety priorities. Major weather and geological events can impact the use of transit systems and can increase the likelihood of vehicle-based collisions in slippery and/or low-visibility conditions.

Security Technologies

Effective security measures reduce the number of criminal acts at facilities and make system users feel safer. Three categories of security systems were identified to combat the priority security issues at facilities:

- **Advanced surveillance systems**, including closed circuit television (CCTV) cameras and monitoring devices, were linked to crime reduction and improved response time for safety and security issues in fixed facilities such as transit stations or parking lots. Advanced cameras with tilt and zoom features improve image quality and security response even further. Virtual analytics can automatically detect suspicious activity, improving the efficiency of law enforcement. In addition, new technologies that can serve remote or open-air facilities include unmanned aircraft systems, handheld monitoring devices, and solar powered cameras.
- **Advanced access control systems (ACS)** use sensor technology to deter unlawful entry to fixed facilities such as transit stations or parking lots. In remote or open-air facilities, virtual barriers can be created using sensors and/or cameras, deterring entry and/or triggering a security response. Access control to fixed facilities also can be improved by requiring smart cards

or biologic screening to enter. Integrated systems can link access control, surveillance, and even lighting systems to create a more powerful security presence.

- **Advanced weapon-screening systems** can be used to prevent terrorist or mass-shooting threats. Weapons screening at entry control points can prevent the entry of weapons but is limited to fixed facilities with entry portals, such as train or bus stations. Other options that may be available in the future include the strategic placement of weapons of mass destruction (WMD) sensors (chemical, biological, radiological, nuclear), supplemented with canine detection and security patrols.

Innovative technologies often impact both safety and security. Two examples include lighting improvements and advances to communications:

- **Advanced lighting systems** improve both security and safety outcomes in all facilities. Advances such as energy-efficient lighting using solar power and/or light emitting diode (LED) bulbs lead to improved visibility and reliability. Motion-detecting sensors allow facilities to light only areas in use, thus saving money, deterring crime, and ensuring that areas are well-lit for surveillance. Integrated lighting solutions build upon these technologies using wired or wireless communications to report outages and improve maintenance.
- Improved **communications and emergency response solutions** will help protect users of facilities:
  - Disaster notification systems provide advance notice of man-made and natural disasters through smartphones or other devices, allowing users to keep themselves safe and informing them of facility delays or closures.
  - User-based incident reporting systems/applications allow users to report safety concerns such as damaged equipment or inadequate lighting and to report security threats or incidents.
  - Advanced communications systems that do not rely on traditional phone or broadband service can improve the ability of first responders to reach both man-made and natural disasters.

Safety Technologies

The research team identified five categories of facility-based technologies that can reduce vehicle collisions with pedestrians and bicyclists at crossings and intersections:

- **Pedestrian signals with advanced displays** such as pedestrian advanced count-down timers that can be programmed to be "leading pedcestrian intervals" to give pedestrians additional crossing time or "scanning eyes" that are activated by timers, push buttons, or sensors to alert pedestrians to crossing signals.

- **Pedestrian signal-priority technology** uses a mix of pedestrian-detection sensors and algorithms to activate pedestrian (or bicyclist) priority in intersections or crossings.
- **Technologies for alerting vehicles to pedestrians/bicyclists at crossings** include push-button or sensor-operated beacons such as pedestrian hybrid beacons and rectangular beacons. These technologies are effective, inexpensive, and can run without a separate power source (solar).
- **Facility-to-vehicle technologies** are detection technologies installed at rail stations, large bus depots, or rail track locations that sense a vehicle's or pedestrian's location and send a warning to the vehicle operator if a dangerous situation is imminent.
- **Connected vehicle technologies** currently under development connect infrastructure, pedestrians, and vehicles for the purpose of preventing collisions.

The research team identified three categories of vehicle-based technology that could be applied to transit vehicles to prevent collisions:

- **Vehicle-based pedestrian warnings** alert pedestrians to the movement or approach of a bus or other vehicle using lights, sound, or other warnings. These systems are triggered by a driver action or through the detection of a pedestrian, bicyclist, or other object in a vehicle's path or blind spot.
- **Driver-based warning technologies** provide in-vehicle warnings to drivers so they can avoid collisions. Once a pedestrian is detected in a vehicle's blind spot or anticipated path, a light/display, sound, or tactile warning is provided.
- **Automatic braking systems**, which detect obstacles and automatically apply brakes, can be used in conjunction with warning systems to improve safety outcomes on transit vehicles.

It is likely that most of the technologies described in the safety solutions can be adapted in the near future for use in transit vehicles to prevent collisions. These solutions are based largely on the use of detection sensors in conjunction with computers and communication systems. The future of vehicle-based collision technologies likely lies in further advances in connected vehicle applications.

Conclusions and Recommendations

Security

The following recommendations present an idea of how smaller systems, larger systems, and open or remote facilities could approach innovative security technologies if budgets and grant funding allowed them to expand their security systems.

- Smaller transportation systems with limited budgets could use ACS with sensors to improve deterrence and response to violent and property crime. The ACS could be augmented with video surveillance if budget and staffing allow. In the future, smaller facilities could look into hand-held CCTV monitors, allowing their limited staff to be efficient and effective as they patrol.
- Larger transit systems must tackle security across multiple facilities and geographies. Security systems for such facilities tend to be integrated and are likely to include access control, surveillance, and other support systems such as lighting or emergency response systems. The most cost-effective, first-line additions to basic systems could include advanced access control systems (e.g., smart cards), advanced camera surveillance, and video analytics.
- Open-air and remote systems have been difficult to secure in the past. Security officers on patrol, coupled with strategically-placed surveillance, offer some protection, but cannot cover all areas. Innovations such as hand-held monitors and detection devices will allow existing security to be more effective, but such systems are likely to be expensive.
- Lighting and emergency communication systems can improve safety outcomes at many facilities. Low-cost, energy-efficient lighting is an area all facilities should focus on improving safety and security. Disaster notification systems delivered via smart phone apps are another affordable choice for transit facilities and other systems that face weather or other disaster threats.

Safety

The safety section of this report focuses primarily on solutions that can help prevent collisions between transit vehicles and pedestrians or bicyclists. The following recommendations provide a sense of how transportation agencies could prioritize vehicle-and facility-based solutions.

- Cost-effective technologies that can be added to transit vehicles to improve safety in and around facilities include audio or visual warnings to pedestrians or operators. Pedestrian detection coupled with a pre-collision warning to pedestrians and/or operators will dramatically reduce the potential for collisions. In the future, as research progresses, automatic braking will be more cost-effective and likely will become an industry standard. These advanced technologies will also be capable of gathering huge amounts of user and facility data to better assist with infrastructure investments and operational decisions to improve safety.
- Recommended facility-based technologies to improve safety include advanced forms of flashing beacons and lighting at crosswalks to better warn drivers of pedestrian and bicyclist crossings. At or near rail facilities, track intrusion detection systems may incorporate vehicle detection, and could potentially improve safety outcomes if integrated with positive train control (PTC)

systems, which are mandated by 49 U.S.C. § 20157 for certain passenger and freight railroads' main lines and are designed to prevent certain types of accidents and incidents, including train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position. However, PTC systems, as currently designed and statutorily mandated, do not provide vehicle detection or warnings to pedestrians and bicyclists.

SECTION 1

Introduction

Purpose of Study

Section 3025 of the Fixing America's Surface Transportation (FAST) Act, Pub. L. 114-94, requires the U.S. Department of Transportation (USDOT), Federal Transit Administration (FTA), to research safety incidents at selected transportation facilities that encourage use of alternative transportation. For the purpose of this study, alternative transportation includes modes of travel other than the private motor vehicle (i.e., walking, bicycling, carpooling, public transportation). The study collected information on the frequency and impact of incidents involving property damage, theft, injuries, deaths, and other safety and security issues at selected facilities. After identifying priority issues, additional research identified innovative technologies that can address the issues, increasing safety and security or ensuring a better response by transit security and law enforcement at the facilities. The information from the research was synthesized into a report to Congress summarizing safety and security issues by type of facility and identifying innovative technologies available to address such issues. The report also includes recommendations on how the innovative technologies can be used most effectively to increase safety and security

Scope and Definitions

For the purpose of this report, research focused on a selected set of locations and facilities that pedestrians and bicyclists access as a mode of alternative transportation or as means to connect to public transportation. These facilities include 1) local, state, and regional rail and bus stations/stops/terminals; 2) parking lots associated with public transportation, carpool lots, and college/universities; 3) rest stops; 4) bike paths and walking trails; and 5) sidewalks, streets, and bike lanes used for alternative transportation.

An "all hazards" approach was used to identify hazards that likely would impact the facilities (see Appendix A: All Hazards Approach for more information). Hazards were divided into man-made hazards and natural hazards and then broken down further into the safety and security dimensions shown in Table 1. This table does not include all possible hazards, focusing instead on only those that could be successfully addressed at facilities using innovative technology solutions.

Table 1.
Incident Definitions

Category		Incident	Definition
Man-made Hazards	Security	Mass-casualty crime	Violent acts occurring in a place of public use, intending to kill or inflict injury on multiple people.
		Violent crime	A crime in which the offender uses or threatens force upon a victim or intentionally injures a victim.
		Non-violent (personal) crime	Crimes that do not involve the use of force, usually measured in terms of economic damage or loss.
		Property crime (including trespassing)	Crimes involving the taking or use of property not involving force, or crimes involving the destruction of property.
	Safety	Vehicular crash	A crash in which a motor vehicle (or bicycle) is involved in a collision with a pedestrian or bicyclist.
		Non-vehicular crash	Any type of crash that does not involve a motor vehicle, with the exception of catastrophic crashes.
		Catastrophic crash	A crash that leads to multiple fatalities or injuries (vehicular or non-vehicular).
Natural Hazards	Safety	Advance notice weather or geological hazard	Dangerous weather or geological events that provide notice prior to occurrence.
		No advance notice weather or geological hazards	Dangerous weather or geological events that provide no significant advance warning prior to occurrence.

Study Limitations

This study provides a snapshot of the innovative technologies that can address priority safety and security issues at facilities. The research focused on technologies that currently are or will soon be available and that can be applied to facilities in both large and small transportation systems. Where available, cost and effectiveness data were considered in determining whether to include the technologies. The technologies profiled in this document should not be considered a full scan of all safety and security technologies available or being researched at the time of publication. A full scan was outside the scope of this effort, as many technologies are in the early stages of research or are too expensive for consideration in most public transportation systems.

Methodology

This study used a comprehensive approach to identify safety and security issues at the facilities and to identify innovative technology solutions to address these issues. Methods included a traditional literature search, web research, interviews with Federal Transit Administration (FTA) and Transportation Security

Administration (TSA) staff, as well as informal networking to identify additional data and reports.

Literature Search and Document Review

A literature search was used to identify existing research on safety and security incidents at the facilities. The research team used keyword searches on web search engines and databases to identify incident information from academic journals, government websites, transportation-related media, and other general media. Information on incident frequency and impact was gathered through the review of tabulated data, trends, and report findings. Anecdotes from articles and news stories were used to supplement these sources and to gather information on incidents at facilities where data are not regularly collected. Reports from other countries also were used to understand incident frequency and impact when US data were not available.

Innovative technology solutions were researched using similar methods. A keyword search identified safety and security technology research published in academic journals, government websites, or other transportation-related media sources. Technologies that progressed beyond the research stage were identified through a web search of commercially-available safety and security solutions. Dimensions such as incidents addressed, actions performed, technologies used, cost, and complexity were captured for each technology solution.

FTA and TSA interviews

A small number of interviews with FTA and TSA staff supplemented the literature and web research. Thirty-minute interviews with staff from FTA regional offices were conducted in September and October 2016. Interview questions focused on how FTA staff support regional transit agency safety and security programs through grants and other funding. Interviewees were asked to describe safety and security issues faced by transit agencies and to identify technologies implemented to address these issues. The questions also focused on potential future solutions to address unresolved issues. Additional interviews with TSA staff discussed innovative security technologies emerging in public transportation. A subset of interview questions is shown in Table 2: In-Depth Interview Questions. Full discussion guides and a list of FTA and TSA staff interviewed are listed in Appendix B.

Table 2

In-Depth Interview Questions

Interview Questions
1. In your role at (FTA/TSA), how do you work with transit agencies (in your region)?
2. How does your work with transit agencies involve the safety and security aspects of these transportation systems?
3. What safety issues, involving transit users, pedestrians, and bicyclists have transit agencies identified in recent years?
4. What security issues (e.g., property crime, violent crime, terrorism) have transit agencies identified in recent years?
5. What types of safety and/or security technologies have you seen agencies implement (or seek grant funding for) to address these issues?
6. Are there any innovative technology solutions transit agencies are looking for to improve safety and security in the future?

Creating the Priority Incident Matrix

Using information available from the literature search and interviews, the research team populated a facility-incident matrix with high-priority safety and security incidents (see Table 3: Priority Incident Matrix in Section 2). Decisions to include were made using statistics indicating which crime and safety issues were most common and/or most impactful in the facilities. When statistics were not available, qualitative information from reports, news stories, and interviews was used to identify the priority incidents for a facility. The priority-incident matrix is discussed in more detail in Section 2: Priority Incidents at Selected Locations.

Identifying Technology Solutions

After developing the Priority Incident Matrix, the research focus turned to the search for innovative safety and security solutions. Solutions were identified for the priority incidents identified in Table 3: Priority Incident Matrix. Information from the interviews, coupled with technology solutions identified during the literature and web search, were compiled for review. Technologies that met the following four study criteria were selected for reporting:

- Addresses priority issue(s) at one or more facilities
- Currently or will soon be available on the market
- Widely applicable across transportation systems (smaller, larger)
- Cost-effective

The resulting technologies and their application to specific safety and security issues are described in Section 3: Security Solutions and Section 4: Safety Solutions.

SECTION 2

Priority Incidents at Selected Locations

To develop a set of priority issues at facilities, the research team sought information on the frequency and impact of a select set of safety and security incidents (see Table 1). The team carried out an extensive literature search and conducted interviews with FTA and TSA staff at the national and regional levels to obtain this information. Due to the breadth of incident categories and facilities covered, research took several forms. Initial searches focused on identifying statistically-valid data on incident frequency and impact. When statistical data were not available or needed additional context, qualitative information from interviews, reports, articles, and other media sources was used to fill the gaps. This report focuses on presenting innovative technology solutions that address the priority safety and security issues highlighted in Table 3: Priority Incident Matrix.

Incident Frequency

Where possible, statistically-valid data on security were captured for facility/incident cells from sources such as the Bureau of Justice Statistics' National Crime Victimization Survey (NCVS) (1), the Federal Bureau of Investigation's (FBI) Uniform Crime Reporting (UCR) program (2), and reports from individual transit systems. Safety data were found for some facilities using FTA's National Transit Database (NTD), the National Highway Traffic Safety Administration's (NHTSA) Not-in-Traffic Surveillance (NiTS) system (3) and Fatality Analysis Reporting System (FARS) (4), and from individual transit system reports. Natural hazards incidence from the National Weather Service also was available to understand the frequency and impact of these events (5).

Although these sources matched up well to some facility/incident cells, other facilities were defined differently or combined with other facilities for reporting. In these cases, data from the "closest comparable facility" were used. When raw or formatted incident data did not exist, the research team depended on more qualitative measures of frequency determined through summarizing reports, news articles, and interview notes.

Incident Impact

The research team supplemented the frequency data with information on the impact of a safety or security incident. Impact data included the financial impact of a crime or crash or the change in facility usage levels following a security or safety incident. Although few studies were identified that provided statistical measures of the usage change following an incident, several news articles pointed to security and safety issues as the cause of lower facility use. Interviews with FTA and TSA staff also provided examples of safety and security priorities that involve incidents that are low-frequency but high-impact.

Priority Incident Matrix

The priority matrix displayed in Table 3 shows a mix of high-frequency and high-impact incidents at the facility/incident cell level.

Priority Security Incidents

The facilities vary considerably in terms of the amount of crime reported. The category including sidewalks, streets, and bike lanes[1] tends to account for the most crime, followed by parking lots and then stations, stops, and terminals. Rest areas and bike and pedestrian trails tend to have lower reported crime levels. Despite varying crime frequency, Table 3 identifies the priority security incidents at each facility that may benefit from innovative technology solutions. These incidents are described in more detail below.

- Crowded public spaces such as sidewalks and streets as well as crowded rail and bus stations/stops/terminals are attractive targets for **mass-casualty crimes** such as bombings, mass shootings, or mass assaults. These facilities are at a higher risk for these activities, even though mass-casualty incidents have been rare occurrences in the U.S. (6). Mass-casualty crimes have multiple impacts, including direct injuries and fatalities, as well as psychological impacts leading to decreased use of the facilities for prolonged periods after the event takes place.
- **Violent personal crime** is present in each of the facilities to some degree. Assaults are the most frequently-reported crime across the facilities, and other violent crimes most often are reported on sidewalks and streets. Robbery tends to occur more often than would be expected at rest stops and rail and bus stations/terminals. Bike and pedestrian trails violent crimes, although rare, are listed as high-impact incidents due to noted periods of lower usage seen after events occur. Anecdotal evidence shows that violent crimes are more likely to occur on trails that cross more dense urban areas.
- **Non-violent personal crime** is commonly found at each of the facilities. Crowded spaces attract pickpockets and purse-snatchers, and unattended motor vehicles are attractive targets for theft of electronics or other goods.

[1] The FBI Uniform Crime Report defines this category as highways/roads/streets and alleys. For the purpose of identifying the most frequent crimes on sidewalks, streets, and bike lanes, this category was used.

Theft of motor vehicles is also a priority problem for parking lots, and bike theft impacts bike and pedestrian trails.

- **Non-violent property crime** tends to show up as vandalism or property destruction and is a challenge across all facilities.
- **Nuisance issues** were mentioned by regional FTA staff when identifying priority incidents for transit-related facilities. Homeless persons or trespassers who sleep or linger in rail and bus stations and terminals can make users feel unsafe, and unruly passengers can incite fear or instigate confrontations with other facility users.

Table 3 *Priority Incident Matrix*

			Facility				
			Sidewalks/ Streets/Bike Lanes[2]	***Stations, Stops, Terminals***	***Parking Lots***	***Rest Areas***	***Bike/Pedestrian Trails***
Man-made Hazards	**Security**	Mass casualty crime	• Bombing* • Mass shooting or assault*	• Bombing* • Mass shooting or assault*	Bombing*		
		Violent Crime	• Assault • Robbery** • Homicide**	• Assault • Robbery** • Homicide**	Assault	• Assault • Robbery**	• Assault • Homicide** • Rape
		Non-violent (personal)	Larceny	Larceny	• Larceny • Motor vehicle theft	Larceny	Larceny (bike theft)
		Non-violent (property)	• Vandalism • Trespassers or homeless persons • Nuisance persons	• Vandalism • Trespassers or homeless persons • Nuisance persons	• Vandalism • Trespassers or homeless persons • Nuisance persons	• Vandalism • Trespassers or homeless persons • Nuisance persons	• Vandalism • Trespassers or homeless persons • Nuisance persons
	Safety	Suicides		Suicides (rail)			
		Vehicular crash (inlcuding bike)	• Rail collision with pedestrian/bike • Bus collision with pedestrian/bike	• Rail collision with pedestrian • Bus collision with pedestrian/ bike	Vehicle collision with pedestrian (backward car collision)		• Vehicle collision with bike at road crossing • Bike collision with pedestrian
		Severe/catastrophic crash		• Train collision • Train derailment			
Natural Hazards	**Safety**	Advance warning	Weather and geological hazards: winter storms, hurricanes, extreme heat, extreme cold				
		No advance warning	Weather and geological hazards: wildfires, flash flooding, earthquakes				

*Low (or no) frequency of occurrence domestically, but high potential impact including death, serious injury, or intense fear of future facility use.

**Low frequency of occurrence, but occurs more often than expected given facility crime rate.

[2] Sidewalks and streets are included in this category, as they are associated with use of or connection to alternative transportation.

Priority Safety Incidents

FTA is working towards meeting the USDOT's goal of reducing transportation-related deaths and injuries by advancing research. The following types of incidents (also shown in Table 3) represent areas in which innovative technologies may be used to help meet these safety goals:

- Although considered a low-frequency incident overall, **suicides** at rail facilities (or on rail property) were cited as a priority concern in several FTA regions.
- **Crashes involving public transportation vehicles** also rose to the top as a priority concern. Preventing transit-related deaths and reducing injuries is a high priority for FTA. Bus collisions with pedestrians and bicyclists—on streets, at intersections, and in bike lanes—are the highest priority to address. Heavy, light, and commuter rail collisions with bicycles and pedestrians on streets, at intersections (grade crossings), and, to a smaller extent, at stations and stops are also a concern.
- **Pedestrian and bicycle collisions with motor vehicles** at an intersection of bike/pedestrian trails and streets is a priority issues for those trying to keep trails and walking paths safe.
- **Backward pedestrian collisions**, in which pedestrians are struck by a backing vehicle,are problematic across all types of parking lots.
- Although rare, **commuter or passenger train derailments and collisions** have become a higher priority due to recent collision incidents in New Jersey and Pennsylvania. In addition to passengers, these incidents can injure or kill pedestrians at stations and nearby walkers or bicyclists (6).
- The **Natural Hazards** category as a whole is included in the list of safety priorities. Major weather and geological events (e.g., floods, wildfires, winter storms, etc.) can impact the use of transit systems and can increase the likelihood of a vehicle-based collision in slippery and/or low-visibility conditions.

Connecting Incidents with Technology

Section 3: Security Solutions and Section 4: Safety Solutions identify innovative technologies that can help address the priority safety and security issues outlined herein. Although the priority incidents shown are identified at the cross between facility and incident, many of the technologies are applicable to multiple facility and/or incident cells in the Priority Incident Matrix. Solutions that can tackle multiple issues, addressing safety and security, may be the most cost-effective and feasible to local transit agencies and other facility managers.

Facility Data Gaps

The Priority Incident Matrix was developed using a variety of information sources. Because there was imperfect alignment between the facilities and the data reported at the national level for both safety and security, other sources were used to identify priority incidents. Areas with major data gaps are described below.

Security

Although the Bureau of Justice Statistics' National Crime Victimization Survey (NCVS) (1) and the FBI's Uniform Crime Report (UCR) (2) identify violent and property crime by location, these locations are not always specific to the transit and alternative transportation facilities.

- Parking lot statistics include all lots and garages, not just those associated with alternative transportation and colleges/universities.
- Streets, sidewalks, and bike paths statistics were pulled from similar but imperfectly-defined categories (e.g., "On street other than near own or friend/neighbor/relative house" in NCVS [1], "Highway/Road/Alley/ Street" in UCR [2]).
- Station, stop, and terminal statistics (UCR) include air transportation; NCVS statistics include airports and on-vehicle crime incidents.
- Bike and pedestrian trails were not included in either crime data source.

Due to these gaps, other sources were used to supplement the national crime reports. A sample of local transit agency reports, such as those from the Massachusetts Bay Transit Authority (MBTA), Bay Area Rapid Transit (BART), and Washington Metropolitan Area Transit Authority (WMATA), helped identify issues in parking lots, stations, and stops. Reports from government agencies, academia, and interest groups provided information on security issues on bike and pedestrian trails and non-transit parking lots. Interviews with FTA and TSA staff helped identify issues involving terrorism threats (mass-casualty) and other security issues.

Safety

Safety data related to alternative transportation users were difficult to find at the national level. Some facilities could be located in FTA's National Transit Database (NTD) (7) or estimated from information from NHTSA's Fatality Analysis Reporting System (FARS) (4) or the Not-in-Traffic Surveillance (NiTS) system (3), but data on crashes at other facilities (i.e., bike paths, rest stops) was largely unavailable.

- Safety data in the NTD was not broken out for parking lots.
- Backward collision incidents from FARS and NiTS were used to estimate frequency of parking lot collisions, but data include all types of parking lots and driveways.
- No national data was found on crashes at rest areas or bike/pedestrian trails.

As with security data, other sources of information were used to supplement the available databases and safety reports. Safety studies and reports from academia and interest groups were combined with news articles to provide information on crashes and other safety issues at facilities. Interviews with FTA regional staff also helped identify issues at the regional level.

Filling the Gaps

Despite the lack of sufficient data to fully inform the safety and security issues at the facilities, the research team is confident that the major issues have been identified with supplemental qualitative data sources. To improve FTA's and other agencies' ability to collect quantitative data on facilities in the future, the study examined how the identified technologies can be used to collect data on specific safety and security incidents. Technologies capturing incidents via video, sensors, or other devices could make the capture of information easier. Data collected at the local and regional levels could be used as case studies or rolled up to provide national statistics.

SECTION 3

Security Solutions

Overview of Security Technology

Security technology usage in transportation is evolving as quickly as new technologies develop and agencies allocate funding resources to access them. One funding source is the Urbanized Area Formula Grants program (49 U.S.C. 5307), in which transit agencies must certify they will expend, for public transportation security projects, at least 1% of the funds the agency receives from FTA (8). The grant-specific fiscal year funding is targeted toward reducing threats from crime through projects such as enhanced lighting systems, surveillance systems, and communications enhancements that allow security and law enforcement (LE) responders to more effectively react to security threats. Additional funding is available through the Federal Emergency Management Agency (FEMA), which, with support from TSA, provides funding opportunities through Surface Transportation Security Grant programs that support surface transportation risk mitigation by applying federal funding to critical security projects with the greatest security effects (9).

Security systems are designed to deter, detect and assess, and respond to man-made threats to the traveling public. Train stations, bus stops, rest areas, parking lots, bicycle paths, and walkways must remain readily-accessible, convenient, and economical, yet be secure to the satisfaction of users. Effective security measures reduce the number of criminal acts in the facilities and have a positive psychological effect on system users by demonstrating owner/operator commitment to keeping them safe. Threats by criminals within the facilities range from individual violent crimes (assault, robbery, homicide, etc.) and mass-causality crimes (bombing, weapons attack), to non-violent personal crimes (larceny, motor vehicle theft) and property crimes (arson, vandalism, trespassing).

The public's demand for transportation services must be balanced with effective security and emergency preparedness through design strategies, education and training, application of technologies, implementation of policies and procedures, and multi-agency emergency response protocols integrated into a comprehensive system. This study focused on innovative technology subsystems while incorporating design strategies, policies and procedures, and multi-agency emergency response protocols, although these system aspects are not always discussed in detail. Ideally, the **innovative technologies** presented herein will improve security outcomes such as crime reduction, faster emergency response, and resiliency to catastrophic events.

Surveillance Systems

Surveillance systems permit the monitoring of interior and exterior areas of facilities and transit vehicles. For the purpose of this report, the term "surveillance" includes visual assessment systems otherwise known as closed circuit television (CCTV) cameras and their related technologies for security/LE detection and assessment uses. Surveillance of a facility and its assets will help deter some criminals from committing violent or property crimes, such as those identified in the Priority Incident Matrix, through fear of security/LE apprehension. Surveillance improves the odds of capturing or thwarting even those criminals who are not deterred by the presence of cameras. Additionally, surveillance systems improve both facility security and safety by enhancing emergency response to incidents, including observing and responding to potential suicidal persons. Finally, the positive psychological effect on facility users fostered by the presence of visible cameras is a reassurance of a relatively secure environment and a commitment by the owner/operators to their safety.

Basic Surveillance Systems

Basic surveillance systems use fixed-view CCTV cameras within facilities such as bus stations, train stations, and parking lots. The fixed views are limited to what is seen in the cameras' field of view, which is stationary. CCTV surveillance requires security personnel support to view and respond to incidents, as well as many supporting systems and subcomponents to run the system. A supporting electrical power system is needed to run the components, and lighting systems are essential during hours of darkness and inclement weather. CCTV systems are commonly used in transit systems today, with the exception of remote facilities that lack power or a communications infrastructure. A survey of rail transit agencies from 2011 showed that a majority of rail-based transit facilities operate video surveillance somewhere on their property and a smaller number used them in parking areas (10).

Video recording systems capture the camera's images. More advanced networked systems capture digital images along with date, time, and scene for archival storage and retrieval. In most systems, a means to transmit those camera images quickly back to a security command center is needed. Both hard-wired and wireless technologies can transmit the camera images. Many facility factors, such as layout, power sources to camera locations, camera type, budget resources, local environment, and technical constraints, will determine which transmission method is used. Given these factors, the correct solution choice is the one that best facilitates security/LE detection and assessment with real-time awareness to what is happening within their respective area (11).

Enhanced Surveillance Systems

Enhanced surveillance systems add additional digital technology applications to CCTV to improve security outcomes. These include pan-tilt-zoom (PTZ) camera views, mobile CCTV cameras and monitors, and automated image analysis through video analytics. PTZ cameras are in stationary mounts but have either mechanical or digital movement abilities that can be controlled by a security operator. The operator can find a viewing scene by panning the camera, tilting it to better orient the view, and zooming in to magnify the view to the technical specifications of the lens.

High-resolution cameras will yield better surveillance scenes for analysis and further investigation by LE. The ideal fidelity of a camera surveillance image useful for LE would allow recognition of the physical characteristics of a perpetrator or threat figure ("6 ft tall white male with tattoo on neck, wearing black hooded sweatshirt with white logo on chest and carrying bladed weapon in left hand"). Less ideal is an image whose fidelity would permit only the identification of a figure ("tall white male wearing black sweatshirt"). Least favorable for LE use is a picture quality that simply generally characterizes a potential threat ("individual holding sometime in his hand").

Mobile CCTV systems can be installed on public transportation vehicles—buses, trains, ferries, etc. Images typically are recorded and retrieved from the surveillance system for review. The functionality of a mobile CCTV system is limited by its mobile platform constraints—space, mounting options, and video recording ability. Wireless connectivity to a central monitoring system is currently cost-prohibitive because of the ongoing service costs, in addition to transmitting bandwidth constraints.[3] Data from the vehicles are used by security/LE for crime and crash investigations. This type of system is prevalent on larger bus systems, and is becoming more common on rail.

Example: A wireless CCTV camera system on light rail or bus equipment with cameras viewing the operator, passengers, and fare collection equipment. The camera feeds are recorded and retrieved later when back at the station to examine for security/LE purposes.[4]

An innovative addition to CCTV surveillance includes mobile or hand-held CCTV monitors that can be used to view fixed or mobile CCTV cameras. Tablets, smartphones, or other devices can view CCTV camera feeds, allowing security/LE to monitor areas while away from security command center monitors. These devices are slowly being introduced to LE agencies and could soon be used by transit agencies or other transportation systems.

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[3] Interview with William Baron, Wireless Systems Specialist, Volpe Center, November 3, 2016.

[4] *Ibid.*

Example: Security/LE using a smartphone to view and assess an incident transmitted from a CCTV camera view at fixed and open-air facilities.

Finally, in the remote or open-air systems in which electric grid power is not available, an innovative option to power CCTV surveillance is the installation of solar panels to harvest energy to charge battery banks that operate surveillance electronic components. The effectiveness of the solar panel and linked batteries is dependent on a variety of meteorological and environmental factors, including daily and seasonal sun exposure, ambient temperature, etc. Due to the remote nature, any CCTV data must be stored at the remote site on a time-lapse digital video recorder for later retrieval.

Video Analytics

Integrating video analytics (VA) into a CCTV system may improve the performance of the surveillance system. VA software can be programmed to discriminate CCTV field-of-view behaviors appropriate to each surveillance scene. For example, a field-of-view behavior at a train platform scene is passengers loading and unloading. An anomaly behavior to that scene is a person loitering after the train loads with passengers and pulls away. The VA senses the abnormal behavior from the scene, sends an alert through the system, and announces at the security command center, which orients the security operator to that CCTV scene, at which time the situation is assessed and responded to appropriately. VA software can be programmed to detect various abnormal behaviors or emergency incidents from the camera scenes:

Table 4 *Examples of Potential VA Applications*

Security	Safety
Access control intrusion detection	Potential suicide detection
Monitoring of "No Parking" and drop-off zones	Pedestrian crossings, bus lane crash detection
Automatic tracking of unattended objects or removed objects	Flooding or oil spill hazard detection
Loitering detection	
Tracking of individuals	
Parking lot vehicle theft monitoring	
Pre-event surveillance	
Graffiti detection	

VA requires programming with the CCTV camera system and must be well-integrated with manufacturer components to work effectively. VA technology is maturing at a rapid pace and has been implemented at large transit systems such as the Metro Atlanta Rapid Transit Authority (MARTA) (12) and the Maryland

Transit Administration (MTA) (13), but it has not yet been fully proven in an operational transit environment.[5]

Examples:

- VA CCTVs installed throughout Atlanta's MARTA rail system distinguish normal from suspicious behavior and send an email alert to police communications dispatchers (12).
- VA CCTVs installed on buses for LE assessment of crimes against bus operators and passengers.
- Water flooding or oil spill hazard detected by VA CCTVs on a train platform or any selected VA camera view within a facility.

An innovative option for surveillance is mounting cameras on unmanned aircraft systems (UAS). UAS are used in many industry sectors to access dangerous or remote areas, such as high-rise building structural engineering inspection, remote agricultural lands assessment, pipeline or power line integrity checks, etc. UAS with CCTVs programmed with VA could be used in remote area facilities (e.g., bike paths, walkways, parking lots) as access control systems and for fixed-facility (train station, bus yard, etc.) perimeter surveillance. UAS operations require Federal Aviation Administration (FAA) authorization for UAS operating as public aircraft. Alternatively, the UAS may be operated as civil aircraft under the FAA's regulations for small UAS – 14 C.F.R. Part 107. UAS operations under Part 107 require FAA remote pilot certification. In addition, all unmanned aircraft weighing greater than 0.55 lbs must be registered. If a UAS is tethered (connected to the ground), it is required to operate under the same operating requirements as a non-tethered UAS.

Examples:

- A tethered surveillance system on a floating helium balloon with a CCTV camera mounted at a height to provide wide-area coverage of a fixed facility.
- UAS at an open or remote system using a UAS with a camera viewing a bike or pedestrian trail.

[5] Interview with Daryl Song, Security Technology Programmer, Volpe Center, October 24, 2016.

Table 5 *Surveillance Security Solutions*

Solution	Actions	Technology	Cost [6,7]	System Type	Effectiveness	Facility
Basic video surveillance– CCTV systems (wired, wireless I/P)	• Monitoring for detection and assessment	• CCTV cameras • CCTV monitor (including digital video recorders)	• ~$1k–$1.5k per CCTV camera • ~$500–$5k per CCTV monitor unit[8]	Wired, wireless I/P integrated	• 16% crime reduction in all environments • 51% decrease in parking lots (14)	Streets/sidewalks, transit stations/ terminals, bike/ped trails, parking lots, rest areas
Enhanced surveillance– fixed CCTV with video analytics, mobile CCTV	• Monitoring for detection and assessment • Mobile detection and assessment • Automated surveillance detection/alert	• CCTV with video analytics software • Mobile CCTV cameras with wireless technologies • Hand-held CCTV monitoring devices	• ~$1k–$1.5k per CCTV camera • ~$4k per wireless CCTV camera • ~$3k per handheld CCTV monitor unit	Wired, wireless I/P integrated	Anecdotal evidence of effectiveness of advanced surveillance systems	Streets/sidewalks, transit stations/ terminals, bike/ped trails, parking lots, rest areas
Unmanned aircraft systems (UAS) – tethered, untethered	• Monitoring for detection and assessment • Automated surveillance detection/alert	• UAS CCTV cameras with wireless technologies	• ~$13k per UAS camera unit (e.g., sensors, camera)	Wireless, I/P integrated	Anecdotal evidence of effectiveness of UAS surveillance systems; testing continues	Streets/sidewalks, transit stations/ terminals, bike/ped trails, parking lots, rest areas

[6] Examples from interviews with subject matter experts and industry experience.

[7] Does not include cost of hard-wired or wireless communications systems necessary to transmit video to monitoring stations, which vary significantly by facility. Cost of Virtual Analytic technology systems also not included, as costs vary significantly depending on size and complexity of systems.

[8] Depends on digital video recorder system specifications.

Access Control Systems (ACS)

Basic ACS

Basic ACS leverage physical obstacles (e.g., fencing, barriers, walls, doors, etc.) to deter unauthorized persons from accessing or bringing dangerous devices into a facility. Access to controlled facilities is achieved using a key or by being granted access by an owner/operator. Enhanced ACS improve upon basic systems using technologies to enhance or substitute for physical obstacles and/or access methods. They help prevent unauthorized facility access and can trigger a security response to unauthorized entry, both of which can reduce violent and property crime, at facilities such as transit stations, stops, terminals, and parking lots (see Table 3).

Enhanced Fixed-Facility ACS

Physical barriers that restrict entry to fixed parking or transit facilities can be enhanced by integrating technologies including sensors, CCTVs with stationary or PTZ cameras, and electronic entry control. The customary fence, barrier, wall, door, and window entry control of a fixed facility can be enhanced with added motion-detection sensor alerts (e.g., passive infrared, fiber optic, break beam, piezoelectric, ultrasound, and others) and CCTV video surveillance (manual, automated, or video analytics). These methods provide additional layers of protection and system resiliency by including solutions that alert, orient, and assess for security/LE response. Electronic entry control points (ECP) controlled with smart cards or other devices can restrict entry at designated entry portals.

Examples:

- Transit station card reader access with intrusion detection sensors for climbers and jumpers over ECP barriers, gates, turnstiles, etc. (15).
- Parking lot user entry control points (ECP) using smart card (transit card) technologies.
- Bicycle pavilion with card reader access and integrated fixed CCTV cameras allowing assessment for LE response.
- Parking lot PTZ and fixed CCTV cameras integrated with motion detection to alert security when someone approaches a certain area, allowing assessment and response.

Enhanced Open-air Facility ACS

In addition to enhancing basic ACS, advanced technologies can extend the use of ACS from fixed facilities to open-air facilities (e.g., bike and pedestrian trails, open-air parking lots, etc.) which are difficult to restrict because they typically do not establish boundary barriers. A "virtual" ACS can be developed using

CCTV cameras that are manually monitored or embedded with VA software programmed to discriminate and alert security/LE when an unauthorized person breaches the virtual boundary of the facility. These "trip wires" are virtual geometric lines programmed into the CCTVs view to detect objects passing into exclusion zones created by security system operators.

Example: CCTV cameras with VA software that detect certain suspicious activities or behaviors are used by the New York Police Department in its "Domain Awareness System" (16).

Finally, in the near future, for remote or open-air systems where electric power may be scarce or unavailable, an innovative option may be to install "virtual" ACS on a controlled UAS. The mobility and flexibility afforded by a UAS is difficult to compete with using traditional land-based technologies, especially in remote areas. With proper FAA authorization, certification, and registration, security/LE may enhance capabilities into nighttime and remotely monitor parking lots, rest areas, and bike/pedestrian trails with UAS mounted with infrared (covert) equipment.

Integrated Systems

ACS currently in use are integrated systems that can include sensors, surveillance, ECP, and other technology subsystems such as lighting and emergency response systems, as discussed elsewhere in this report. Integrating disparate subsystems and linking technology outputs for improved transit agency security and LE security situational awareness and response distinguishes these solutions from traditionally-independent basic security ACS. The supporting systems are integrated for access control at ECPs and other locations through a central security command center, using wired or wireless connections.

Examples:

- A train station turnstile ECP with integrated break beam sensor to detect turnstile jumpers linked to automatic high intensity lighting systems linked to CCTVs for LE assessment.
- A track intrusion detection system linked to automatic lighting systems and CCTV surveillance for trespasser, or possible suicidal person assessment (17).

Integrated Weapons Screening Systems

The integration of screening systems into access control at ECPs can assist law enforcement with preventing dangerous devices from entering a populated facility. Such systems are applicable in station or terminal facilities where it is feasible to channel travelers through screening portals. Security personnel may also lock down a facility's ECPs in an emergency threat situation and then LE will respond.

Examples:

- A combination of millimeter wave and x-ray screening technologies to detect most weapons and explosives through 3-D, whole body silhouette imaging and traditional x-ray imaging of packages.
- Hand-held metal detectors used by security/LE personnel to complement passive screening and detect metallic objects.

CBRN (chemical, biological, radiological, nuclear) detection in facilities is more challenging. Most CBRN screening requires a controlled temperature environment, threat agent analysis processing time, and linked redundant systems to screen false-positive readings. Expensive CBRN systems are deployed in some public transportation metropolitan areas and are funded through Department of Homeland Security grants (18).

Table 6 *Access Control System Solutions*

	Action	Technology	Cost [9,10]	System Type	Effectiveness	Facility
Facility access control system – enhanced	Restrict unauthorized access to facilities; prevent violent crime, property crime	• Fiber optic or other sensors at perimeter fence lines • ECP card reader access with intrusion detection • Fixed CCTV system (camera and monitor)	• Up to $10k per unit set depending on array • ~$1k–$10k per ECP unit • ~$500–$5k per CCTV monitor unit	Hard-wired and wireless integrated technologies	• 16% crime reduction in all environments, 51% decrease in parking lots (14) • Anecdotal evidence of effectiveness of ACS systems	Transit stations/ terminals, parking lots, rest areas
Facility access control system – Video Analytics (VA)	Restrict unauthorized access to facilities; prevent violent crime, property crime	• CCTV with video analytics software • VA CCTV on UAS	• ~$1k–$1.5k per CCTV camera • ~$13k per UAS camera unit (sensors, camera)	Hard-wired, and wireless flying, tethered technologies	Applying predictive analytics technology showed 30% decrease of serious street crime in Memphis (19)	Streets/ sidewalks, Transit stations/ terminals, remote bike/ ped trails, parking lots, rest areas
ACS integrated systems – WMD – explosive, chemical, biological, radiological, nuclear, and weapons screening	Prevent introduction of violent crime threats, WMD, and other weapons at the ECP	• X-ray, millimeter wave, magnetometer passive and active screening • Hand-held metal detectors	• ~$500k per ECP • ~$100–$500 per unit (20)	Hard-wired and wireless integrated supporting technologies	Anecdotal evidence of effectiveness of WMD detection systems	Fixed transit stations/ terminals, facilities

[9] Examples from interviews with subject matter experts and industry experience.

[10] Does not include cost of hard-wired or wireless communications systems necessary to transmit video to monitoring stations, which vary significantly by facility. Cost of Virtual Analytic technology systems also not included, as costs vary significantly depending on size and complexity of systems.

Weapon Screening Systems

Mass-casualty and Mass-shooting Weapon Screening Systems

This section discusses technologies to counter mass-casualty and mass-shooting threats that may impact facilities. These man-made incidents intend to produce a large number of fatalities or injuries in a short period of time. Whereas mass-shooting threats involve only firearms, mass-casualty threats cover all WMD and may include an explosive, chemical, biological, flammable, or radioactive weapon capable of causing widespread death and destruction.[11]

Fixed facilities with busy stations and crowded, peak travel times are attractive targets for mass-casualty and mass-shooting crimes, such as those identified in the Priority Incident Matrix. In these facilities, weapons will have a deadlier effect than in open-air facilities such as rest areas, streets, or sidewalks. WMD attacks in public transportation fixed facilities are more commonplace and lethal due to their effects within a closed area (21). Contrary to that notion is an example of an open-air venue mass-causality attack, the 2013 Boston Marathon bombings, in which 3 fatalaties and more than 200 injuries were the result of an improvised explosive device (IED) (22). Mass-casualty and mass-shooting detection systems are generally integrated with other security systems. These tend to be among the highest-priced security measures and likely will be cost-effective only in larger transit systems or high-traffic facilities.

Fixed-Facility WMD Systems

Systems solutions to mass-casualty threats should detect and prevent the placement of WMD devices into facilities. These include explosive, chemical, biological, flammable, and radiation detection systems. Although sensor detection systems have been proven effective in preventing WMD threats in air transportation, detection outside of airports is constrained. Specific indoor environment factors (controlled temperatures, humidity, and air quality) are needed to support the technology's capabilities to detect.

Fixed transit facilities have less controlled environmental factors, so the use of WMD sensors has been limited, although testing continues. Fixed-facility WMD detection systems integrated with ECP, discussed previously, are currently operational, with some constraints. Systems using strategic placement of explosives and chemical sensors throughout transit facilities also have been tested and, despite technical limitations, help protect against the threat of WMD as one of multiple security components.

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[11] 18 U.S.C., Sections 2332a and 921(a)(4)(A); terrorism acts are defined by the weapons used.

Examples:

- ECP weapon detection technology.
- ECP with hand-held metal detectors.
- Strategic placement of WMD sensors (explosive, chemical), supplemented with canine detection and security patrols.

Due to the current technical limitations of WMD detections systems in transit facilities, other security components are used to compensate. Examples include bomb-sniffing dogs or technically-augmented security patrols with portable situational awareness systems. These systems can offer multiple capabilities, including mobile WMD threat detection (e.g., spectrometer), real-time monitoring and situational awareness, and wireless communications and data transmission capabilities to enhance decision-making abilities.[12] (23)

Examples:

- Decentralized, hand-held CCTV monitoring devices for assessment, decision-making, and response.
- Hand-held spectrometer devices for chemical assessment, decision-making, and tailored response.

Open-air Mass-casualty Systems

The environmental constraints described above are compounded in open-air facilities, making effective use of current WMD detection systems a low probability. In the future, an innovative option for operating WMD detection systems in open facilities or remote areas where electric power may be scarce is the use of UAS. UAS may be employed through integrated systems with WMD sensors attached to an aerial platform. Research currently is being conducted by the Department of Homeland Security into metropolitan WMD surveillance systems that could integrate UAS technology.

Example: UAS-mounted WMD sensors communicating to a data processing unit for analysis and possible threat dissemination.

With the reality of limited capabilities of detection in open-air facilities, tighter surveillance measures and technically-augmented security patrols (described above) can have a deterrent effect, minimizing the potential for mass-casualty victims and accelerating response times to an incident.

[12] "WMD Preparedness Best Practices and Emerging Trends," Government/LE Coordinator, STAR Consortium, LLC, and Direct Measures International, Inc.

Active Shooter Detection Systems

"Active shooter" (AS) is a term used by law enforcement to describe an individual actively engaged in killing or attempting to kill people in a confined or populated area (24). The FBI's "A Study of Active Shooter Incidents in the United States Between 2000 and 2013" lists seven common locations for AS incidents. Although none are directly related to facilities, as the locations were based on past shootings in the U.S., busy public transportation facilities should consider such incidents in their security planning.

Much like a WMD threat, the best approach to preventing an AS threat is keeping the perpetrator(s) out of the facility. Weapons detection systems such as those integrated with ECP, described previously, are the best means of preventing access to potential shooters. Once inside, the next best defense is attempting to contain and isolate the shooter until security/LE can respond (23). Integrating ballistic (gunfire) detection sensors with surveillance systems and access control may help security/LE remotely restrict the shooter's freedom of movement by locking selected doors and passageways or all ECPs. All facility surveillance systems may be used with facility access control and communications systems to assist security/LE with accessing, orienting, and responding to an AS threat, as well as alerting facility users of the danger.

Examples:

- Automated PTZ CCTVs linked to ballistic acoustic sensors for security/LE assessment and decision-making.
- Security/LE decentralized, hand-held CCTV monitoring devices for assessment, decision-making and response.
- Public address system inside and outside the facility broadcasting pre-scripted messages to selected areas from the security/LE command center or mobile platform.

Table 7 *Mass-Casualty and Mass-Shooting Solutions*

Solution	Actions	Technology	Cost	System Type	Effectiveness	Facility
Fixed facility, WMD detection systems	• Detect WMD using sensors or other monitoring device • Supplemental detection systems, CCTV, canine • Threat assessment, decision-making and response	• WMD sensors (explosive, chemical) • CBRN area monitors with alerting capabilities • Hand-held CCTV and spectrometer monitoring devices	• ~$165k per sensor suite • ~$10k per monitor unit • ~$3k per hand-held unit	Wired, and wireless (I/P) system integrated	• Toxin activity determination in less than 30 mins with off-the-shelf equipment • Near-real-time chemical aerosol detection and identification (25)	Transit station/ terminal
Remote or open system, WMD detection systems	• UAS remote sensing • Supplemental detection systems, CCTV, canine • Threat assessment, decision-making and response • Portable command and control situational awareness	• UAS mounted sensor with communications link • Hand-held CCTV monitoring • Hand-held spectrometry	• Unknown • ~3k per hand-held CCTV unit • ~$3k per hand-held spectrometry unit	Wired, and wireless (I/P) system integrated	Detection of all versions of cargo with 3D scanning and "trainable" advanced machine learning algorithms (26)	Streets/sidewalks, remote bike/ped trails, parking lots, rest areas
Active shooter detection systems	• Integrated surveillance and gunshot sensors for LE assessment and decision-making • Decentralized monitoring for assessment, decision-making and response • Public alert broadcasting	• Automated PTZ CCTVs linked to ballistic acoustic sensors • Portable command and control situational awareness system (CCTV, sensors, monitors) • Public address system with scripted messages and location transmission	• ~$5k–$15k per linked PTZ/ CCTV unit[14] • ~$10k per portable command unit • ~$5k per PA unit	Wired, and wireless (I/P) system integrated	96% of gunfire reports would have gone unreported otherwise (27)	Streets/sidewalks, transit station/ terminal, select bike/ped trails, parking lots

[13] Examples from interviews with subject matter experts and industry experience.

[14] Depending on acoustic sensor array specifications and cameras selected.

SECTION
4

Safety Solutions

Overview of Safety Technology

Research into innovative safety technologies that can help reduce transit-related crashes and fatalities has been expanded in recent years. There are numerous examples of USDOT and FTA programs that fund innovative safety research that apply to transit facilities and other means of alternative transportation. One source is Urbanized Area Formula Grants (49 U.S.C. 5307. Other sources include FTA's recently-authorized Safety Research and Demonstration (SRD) program and Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Demonstration (SRER) funding (17), which recently awarded $29 million in safety research funding grants to 9 states to support cutting-edge safety developments in public transportation using state-of-the-art technology.

The most prominent issue identified within facilities concerning safety for pedestrians and bicyclists is collisions with motor vehicles (transit and other). Such incidents occur due to lack of awareness and/or cognition of danger on the part of the pedestrian/bicyclist or vehicle operators or the inability to act quickly to prevent a collision. For example, the risk of collision increases when a vehicle operator lacks knowledge of the immediate surroundings or faces danger in the form of weather or construction. Innovative technologies can improve safety through improving awareness of or reaction to dangerous situations involving pedestrians or bicyclists, and communications systems can inform of dangerous circumstances or help report incidents to include "near misses" that occur due to such circumstances.

Collision Prevention

Facility-Based Technology

Keeping pedestrians and bicyclists safe is critical to supporting these modes transportation. Whether walking or biking to a final location or to a public transit connection (e.g., bus stop, train station, etc.), a safe environment promotes use. Vehicle collisions involving pedestrians and bicycles occur most often at intersections or mid-block, right-of-way crossings, a priority safety incident noted in Table 3. Municipalities and transit agencies should work together to ensure that these crossings are safe for pedestrians and bicyclists, so they feel safe as they travel to transit stops or their final destination. The research team identified five categories of facility-based technology that can reduce vehicle collisions with pedestrians and bicyclists at crossings and intersections: Pedestrian Signals, Pedestrian Signal Priority Technology, Vehicle Warnings, Facility-to-Vehicle Solutions, and Connected Vehicle Solutions.

Many of the innovative facility-based technologies discussed in this section include pedestrian/bicyclist detection and vehicle proximity detection technology.

Pedestrian/bicyclist detection includes traditional loop detectors, pressure sensors, video-based motion sensors, infrared sensors, numerous forms of radar technology, and other advanced sensor technology. Such sensors identify pedestrians and/or bicyclists as they approach an intersection or crossing.

Vehicle proximity detection uses different technologies to identify moving vehicles over larger geographic areas. Global Positioning Systems (GPS) locate vehicles based on their coordinates. Radio Frequency Identification (RFID) tags placed on a facility and vehicle allow them to communicate with intersection infrastructure and provide location information without needing to access GPS (28). Some positive train control systems communicate via radio frequency spectrum at 220 MHz; similar methods of communication have the potential to be deployed in other forms of transit (29).

Pedestrian Signal Solutions

Basic collision-preventing technologies that provide alerts and information to pedestrians/bicyclists at intersections and crossings include traditional crossing signals and signals with enhanced displays. Traffic signal timing controllers or manual push buttons activate the technologies. Crossing signals with advanced displays are readily available, inexpensive, and can be added to existing intersections and crossings.

Examples:

- Pedestrian count-down timers that show pedestrians how much time they have to cross safely.
- Light-Emitting Diode (LED) horizontal "eyes" or "scanning eyes" that remind pedestrians to look for turning vehicles.

These systems could be advanced by adding pedestrian/bicyclist detection sensors to automatically activate the alerts once a pedestrian is present. Adding such technology would add cost to each crossing but would result in further reductions in collisions.

Pedestrian signal priority technology is a more advanced solution than the signals described above. It uses a mix of pedestrian-detection sensors and algorithms to activate pedestrian (or bicyclist) priority in intersections or crossings. These systems can lengthen pedestrian crossing times to increase safety or reduce them when few or no pedestrians are present. Audio and visual warnings for pedestrians and drivers also can be activated by these systems. Studies conducted in New York City showed a 50% decrease in crashes for updated intersections relative to a 4% decrease in collisions in the control group (30).

Vehicle Warnings

Basic technologies for alerting vehicles to pedestrians/bicyclists at crossings, beyond traditional traffic signals, include **push-button flashing beacons** such as pedestrian hybrid beacons and rectangular beacons. These technologies are effective, inexpensive, and do not require a communications systems or separate power source to operate (if solar). Other systems may use pedestrian-activated LEDs to light-up crosswalks, with lights either embedded in the crosswalk itself or on posts adjacent to the crossing.

Examples:

- Pedestrian-activated embedded LED crosswalk lights that increase driver awareness by lighting up the entire crossing.
- Hybrid Flashing Beacons (HFBs) or Rectangular Rapid Flashing Beacons (RRFBs) that prompt drivers to slow down when pedestrian and bicyclists are present at crossings (FHWA lists this technology as a proven safety countermeasure).

More advanced systems can add **pedestrian/bicyclist detection sensors** to the technologies described above to improve effectiveness

Facility-to-Vehicle, Collision-Prevention Technologies

Technology currently in development shows the potential to place detection technologies on facilities such as rail stations, large bus depots, or rail track locations that sense a vehicle or pedestrian location and send a warning to the vehicle operator if a dangerous situation is imminent. Advanced systems could activate automatic braking in such situations. Such technologies can prevent collisions with passengers, workers, vehicles or other obstacles.

The research team identified two rail safety solutions in development today that can prevent accidents and incidents under certain circumstances:

- Positive train control (PTC), a federally-mandated rail safety system, uses technology to monitor train speed and train locations and provides warnings and/or automatic braking prior to certain dangerous situations, including when train speed exceeds the authorized level. The technology has been only partially implemented, as costs and other barriers prompted the extension of the statutory deadline to December 31, 2018, for freight and passenger rail, with the opportunity for an additional extension to December 31, 2020, subject to USDOT approval, if a railroad demonstrates it has completed certain statutory prerequisites and made sufficient progress (31).

- A $1.7 million federal grant was issued to Los Angeles Metro to implement a new Platform Track Intrusion Detection System (PTIDS), which is not a PTC system, but a radar-based system that alerts operators if a pedestrian is detected on the track at the station or along the train route (32).

Infrastructure/Pedestrian/Vehicle (Connected Vehicle)

Technologies currently are under development that connect infrastructure, pedestrians, and vehicles for the purpose of preventing collisions (33, 34). Many of these fall under the Connected Vehicle program. A recent project awarded by USDOT's SBIR program describes a technology that connects pedestrians, signal infrastructure, and vehicles—a smartphone-based application that uses short-range wireless technologies such as wi-fi and/or Bluetooth to interface with traffic signals to alert pedestrians when they have the signal to cross and gives users the ability to request pedestrian priority.

Additional technologies connecting infrastructure, vehicles, and pedestrians/bicyclists are expected to enter the market in the next decade. A report from National Highway Traffic Safety Administration (NHTSA) noted that:

> *By communicating with roadside infrastructure, drivers would be alerted when they are entering school zones, if workers are on the side of the road, and if an upcoming traffic light is about to change. (35)*

NHTSA predicts a significant reduction in collisions for non-impaired drivers that can be accomplished through connected vehicle technology.

Table 8 *Facility and Vehicle-Based Collision Prevention Solutions*

Solution	Actions	Technology	Cost	System type	Effectiveness	Facility
Innovative Pedestrian Signal Technology	• Detect pedestrian (or push-button activated) • Activate crossing-signals	• Countdown timers • Walk signs with LED "eyes"	$300–$800 per unit (36)	Wired, stand-alone	59–94% reduction of conflicts between vehicles and pedestrians (37)	Streets/sidewalks, Intersections
Pedestrian Signal Priority Technology	• Detect pedestrian (or push-button activated) • Pedestrian detection adjusts crossing times (priority)	• Pedestrian signal priority algorithm • Detection	Cost currently unavailable	Wireless and/or wired, System integrated systems or stand-alone	By increasing signal timing life, collisions between vehicles and pedestrians decreases by 50% (30)	Streets/sidewalks, Intersections – particular those near stations/ stops/ terminals
Vehicle Warning Technology	• Detect pedestrian (or push-button activated) • Warning to vehicles activated	• Embedded crosswalk lights • Hybrid beacon or rectangular rapid flash beacon • Detection technology	• LED bulbs $10–$300 per unit (38) • Beacons ~$6k–$10k per unit (39) • Infrared detection ~$1k–$2k per unit (40)	• Wired and/or wireless, stand-alone • Energy – solar or wired to grid	• Increased driver awareness and decreased speeds (41); collisions reduced by up to 69% (42) • Switching from no beacon to mid-block beacon increases yield percentage from vehicle operators from 18 to 81%	Street, Intersection, or mid-block crossing, Bike path street crossing
Accident-Prevention Technology – Positive Train Control Systems	• Warn operator to slow down and/or automatically brake the vehicle	• Track intrusions sensors (on vehicle or track) • Communication system	Metrolink has invested ~$218.8 million in PTC as of 9/16 (43)	Wireless and/or wired, system integrated	Projected to reduce crashes in rail caused by human error (35% in rail) (45)	Certain railroad main line tracks (implementation is ongoing)
Connected Vehicle – Smartphone Pedestrian Crossing Application	• Traffic signal detects pedestrian approach • Pedestrian gets traffic signal alert • Pedestrian may request signal priority (walk signal)	• Detection technology (blue-tooth, Wi-Fi) • Application Software • Traffic signal communications	Unknown	Wireless, system integrated	Unknown	Streets/Sidewalks, intersections, crossings

Transit Vehicle-based Technology

Several vehicle-based technologies have been developed in recent years to help prevent collisions between transit vehicles and pedestrians/bicyclists. Basic technologies include warnings triggered by driver action (e.g., shifting into reverse), regardless of whether a pedestrian or bicyclist is nearby. More advanced technologies trigger warnings or vehicle actions when a vehicle detects pedestrians, bicyclists, or obstacles in its path or blind spot. A Federal Highway Administraton (FHWA) document describing the Concept of Operations for the Transit Safety Retrofit Package noted:

> *It is a tremendous benefit, both in terms of public perception and costs to the agency, to improve safety by reducing or eliminating incidents involving transit vehicles through the use of detection systems. (46)*

The research team identified three categories of vehicle-based technology that could be applied to transit vehicles to prevent collisions: Pedestrian Warning Technologies, Driver Warning Technologies, and Automatic Braking Systems. Vehicular crashes with pedestrians (including bikes) is a high-impact safety priority noted in Table 3. In addition to these technologies, this section discusses how Connected Vehicle technologies, a collaborative research effort for transportation stakeholders, will help municipalities and transit agencies enhance safety.

Most detection systems currently in practice use **motion-sensing video cameras** to detect objects and **radar waves** to ensure the proximity to the vehicle is correct (47). These vehicle-mounted sensors have been proven effective and range in cost from $150–$1,000 per vehicle. More innovate forms of detection include **LIDAR** (laser-based detection) and night-vision **infrared sensors or cameras**. There is evidence that these technologies are effective, but they have not been widely implemented and are more expensive than the more commonly-used systems, at $8,000-$40,000 per vehicle; however, the cost has dropped by a factor of 10 since 2007 (48).

Pedestrian Warning Solutions

Vehicle-based pedestrian warnings alert pedestrians to the movement or approach of a bus or other vehicle using lights, sound, or other warnings. These systems are triggered by driver action or through the detection of a pedestrian, bicyclist, or other object in a vehicle's path or blind spot. These technologies have been tested and have been shown to significantly reduce vehicle/pedestrian collisions. Technologies can improve safety at intersections, and bike path/road intersections, on streets (with and without bike lanes), and at or around bus stops. The research team did not identify any vehicle-based warnings used on rail vehicles, as most warning technology for rail is facility-based. It is possible the technology could be adapted for this purpose in the future.

Examples:

- An audible warning (beep) triggered when a vehicle shifts into reverse or uses a turn signal.
- Blind spot detection systems activated as pedestrians or bicyclists are sensed in non-visible areas near a vehicle, triggering flashing lights on the side of the vehicle to warn them of their dangerous proximity.
- Night-vision systems currently in development that use infrared heat-seeking cameras to detect obstacles in a vehicle's path, illuminating bright headlights to warn pedestrians and alert drivers (49).

Vehicle Warning Solutions

Driver-based warning technologies operate similarly to pedestrian warning systems, providing in-vehicle warnings to drivers so they can operate to avoid collisions. Passenger vehicles currently use this technology and it is being tested for use in transit vehicles including bus and light rail. Once a pedestrian is detected in in a vehicle's blind spot or path as it drives forward or in reverse, a light/display, sound, or tactile warning is provided. These technologies can be installed within the vehicle or operated through personal technologies such as smart-phones. The effectiveness of in-vehicle warnings has been well documented in reducing collisions (see Table 9). These technologies will improve safety at facilities including streets, intersections, pedestrian/bike path crossings, and in the vicinity of bus/rail stops.

Examples:

- Vehicle system technologies providing an audio warning, dashboard warning (flashing lights, screen visual), or tactile warning (seat or seatbelt) after pedestrian/bicyclist is detected.
- Smartphone-based systems that alert driver using vibration or sound after pedestrian is detected.

Sound, light, and tactile warnings have been proven effective for increasing the awareness of transit operators and pedestrians/bicyclists in dangerous situations, helping to prevent collisions. These technologies, however, depend on the reaction of the driver or pedestrian/bicyclist to succeed. **Automatic braking systems**, which detect obstacles and automatically apply brakes, can be used in conjunction with warning systems to improve safety outcomes at similar facilities. This technology has been proven in automotive tests at up to 25 mph for front collisions (50, 51).

Examples:

- Forward collision braking systems, which soon will be standard on passenger vehicles and currently are being tested on bus and rail systems.
- Reverse collision braking systems, increasingly found on construction vehicles and currently in research for transit vehicles.
- Side-based collision systems that apply brakes on one side of the vehicle if it is detected drifting out of its lane, implemented by the automotive industry and currently in research for transit vehicles to pair with current pedestrian detection systems.

Connected Vehicles

It is likely that most of the technologies described in the examples above can be adapted in the near future for use in transit vehicles to prevent collisions. These solutions are largely based on the use of detection sensors in conjunction with computers and communication systems.The future of vehicle-based collision technologies likely lies in advancing these technologies further through connected vehicle applications. The Connected Vehicle Program is a collaborative effort among USDOT, key stakeholders, the automotive industry, and the public (52). FHWA defines connected vehicle technology as applications that use advanced wireless communications, on-board computer processing, advanced vehicle-sensors, GPS navigation, smart infrastructure, and other technologies to identify threats and hazards on the roadway and communicate this information over wireless networks. This program connects facilities, infrastructure, vehicles, and pedestrians to improve transportation safety.

Connected vehicle technologies can enhance safety technology by sharing vehicle and pedestrian positioning information using detection sensors, GPS, and wireless communications systems. Advanced on-board computers and smart infrastructure could then provide warnings or automatically trigger actions that help prevent collisions. Some of the technologies discussed in this report likely fall under the Connective Vehicle heading. Research in this area is ongoing, constantly advancing, and beyond the scope of this report. In the future connected vehicle solutions likely will be at the forefront of innovative technologies that can improve vehicle, pedestrian, and bicyclist safety as our communities become more connected.

Table 9 *Vehicle-Based Pedestrian Collision Avoidance Solutions*

Solution	Actions	Technology	Cost	System Type	Effectiveness	Facility
Basic pedestrian warnings – reverse warning, turn warning	• Warning activated when driver uses turn signal or shifts into reverse (e.g., beeping) • Pedestrian awareness increased	Warning system (lights, sound, etc.)	$500–$1k (53)	Stand-alone, vehicle add-on, or system-integrated	Reduction in "close call" incidents in Tri-County Metropolitan Transporta-tion District of Oregon (54)	Transit stations/ stops, intersections, streets
Advanced pedestrian/ bicyclist warnings – blind spot warning systems, night vision warning systems	• Pedestrian/bicyclist detected in path or blind spot of vehicle • Pedestrian light or sound warning activated • Pedestrian awareness increased	Detection sensor (Video w/radar, other); warning system (lights, sound, etc.)	• ~$900–$3k per unit (55) • Up to ~$1.5k per unit (56)	Stand-alone, vehicle add-on or system-integrated	No information available	Transit stations/ stops, intersections, bike path crossings, streets
Vehicle-based driver warnings	• Pedestrian/bicyclist detected in path or blind spot of vehicle • In-vehicle sound, light, display or tactile warning activated • Driver awareness increases	Detection sensor (Video w/radar, other); warning system (lights, sound, etc.)	• Similar applications ~$2k per unit (57) • Up to ~$1.5k per unit (56)	• Stand-alone technology • Vehicle add-on or system integrated	Proven to reduce collisions with pedestrians by more than 50% (58)	Transit stations/ stops, intersections, bike path crossings, streets
Mobile vehicle warning device	• Pedestrian/bicyclist detected in path or blind spot by device (communication) • Device based sound or tactile (vibration) warning • Driver awareness increases	Wi-fi/LTE/ Bluetooth (environmental signals); warning system (lights, sound, etc.)	Experimental only	Wireless communication based (Connected Vehicle)	Unknown	Transit stations/ stops, intersections, bike path crossings, streets
Automatic braking systems – forward braking, reverse braking, side-pulling braking	• Pedestrian detected in front of vehicle or detected while reversing • Vehicle pre-emptively brakes • Object detected in dangerous proximity one side of vehicle • Vehicle pulls in opposite direction via brakes on one side	Detection (LIDAR, camera/radar combination, infrared, other); communication signal to activate brakes	~$3k per unit for similar models used in private automotive industry (59)	• Stand-alone technology • Vehicle add-on or system integrated	Proven by industry to successfully stop automobile at up to ~25 mph; reduction of speed before impact of 10 % can reduce fatal injuries in car crashes by approximately 30% (60)	Transit stations/ stops, intersections, bike path crossings, streets

SECTION
5

Safety and Security Solutions

Innovative Lighting Solutions

Improving lighting is a direct way to improve safety and security at all facilities. By improving a vehicle operator's ability to see pedestrians or bicyclists on streets, sidewalks, and crossings, the risk of collision decreases. Adequate lighting also helps pedestrians and bicyclists see and avoid approaching vehicles. Effective lighting is also critical in and around facilities for pedestrians and bicyclists to avoid injury due to dangerous conditions such as construction areas, uneven pavement, and other obstacles.

Proper security lighting increases the visibility of surroundings for pedestrians and bicyclists, allowing them to be aware of what is going on around them and avoid suspicious persons. It also makes it more difficult for unauthorized persons to enter a facility undetected or loiter unnoticed. Adequate lighting allows access control sensors and surveillance cameras to operate effectively, allowing security/LE to assess and respond to incidents.

Technological improvements have made lights brighter, longer lasting, and more cost-effective. As a result, updated lighting systems that use LED bulbs provide a more illuminated environment that requires less maintenance. Advances in computers and networking technology also have led to the development of "smart" lighting networks, which improve the function, efficiency, and maintenance of lighting systems. Lighting improvements can be used across all facilities described in, including stations, stops, terminals, parking lots, streets, sidewalks, bike paths, and rest stops. These lighting improvements directly address both safety and security incidents, most notably vehicular crashes and non-violent crimes, addressed in Table 3.

Energy Efficient Lighting Technology

As technology improves, municipalities and transit agencies responsible for providing lighting in and around facilities can expand lighting coverage using brighter, longer lasting, and more cost-efficient LED bulbs. These lights require less maintenance and are less expensive in the long run, as they can last up to 50,000 hours. These lights can also be coupled with other motion sensors and solar energy sources to improve efficiency further.

Examples:

- Lower-energy LED light bulbs that provide brighter lights at lower usage costs.
- Longer LED bulb life that enhances safety and security by reducing the frequency of burned-out bulbs.
- Solar-powered light posts that provide cost savings in off-grid areas and eliminate dependence on the energy grid.
- Motion sensor technologies that turn on or increase lighting only when activity is detected in area.

Integrated Lighting Systems

Communications and computer processing improvements now allow facilities to monitor their lighting infrastructure using a centralized system that integrates multiple technologies. These integrated systems can control lighting levels, detect maintenance issues, and enhance security efficiency and can be programmed by time of day or by lighting environment (e.g., dawn, dusk) to adapt to the optimal lighting level. The technology sends messages through wires or wirelessly to the system operator during power outages or when bulb replacement or other maintenance is needed, allowing facilities to promptly address issues and ensure adequate lighting. Sensors embedded in these systems can also be programmed to turn lights on only when there is activity in an area. When linked to surveillance, security personnel can monitor only areas where there is light/ activity. Use of the sensors improves energy efficiency and can make surveillance efforts more efficient and effective.

Table 10 *Lighting Solutions to Improve Pedestrian Safety and Security*

Solution	Action	Technology	Cost	System Type	Effectiveness	Facility
Energy efficient lighting – lower energy, brighter, longer-lasting LEDs; solar- powered lights; motion sensor lights	• Use innovative lighting technology (e.g., LEDs) to improve energy efficiency and lifespan • Brighter lighting • Expanded coverage area	• Solar panels • LEDs • Motion sensor light bulbs	Solar panel streetlight with LED ~$200–$300 per unit (61, 62)	Stand-alone or wired or wireless system integrated	• Reduces nighttime crashes up to 50%, fatal crashes up to 43% • Keeping lights on dramatically improves pedestrian safety and feelings of security (63)	All facilities
Integrated lighting systems – sensor or timer driven use; communications for outage/ maintenance; integration with other systems	• Use wired or wireless communications to report power outages/expired light bulbs • Use sensors and software to use lighting where/when needed • Security monitoring focused on areas detecting activity (lit)	• Wireless networking • Intelligent software	$1,800 for full assembly (64)	Wire or wireless, system Integrated	Citywide crime increases 7% when blocks of streetlights not operating (65)	All facilities

Communications and Emergency Response Solutions

Communicating for Safety and Security with New Technology

Having access to real-time information is improving on a regular basis as communications technology evolves. Improved communications can be used to improve safety and security at all facilities for incidents such as those noted in Table 3. Through disaster and crisis notifications, pedestrians, bicyclists, and would-be transit passengers can adequately prepare and adjust their intended destination and routes accordingly, avoiding unnecessary danger. At the local level, safety and security incident reporting through smartphone-based applications can assure a prompt response from facility owners/operators, leading to a more positive experience for all facility users. Improved communications also aids first responders in addressing emergencies quickly and appropriately. Communication technologies will improve safety in regards to advance warnings for weather and geological hazards as well as hazards with no advance warnings noted.

Disaster Notification Systems

Exposure to natural or man-made disasters can be avoided or mitigated with sufficient advanced warning. Agencies such as FEMA and the National Weather Service are developing their own smartphone-based warning systems or are sharing information with other developers to provide the public with frequent and up-to-date information on potential disaster situations (66). One smartphone application designer noted that during a disaster event:

> *One of the more fundamental questions that gets asked is, 'Where do we go?' To have real-time government data available so residents can understand where the up-and-running disaster location centers are is step one in really recovering and trying to get reoriented. (66)*

Transit agencies and other facilities can use disaster warning systems by incorporating them into transit applications or delivering the warnings through other methods such as SMS or e-mail notifications, website postings, or announcements within the facilities themselves. Facilities can also add their own warnings to supplement those from federal, state, or local agencies, which can improve the disaster preparation level of local populations. Studies find that people assume more credibility when a warning comes from a variety of authorities (67).

Examples:

- Providing users with information regarding route changes in the events of road closures, and rail shutdowns.
- Aiding passengers by supplying evacuation route information and providing transit to move people to shelters and into safer communities.
- Providing real-time updates to passengers related to upcoming weather events that may affect them based on GPS location

Notifications about impending natural disasters or man-made crisis events are becoming more common in our connected society. Although costs may prohibit smaller systems from developing their own smartphone applications, information can be pushed to users through emails, SMS, or other communications methods.

Examples:

- FEMA's disaster notification app, which notifies users with alerts from the National Weather Service, locates open shelters where users can find and communicate with FEMA employees, and offers a portal to upload and share disaster photos for first responders (68).
- New York MTA provides users with email notifications about weather-related or emergency disruptions (69).
- Miami-Dade County allows users to sign up to receive emergency alerts via text message related to public safety issues and extreme weather events (70).

User-Based Incident Reporting Systems

Communication data may flow from a user to a facility. These user-based notification systems recently have been added to transit agency smartphone-based applications, but could also be used on applications that focus on other facilities such as bike/pedestrian trails or parking lots. Users can employ this application to report safety concerns such as damaged equipment or inadequate lighting or security threats or incidents such as someone exhibiting threatening or suspicious behavior. As with disaster/crisis notification systems, incident-reporting systems using smartphone applications may be limited to larger transit agencies and facilities. Less technical means are still available through SMS, email, or websites to notify facilities of non-urgent safety and security threats.

First-Responder Communications Equipment

First-responder communications have not improved as expected since the events of September 2001. Although not widely in practice today at facilities, technology companies are working on improving communication systems that link facilities to first responders.

Examples:

- A mobile wireless communication system that allows users to all connect via broadband smartphones and communicate when disaster may have disrupted other means, over a range of 2.5 miles; systems like this are essential for first responders to be able to communicate in rural areas that may possess less coverage (72).
- Systems that maintain communications among separate devices without cell towers or internet connection, using radio-based signals; such systems could connect transit with local LE and directly with FEMA's Integrated Public Alerts and Warning System (73).

These technological innovations are still evolving but may be available to transit agencies and other facilities in the near future. Clear paths of communication will improve response times and provide critical information to first responders directly from the facilities, thus providing better responses to safety and security issues, including incidents arising from natural disasters and mass-casualty situations. Funding such systems could substantially improve both safety and security outcomes at facilities.

Table 11 *Communications Systems Solutions*

Solution	Actions	Technology	Cost	System Type	Effectiveness	Facility
Disaster notification systems	Provides facility users with information on how to use transit and other facilities during man-made or natural disasters	• App-based disaster warning systems • Facility-based disaster notification (SMS, email, on-site warnings)	• App development ranges from ~$50k to over $500k. On average, ~$270k (74) • Email/SMS costs much lower	Stand-alone (facility-based) or System-integrated (wired or wireless)	48-hour warning public-alert system (outside US) showed decrease in casualties between two cyclones from 300,000 to 3,000 (75)	All facilities
User-based security and safety reporting	Allows transit users to report safety and security concerns through smartphone app-based reporting system	• App-based transit owned notification system • Facility-based security and safety reporting (SMS, email, website reporting)	• App development ranges from ~50K to over $500K. On average, the cost is ~$270K (74) • Email/SMS costs much lower	Wired or wireless, System integrated	Anecdotal evidence of users and responders noting life-saving capabilities of mobile-based panic reporting system	All facilities
First-responder communications equipment	Improves quality and reliability of facility communications with first responders	• Portable wireless communication nodes • Improved software using wi-fi and LTE signals	N/A	Wired or wireless, system integrated	N/A	All facilities

SECTION 6

Conclusions and Recommendations

Innovative Security Technologies

Many of the innovative security technologies discussed in this report would be considered components of larger integrated security systems, which require a source of energy, a communications system, and a central command station to operate. The subsystems discussed can help security/LE deter, assess, and respond to critical security issues.

Security systems use sensors, cameras, and monitoring equipment to deter unauthorized entry and prevent crime and provide information to security/LE to expedite security-incident response times. Security systems range from very basic and inexpensive (e.g., using motion sensors that trigger security/LE response) to extremely complex and expensive (e.g., advanced CCTV and PTZ cameras linked to virtual analytics and reported on stationary or mobile monitoring devices). Not all transit facilities need the most innovative security systems, nor can they afford them, but advancing technologies offer options for all facilities.

Although there is no formula to determine the best security solution, the following recommendations present an idea of how smaller systems, larger systems, and open or remote facilities could approach innovative security technologies if their security budgets and grant funding allowed them to expand their security systems. The recommendations are based on three key factors:

- **Cost-effectiveness** – if the cost of implementing a technology is less than the expected value of the technology's impact on security—for example, if a technology is shown to reduce crime and/or improve how a facility's security efforts are perceived within possible budgetary constraints.
- **Comprehensiveness** – if a technology, used on its own or in conjunction with other technologies, can deter or mitigate the effect of violent, property, or mass-casualty crimes.
- **Degree of complexity** – if a technology can be installed, managed, and maintained by the staff available at a facility or transit system, with only limited outside assistance.

Solutions that meet these criteria and are widely available today are shown in Tables 12 and 13 under "Today's Solutions." High-potential technologies that may need additional research or are not yet cost-effective are listed under "Future Solutions."

Smaller Systems

Smaller transportation systems made up of one or only a few facilities must maximize small security budgets to address priority issues. Such systems could use ACS to deter both violent and property crime, which could be augmented with video surveillance if the security budget and staffing allowed. In the future, these facilities could look into hand-held CCTV monitors, as they would allow the limited security/LE staff to be more efficient and effective as they patrol a facility.

Table 12

Smaller Transportation System Security Recommendations

	Today's Solutions	Future Solutions
Facility type	Smaller transit systems and stand-alone facilities (rest stops, parking lots, etc.)	Smaller transit systems and stand-alone facilities (rest stops, parking lots, etc.)
Recommended technologies	ACS with barrier sensors; CCTV and PTZ cameras with manual surveillance	Hand-held CCTV monitors
Incidents	Violent crime, property crime, trespassing	Violent crime, property crime, trespassing
Cost	Low to moderate	Low to moderate
Complexity	Low to moderate	Moderate

Larger Systems

Larger transit systems have to tackle security across multiple facilities and geographies. Security systems for such facilities tend to be integrated and are likely to include advance access control, surveillance, lighting, or emergency-response systems. Larger systems have fewer budgetary constraints; however, diminishing benefits from additional components likely will be the factor that limits how much can be added to security systems, particularly as sensors and surveillance equipment get more complex. Effective solutions, therefore, may target especially high-crime or high-impact (e.g., high-traffic) areas. Mass-casualty and active-shooter systems are likely integrated only in the largest systems and even then only with funding from state or federal sources.

Table 13

Larger Transportation System Security Recommendations

	Today's Solutions	Future Solutions
Facility type	Larger transit systems, including stations, stops, terminals, parking lots, etc.	Largest transit systems – bus or rail stations or terminals
Recommended technologies	• Electronic (smart card) entry control points (ECP) with sensors • CCTV and PTZ surveillance • Video analytics	• Hand-held CCTV monitors • WMD sensors at ECP (for long-haul bus or train transportation) • WMD sensors in facility • Hand-held WMD sensors
Incidents	Violent crime, property crime, trespassing	Violent crime, property crime, mass-casualty
Cost	High	High
Complexity	Moderate to high	High

Open-Air/Remote Facilities and Systems

Open-air or remote transportation systems such as bike and pedestrian trails, open-air parking lots, and streets and sidewalks can be difficult to secure. Security/LE officers on patrol, coupled with strategically-placed surveillance, offer some protection, but cannot cover all areas. Innovations such as hand-held monitors and detection devices allow existing security/LE to be more effective, but such systems are likely to be expensive. UAS are another promising technology.

Table 14

Open-Air/ Remote Security Recommendations

	Today's Solutions	Future Solutions
Facility type	Bike or pedestrian trails, open-air parking lots, streets/ sidewalks	Bike or pedestrian trails, open-air parking lots, streets/sidewalks
Recommended technologies	• Virtual ACS – strategic surveillance cameras (CCTV, PTZ) • Manual surveillance	• Virtual analytics • Hand-held CCTV monitors • UAS surveillance with access control
Incidents	Violent crime, property crime	Violent crime, property crime
Cost	Moderate to High	High
Complexity	Moderate to High	High

Innovative Safety Technologies

The safety section of this report focuses primarily on solutions that can help prevent collisions between transit vehicles and pedestrians or bicyclists. Most of the innovative safety solutions discussed in this report can be implemented today or are available for field testing. Safety technologies added to facilities, infrastructure, and vehicles can detect pedestrians, bicyclists, and other obstacles then activate warnings to improve situational awareness, activate a vehicle's brakes, or reduce its speed. Each of these responses reduces the risk of collision. The research team identified a range of safety solutions, some very inexpensive and stand-alone and others system-intensive and costly. The identified solutions together offer some options for all facilities, regardless of size, to reduce transit vehicle-related fatalities and injuries. In addition to detection-based safety technologies, all facilities can achieve safety benefits by improving communications systems and lighting infrastructure.

The following recommendations are examples of how different types of facilities could approach innovative safety technologies if their budget or grant funding allows them to add to their existing safety systems. Recommendations were based on three key factors:

- **Cost-effectiveness** – if a technology's effectiveness outweighs its costs—for example, if a technology will dramatically reduce collision incidents and can be implemented within an agencies budget (or with expected grant funding); technologies that can reduce costs in the long-term also apply.
- **Adaptability** – how widely the technology could be implemented—for example, a technology could be used in multiple facilities and/or in both small and larger transit systems to reduce vehicle/pedestrian collisions.
- **Inevitability** – the likelihood that a technology might become a safety requirement in the future—for example, automatic braking will becoming standard in the private automotive industry and early adopters will benefit if it becomes a requirement for transit vehicles (76).

Transit Vehicle-Based Solutions

Installing safety technology in transit vehicles can dramatically improve pedestrian and bicyclist safety. By improving driver awareness of their surroundings and improving pedestrian awareness of oncoming transit vehicles, the number of collisions and related fatalities and injuries can be reduced. The most cost-effective, currently-accessible vehicle-based solutions available are listed in Table 15 under "Today's Solutions." Technologies that may become more available and cost-effective in the future are listed under "Future Solutions"; these are technologies that may benefit from additional research funding, to expedite their development and adoption.

Table 15 *Transit Vehicle-Based Safety Recommendations*

	Today's Solutions	Future Solutions
Vehicle types	Bus and light rail	Bus and light rail
Recommended technologies	• In-vehicle audio/visual warnings to drivers paired with detection technology • Audio or visual warnings to pedestrians with detection	• Forward collision prevention through automatic braking • Smartphone-based (mobile) detection and driver warning
Incidents	Bus or other vehicle collisions with pedestrians/bicyclists	Bus or other vehicle collision with pedestrians/bicyclists
Cost	Low to moderate	Moderate
Complexity	Low	Moderate

Facility-Based Solutions

Commuter and Heavy Rail

Some vehicle proximity detection and pedestrian detection technologies can be used to warn rail operators of dangerous situations such as workers or pedestrians on tracks or upcoming stations or stops. The solution listed in Table 16 under "Today's Solutions" represent that PTC technology of some type has been mandated by the federal government to be implemented on certain main line tracks, including where intercity rail passenger or commuter rail passenger transportation is regularly provided. The "Future Solutions" represent advanced PTC options that are not currently being implemented by railroads and are not statutorily mandated, as well as a track intrusion detection technology system that recently received a FTA research grant.

Table 16 *Facility-Based Safety Recommendations*

	Today's Solutions	Future Solutions
Facility types	At or near rail stations/stops and certain railroad main line tracks	Rail stations/stops and tracks
Recommended technologies	PTC systems	• Platform Track Intrusion Detection System (with radar detection) • PTC system with vehicle-proximity detection functionality
Incidents	Designed to prevent train-to-train rail collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position	Rail collisions with pedestrians/ bicyclists or other
Cost	High	High
Complexity	High	High

Intersections and Crossings

Pedestrian detection technology at intersections and crossings can improve pedestrian and bicyclist safety by prioritizing the pedestrian signals, providing adequate warning to drivers, and increasing situational awareness of all actors involved. The most cost-effective and currently accessible technologies are listed in Table 17 under "Today's Solutions." Technologies that would benefit from additional research funding are listed under "Future Solutions."

Table 17

Intersection and Crossing Safety Recommendations

	Today's Solutions	Future Solutions
Facility types	Intersections/crossings	Intersections/crossings
Recommended technologies	• Mid-block crossing beacons (with detection) • Crosswalk lighting (with detection)	• Pedestrian signal priority algorithms • Smartphone based pedestrian crossing application
Incidents	Collisions with pedestrians/ bicyclists	Collisions with pedestrians/ bicyclists
Cost	Low	Moderate to High
Complexity	Low	Moderate to High

Integrated Systems Solutions

When municipalities and transit agencies are responsible for maintaining a reasonable level of safety in all areas with pedestrian travel, lighting and emergency communications are the most widely-applicable integrated safety solutions. Simple lighting improvements cannot reduce maintenance requirements while simultaneously improving pedestrian safety by heightening visibility. By improving communications with frequent transit users, agencies can stay informed of safety and security issues to improve daily travel, as well as to improve transit use during natural disasters and man-made hazards. The most cost-effective lighting and communications technology are listed in Table 18 and Table 19 under "Today's Solutions"; those that require more investment and research are listed under "Future Solutions.

Table 18

Lighting Recommendations

	Today's Solutions	Future Solutions
Integrated systems	All facilities	All facilities
Recommended technologies	Cost/energy efficient lighting	Smart lighting systems
Incidents	Collisions, slips trips, falls, and security incidents	Collisions, slips trips, falls, and security incidents
Cost	Low	Moderate
Complexity	Low	Moderate

Table 19
Communications Systems Recommendations

	Today's Solutions	Future Solutions
Facilities	Transit systems	Transit systems
Recommended technologies	Disaster notification systems (apps or other communications)	• User safety and security incident reporting systems • Improved first responder communication technology
Incidents	Natural and man-made hazards	Natural and man-made hazards, safety and security reporting
Cost	Low to moderate	Moderate to high
Complexity	Low to moderate	Moderate to high

Data Collection

As noted, the security and safety data available at the national and local levels is not a perfect match for the facilities. In most cases, the available data include some facilities as well as other facilities that are out of scope for the project (e.g., airports, streets, etc.). These imperfect groups offered the best available data to identify the priority safety and security incidents for this report. These data can be improved upon by using the innovative safety and security technologies recommended to collect more precise data at the local level. For instance:

- Access control systems can measure the total number of times unauthorized people breach a facility boundaries (trip a sensor), which can be linked to property and violent crime.
- Video images from surveillance systems (particularly those with VA technology) can be coded to identify threats or incidents at facilities or throughout a system.
- Systems that use hand-held sensors or monitoring could collect data on these devices to record safety and security threats and incidents.
- Smartphone based safety and security incident reporting systems provide a way for system users to identify and log threats and incidents.

This will help facilities monitor their own safety and security threats and incidents more closely. If the technologies become standard, safety and security data obtained from the technology systems could be rolled up to regional and national aggregates.

REFERENCES

1. Bureau of Justice Statistics. Data Collection: National Crime Victimization Survey. http://www.bjs.gov/index.cfm?ty=dcdetail&iid=245.
2. Federal Bureau of Investigation. Uniform Crime Reporting. July 22, 2016. https://ucr.fbi.gov/ucr.
3. Federal Transit Administration. National Transit Database. July 6, 2016. https://www.transit.dot.gov/ntd.
4. National Highway Traffic Safety Administration. Not-in-Traffic Surveillance: Fatality and Injury Statistics in Nontraffic Crashes, 2008 to 2011. April 2014. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811813.
5. National Highway Traffic Safety Administration. Fatality Analysis Reporting System. September 23, 2007. http://www-fars.nhtsa.dot.gov/Main/index.aspx.
6. National Weather Service. Summary of 2014 Weather Events, Fatalities, Injuries, and Damage Costs. July 1, 2015. http://www.nws.noaa.gov/os/hazstats/sum14.pdf.
7. Office of Safety Analysis. Train Accidents by Railroad Groups. April 12, 2008. http://safetydata.fra.dot.gov/officeofsafety/publicsite/Query/inctally3.aspx.
8. Gerhart, Richard L. Safety Assurance and Risk Management Division, Office of System Safety, FTA. September 9, 2016.
9. Neffenger, Peter. Transportation Security: Protecting Passengers and Freight. April 6, 2016. https://www.tsa.gov/news/testimony/2016/04/06/statement-peter-neffenger-administrator-transportation-security-0.
10. Transit Cooperative Research Program. Video Surveillance Uses by Rail Transit Agencies. March 23, 2016. http://www.trb.org/Publications/Blurbs/165822.aspx.
11. Interagency Security Committee. Best Practices and Key Considerations for Enhancing Federal Facility Security and Resilience to Climate-Related Hazards. December 2015. https://www.dhs.gov/sites/default/files/publications/isc-enhancing-resilience-climate-hazards-dec-2015-508.pdf.
12. Simmons, Andria. "Eyesight" Software Will Scan MARTA for Suspicious Behavior. September 12, 2014. http://www.securityinfowatch.com/news/11686759/marta-transit-security-will-use-video-analytics-to-help-prevent-incidents.
13. Prall, Derek. Maryland Transit Authority's Intelligent Video-Surveillance System Increases Departmental Efficiency, Effectiveness. March 17, 2015. http://urgentcomm.com/video-surveillance/maryland-transit-authority-s-intelligent-video-surveillance-system-increases-depa.
14. Welsh, Brandon C. Public Area CCTV and Crime Prevention: An Updated Systematic Review and Meta-Analysis. October 12, 2009. http://www.tandfonline.com/doi/abs/10.1080/07418820802506206.
15. Technical Operations Manager. August 5, 2016.
16. Francescani, Chris. NYPD Expands Surveillance Net to Fight Crime as Well as Terrorism. June 21, 2013. http://www.reuters.com/article/us-usa-ny-surveillance-idUSBRE95K0T520130621.

17. Gates, Angela. US Department of Transportation Announces $29 Million in Grants to Promote New Technologies to Improve Transit Safety, Emergency Response. December 2, 2015. https://www.transit.dot.gov/about/news/us-department-transportation-announces-29-million-grants-promote-new-technologies-improve.
18. Grants Office. Homeland Security BioWatch Program. http://grantsoffice.com/GrantDetails.aspx?gid=34742.
19. France-Presse, Agence. Police Using "Predictive Analytics" to Prevent Crimes Before They Happen. July 29, 2012. http://www.rawstory.com/2012/07/police-using-predictive-analytics-to-prevents-crimes-before-they-happen/.
20. KellyCo. Metal Detectors Security. 2016. http://www.kellycodetectors.com/catalog/metal-detectors/security?cat=145&utm_source=bing&utm_medium=cpc&utm_campaign=CTGRY%20-%20Security&utm_term=security%20wand&utm_content=Handheld.
21. Arnold, Jeffrey L., Pinchas Halpern, Ming-Che Tsai, and Howard Smithline. Mass Casualty Terrorist Bombings: A Comparison of Outcomes by Bombing Type. February 2004. http://www.sciencedirect.com/science/article/pii/S0196064403007236.
22. Wingfield, Sylvia. Boston Marathon Bombers Used "Sophisticated" Bombs: Prosecutors. May 22, 2014. http://www.nydailynews.com/news/crime/boston-marathon-bombers-sophisticated-bombs-prosecutors-article-1.1801484.
23. Romano, Stephen J., Micol E. Levi-Minzi, Eugene A. Rugala, and Vincent B. Van Hasselt. Workplace Violence Prevention Readiness and Response. January 2011. https://leb.fbi.gov/2011/january/workplace-violence-prevention-readiness-and-response.
24. Federal Bureau of Investigation. FBI Releases Study on Active Shooter Incidents. August 23, 2016. https://www.fbi.gov/news/stories/fbi-releases-study-on-active-shooter-incidents.
25. SRC. CBRN Defense. 2016. http://www.srcinc.com/what-we-do/chembio/index.html.
26. Blinde, Loren. US DoD Combating Terrorism Technical Support Office Awards Decision Sciences Contract. July 27, 2016. http://intelligence-communitynews.com/us-dod-combating-terrorism-technical-support-office-awards-decision-sciences-contract/.
27. Wticrblair and Beau Berman. FOX CT Investigation: Is Costly Gunshot Detection System Worth the Cost? June 11, 2013. http://fox61.com/2013/05/22/fox-ct-investigation-is-costly-gun-shot-detection-system-worth-the-cost/.
28. University of Minnesota. Detecting Vehicle Position using Radio Frequency Identification (RFID). February 19, 2015. http://license.umn.edu/technologies/z05077_detecting-vehicle-position-using-radio-frequency-identification-rfid.
29. Personal communication with Noel, Roger S. May 7, 2015.

30. Li Chen, Cynthia Chen, and Reid Ewing. The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections: Lessons from a New York Experience. 2012. http://nacto.org/docs/usdg/pedestrian_safety_review_salt_lake_city.pdf.
31. Schaper, David. Most Commuter Rails Won't Meet Deadline for Mandated Safety Systems. June 3, 2015. http://www.npr.org/2015/06/03/411464396/most-commuter-rails-wont-meet-deadline-for-mandated-safety-systems.
32. Hymon, Steve. Metro Secures $1.7 Million USDOT Grant to Test Track Intrusion Detection System. February 12, 2015. http://thesource.metro.net/2015/02/12/metro-secures-1-7-million-usdot-grant-to-test-track-intrusion-detection-system/.
33. SBA. SmartCross – Traffic Signal Interface on the Smartphone. https://www.sbir.gov/content/smartcross-traffic-signal-interface-smartphone-0.
34. Turner-Fairbank Highway Research Center and Volpe International Systems Center. Small Business Innovation Research Program Makes Crossing the Street Safer. October 23, 2016. https://www.transportation.gov/fastlane/sbir-program-makes-crossing-street-safer.
35. Fact Sheet: Improving Safety and Mobility Through Connected Vehicle Technology. September 15, 2012. http://www.safercar.gov/staticfiles/safercar/connected/ConnectedVehicleTechnologyFactSheet-081012.pdf.
36. Pedestrian and Bicycle Information Center. Traffic Signals. November 27, 2011. http://guide.saferoutesinfo.org/engineering/traffic_signals.cfm.
37. Florida Department of Transportation. Use of Animated LED "Eyes" Pedestrian Signals to Improve Pedestrian Safety. January 31, 2000. http://www.fdot.gov/Safety/4-Reports/Bike-Ped/led_eyes.pdf.
38. LEDlights. How Much Do LED Lights Cost? November 6, 2011. http://www.ledlights.org/FAQ/How-Much-Do-LED-Lights-Cost.html.
39. Dumont, Thomas. HAWK Pedestrian System. http://ceam.org/vertical/Sites/%7BD96B0887-4D81-47D5-AA86-9D2FB8BC0796%7D/uploads/%7BC83BB08D-26B1-4C13-9C96-E9D82DBADF47%7D.PDF.
40. Office of the Assistant Secretary for Research and Technology. Unit Cost Entries for Pedestrian Detection Infrared. 2013. http://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=Pedestrian+Detection+Infrared&Subsystem=Roadside+Detection+(RS-D).
41. Applications of Illuminated, Active, In-Pavement Marker Systems. 2008. https://www.nap.edu/read/14182/chapter/2#5.
42. Federal Highway Administration. Safety Effectiveness of the HAWK Pedestrian Crossing Treatment. July 2010. http://www.fhwa.dot.gov/publications/research/safety/10042/10042.pdf.
43. Metrolink. An Introduction to Positive Train Control. May 27, 2012. http://www.metrolinktrains.com/agency/page/title/ptc.
44. Federal Railroad Adminsitration. Trespass on Railroad Rights-of-Way. June 2007. http://ntl.bts.gov/lib/42000/42800/42873/rr0719.pdf.

45. Jaffe, Eric. The Billion-Dollar Technology That May or May Not Prevent the Next Big Train Crash. July 31, 2013. http://www.citylab.com/work/2013/07/billion-dollar-technology-may-or-may-not-prevent-next-big-train-crash/6378/.
46. Federal Highway Administration. Transit Safety Retrofit Package Development. May 28, 2014. http://ntl.bts.gov/lib/54000/54000/54069/14-117.pdf.
47. Boudette, Neal E. Tesla Upgrades Autopilot in Cars on the Road. September 23, 2016.
48. SAE International. Lower-cost LIDAR is Key to Self-Driving Future. February 11, 2015. http://articles.sae.org/13899/.
49. FLIR Commercial Vision Systems. BMW Incorporates Thermal Imaging Cameras in Its Cars: Lowering the Risks of Nocturnal Driving. September 6, 2015. http://www.flir.com/uploadedFiles/CS_EMEA/Application_Stories/Media/Downloads/BMW_A_EN.pdf.
50. Toyota. Toyota Safety Sense: A New Level of Active Safety for the Toyota Range. March 2, 2015. http://media.toyota.co.uk/2015/03/toyota-safety-sense-new-level-active-safety-toyota-range/.
51. Nelson, Gabe. Subaru Leads New IIHS Ratings of Automatic Braking Technology. September 30, 2013. http://www.autonews.com/article/20130927/OEM11/130929913/subaru-leads-new-iihs-ratings-of-automatic-braking-technology.
52. John A. Volpe National Transportation Systems Center. Connected Vehicle Policy Analysis. https://www.volpe.dot.gov/infrastructure-systems-and-technology/technology-innovation-and-policy/connected-vehicle-policy.
53. PEDSAFE. Pedestrian Signals. September 13, 2015. http://www.pedbikesafe.org/PEDSAFE/countermeasures_detail.cfm?CM_NUM=46.
54. Applied Engineering Management Corporation. Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists. May 2015. https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0084.pdf.
55. Dunn, Travis, Richard Laver, Douglas Skorupski, and Deborah Zyrowski. Unit Cost Element – Collision Warning System – TV/ Unit Cost Component – Pedestrian Detection System (Transit Bus). 2007. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/ID/F9B2436173DE7F3685257AD300705817?OpenDocument.
56. Office of the Assistant Secretary for Research and Technology. Unit Cost Element – Lane Departure Warning System. 2009. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/ID/C40CFF1F7AC1C09085257A770074627C?OpenDocument.
57. Robinson, B., et al. Unit Cost Element – Sensors for Longitudinal Control/ Unit Cost Component – Advanced Emergency Braking System with Pedestrian Detection. 2011. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/0/BBE9F6E420AF55BA85257AD8005AB2AE?OpenDocument&Query=Home.

58. Gray, J. J. Scott and Rob. A Comparison of Tactile, Visual, and Auditory Warnings for Rear-End Collision Prevention in Simulated Driving. May 2008. https://www.researchgate.net/publication/5333973_A_Comparison_of_Tactile_Visual_and_Auditory_Warnings_for_Rear-End_Collision_Prevention_in_Simulated_Driving.
59. Robinson B., et al. Unit Cost Element – Sensors for Longitudinal Control / Unit Cost Component – Advanced Emergency Braking System with Pedestrian Detection. 2011. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/0/BBE9F6E420AF55BA85257AD8005AB2AE?OpenDocument&Query=Home.
60. Krafft, M., A. Kullgren, A. Lie, J. Strandroth, and C. Tingvall. The Effects of Automatic Emergency Braking on Fatal and Serious Injuries. 2009. https://trid.trb.org/view.aspx?id=1100207.
61. eLEDing. Solar Power SMART LED Street Light for Commercial and Residential Parking Lots, Bike Paths, Walksways, Courtyard. 2016. http://www.homedepot.com/p/eLEDing-Solar-Power-SMART-LED-Street-Light-for-Commercial-and-Residential-Parking-Lots-Bike-Paths-Walkways-Courtyard-EE810W-SFBS/206867815?&cm_mmc=Shopping|THD|DigitalDecor|B|0|B-BASE-D27L+Exterior+Lighting|&mid=nDp09Lxd|dc_mtid.
62. T. Rowe Price. LED Street Lights Investment Cost and Payback. http://paradigmled.com/led-street-lights-investment-cost-and-payback-t-rowe-price/.
63. Lutkevich, Paul, Don Mclean, and Joseph Cheung. *FHWA Lighting Handbook*. August 2012. http://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/.
64. Iteris. Solar Powered Remote Wireless RVD Assembly – Furnish Cost. 2008. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/0/80744148F91E708285257BD0001190EC?OpenDocument&Query=Home.
65. Coffey, Chris. Report Links Chicago Crime to Streetlight Outages. July 2, 2014. http://www.nbcchicago.com/investigations/Report-Links-Chicago-Crime-to-Streetlight-Outages-265639931.html.
66. Shueh, Jason. Appallicious Launches FEMA Disaster Dashboard. July 29, 2014. http://www.govtech.com/public-safety/Appallicious-Launches-FEMA-Disaster-Dashboard.html.
67. Mileti, Dennis S. Public Response to Disaster Warnings. https://swfound.org/media/82620/public%20response%20to%20disaster%20warnings%20-%20dennis%20s.%20mileti.pdf.
68. Federal Emergency Management Agency. Mobile App. https://www.fema.gov/mobile-app.
69. Metropolitan Transit Authority. New York City Transit and Staten Island Railway. 2016. http://alert.mta.info/.
70. Miami-Dade County. Miami-Dade Alerts. 2016. http://www.miamidade.gov/alerts/.

71. National Institute of Standards and Technology. NIST's Rolling Wireless Net Helps Improve First-Responder Communications. August 10, 2016. https://www.nist.gov/news-events/news/2016/08/nists-rolling-wireless-net-helps-improve-first-responder-communications.
72. Pittman, Elaine. Three Emerging Technologies That Will Impact Emergency Management. December 6, 2012. http://www.emergencymgmt.com/disaster/3-Emerging-Technologies-Emergency-Management.html?page=3.
73. Eastwood, Gary. New Report Provides Snapshot of the Global State of Enterprise Mobility. March 18, 2016. http://www.formotus.com/14018/blog-mobility/figuring-the-costs-of-custom-mobile-business-app-development.
74. Pearson, Lucy. Early Warning of Disasters: Facts and Figures. November 21, 2012. http://www.scidev.net/global/communication/feature/early-warning-of-disasters-facts-and-figures-1.html.
75. Stockburger, Jen. NHTSA Accelerates Implementation of Automatic Emergency Braking. November 08, 2015. http://www.consumerreports.org/cars/nhtsa-accelerates-implementation-of-automatic-braking/.
76. National Highway Traffic Safety Administration. Pedestrian Traffic Safety Facts. May 2016. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812270.
77. Metrolink. An Introduction to Positive Train Control. May 27, 2012. http://www.metrolinktrains.com/agency/page/title/ptc.
78. Tate, Curtis. New Jersey Commuter Train Was Going Too Fast. Positive Train Control Can Prevent That. October 6, 2016. http://www.thestate.com/news/nation-world/national/article106517272.html.
79. Honeywell International Inc. Rail Track Safety. October 23, 2015. https://cip.honeywell.com/sol/Pages/RailTrack.aspx.
80. Watson, Tom. Simple Cost Analysis for RFID Options. October 29, 2013. http://www.amitracks.com/2013/10/simple-cost-analysis-for-rfid-options/.
81. Harvard Shorenstein Center. Bus Crashes in the United States: What Does the Research Say? March 9, 2013. http://journalistsresource.org/studies/environment/transportation/bus-crashes-united-states-what-does-research-say.
82. Ehrlichman, Courtney. Pedestrian-Friendly Traffic Signal Control. https://trid.trb.org/view.aspx?id=1302544.
83. Wright, James (AASHTO), et. al. Total Potential Connected Vehicle DSRC Deployment Costs at Signalized Intersections Needing Controller Upgrades May Cost on Average $51,600.00 per Site. June 27, 2014. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/SummID/SC2014-00328?OpenDocument&Query=Home.
84. Office of the Assistant Secretary for Research and Technology. Connected Vehicles 102. https://www.pcb.its.dot.gov/documents/Connected_Vehicles_102.pdf.
85. Cemex. Brigade Electronics Side Scan Side Detection System. http://www.roadpeace.org/resources/Cemex-_Side-Scan_Side_Detection_System.pdf.
86. Secure Micro Solutions. Turn Alert Overview. http://www.securemicrosolutions.com/turn-alert.html.

87. Lewin, Sarah. WiFi-Honk! Smartphone App Gets Pedestrians Out of the Way. July 14, 2014. http://spectrum.ieee.org/cars-that-think/transportation/safety/wifihonk-smartphone-app-for-drivers-and-pedestrians-gets-you-out-of-the-way.
88. DRK Enterprises INC. LED Education. April 2, 2016. http://www.myledlightingguide.com/the-cost-of-street-lights.
89. Flowers, Carolyn. New Grants Fund Critical Transit Safety Research. October 7, 2016. https://www.transportation.gov/fastlane/new-grants-fund-critical-transit-safety-research.
90. Transit Cooperative Research Program. Video Surveillance Uses by Rail Transit Agencies. 2011. https://www.nap.edu/catalog/14564/video-surveillance-uses-by-rail-transit-agencies.
91. Interagency Security Committee. Best Practices and Key Considerations for Enhancing Federal Facility Security and Resilience to Climate-Related Hazards. December 2015. https://www.dhs.gov/sites/default/files/publications/isc-enhancing-resilience-climate-hazards-dec-2015-508.pdf.
92. Nicolas, Roman. A New Infrared Pedestrian Detection System. May 6, 2014. http://www.car-engineer.com/new-infrared-pedestrian-detection-system/.
93. Smart Rail World. How Drones Are Already Being Deployed by Railways Around the World. September 2, 2014. http://www.smartrailworld.com/how_drones_are_already-being-used-by-railways-around-the-world.
94. 18 U.S.C. § 921.
95. Federal Emergency Management Agency, Emergency Management Institute. 15th Annual Emergency Management Higher Education Conference. June 7, 2012. http://training.fema.gov/hiedu/12conf/agenda.docx.
96. Hankin, Abigail, Marci Hertz, and Thomas Simon. Impacts of Metal Detector Use in Schools: insights From 15 Years of Research. December 8, 2009. http://www.edweek.org/media/hankin-02security.pdf.
97. Carts-Powell, Yvonne. Passive Millimeter Wave Imaging Growing Fast. October 21, 2005. http://www.freerepublic.com/focus/f-news/1252611/posts.
98. Department of Homeland Security. National Infrastructure Protection Plan. 2013. https://www.dhs.gov/national-infrastructure-protection-plan.
99. Super Circuits. Portable HD-TVI/VGA/HDMI CCTV Field Monitor Tester with 7" LCD Display. 2016. http://www.supercircuits.com/portable-7-inch-color-lcd-test-monitor-ali-ac5.
100. Federal Highway Administration. Pedestrian Push Button that Confirms Press. June 14, 2009. http://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/miami/ch3.cfm.

APPENDIX

A

All Hazards Approach

For the purpose of this study, alternative transportation risks are in relation to system assets including people, property, and materials. In public transportation, "people" include pedestrians, bicyclists, passengers, operators, employees, and others who come into contact with a system. A customized "all hazards approach" for facilities determines which assets are vulnerable to man-made or natural hazards.

Man-made hazards include criminal activity as well as crashes to persons, or through infrastructure, property, or materials. Intentional acts of harm perpetrated by criminals, disgruntled employees, terrorists, and others against persons are described as violent crimes. The "All Hazards Approach" also categorizes non-violent crimes against persons (e.g., larceny) and against property (e.g., theft, vandalism).

Natural hazards are naturally-occurring incidents and events; some of these events provide notice, and others provide little or no notice. At a national level, many natural hazard risks are known and forecasted ("notice events"). Systems operated by the National Weather Service (NWS) and the U.S. Geological Survey (USGS) provide warnings to the public on predicted natural hazards and present suggested steps on how to mitigate the risks from the hazard.

APPENDIX

B

In-Depth Interviews

FTA Regional Staff Interview Guide

I am part of a team from the Volpe Center researching safety and security incidents at selected transit facilities. Facilities include rail and bus terminals, stations, and stops as well as parking lots related to these facilities. More specifically, we are researching the safety and security of users as they approach/depart bus and rail facilities by foot, bicycle, or motor vehicle (while in parking lots) and as they wait for transit vehicles to arrive. We are also looking into property-related crimes such as arson, vandalism, or other property destruction at transit facilities. First, we'd like to understand your role at FTA.

1. What is your role at the FTA Regional Office? In your role, how do you interact/work with transit agencies in your region?

2. Can you provide a list of the major transit authorities you work with?

3. In your role, how do you address safety and security aspects of transit systems with transit authorities?
   a) Review of safety/security reports?
   b) Discuss or set safety and security priorities?
   c) Assist with Federal grants or funding for safety or security updates?

3. Have the transit agencies identified any major safety issues that involve transit users, pedestrians, bicyclists, or drivers (in parking lots) that they are looking to address?
   a) Do priorities differ for urban, suburban or rural transits facilities?

4. Have the transit agencies identified any major security uses (i.e., property crime, violent crime, terrorism) they are looking to address?
   a) Do priorities differ for urban, suburban or rural transits facilities?

5. What types of safety and/or security technologies have you seen agencies implement or seek grant funding for?

6. Are there any innovative technology solutions you think agencies are looking to for the future to improve safety and security?

7. Often, ridership of transit systems depend on a user's perception of safety/security while using the system. In your experience are there any modes or transit systems that are underutilized due the perception that they are unsafe? Explain.
   a) Does the safety/security data back up this perception?
   b) What could be done to change this perception?

TSA Interview Guide

I am part of a team from the Volpe Center researching safety and security incidents at select transit facilities. Facilities include rail and bus terminals, stations, and stops as well as parking lots related to these facilities. More specifically, we are researching the security of users as they approach/depart bus and rail facilities by foot, bicycle, or motor vehicle (while in parking lots) and as they wait for the transit vehicles. We are also looking into property-related crimes such as arson, vandalism, or other property destruction at the transit facilities. As part of this study, Volpe is researching innovative technology that can improve security at these facilities. To get started, we'd like to understand your role at TSA.

1. In your role, how do you (your agency) interact/work with transit agencies regarding security issue?

2. What would you say are the priority security issues that involve transit users (pedestrians, bicyclists, parking lot users, etc.)?

3. How does the TSA support transit agencies in findings solutions to security issues?
   a) Oversight of security?
   b) Grant funding for security technologies?
   c) Recommended approaches or technologies?

4. Are there any innovative security systems or solutions that you've seen emerging in the transit facilities you oversee?

Interview Participants

Region	Date	Contact	Title	Contact 2	Contact 3
1	8/17/2016	Matthew Keamy	Director, Office of Program Management and Oversight		
2	10/17/2016	Darreyl Davis	Director, Office of Operations and Program Management	Hans Point duJour	
3	9/27/2016	Tony Cho	Director, Office of Program Management and Oversight	Ryan Long	Katie Berrillo
4	9/13/2016	David Powell	Director, Office of Program Management and Oversight		
8	9/15/2016	Donna Douville	Team Leader, Office of Operations and Program Management		
9	9/19/2016	Bernardo Bustamante	Director, Office of Program Management and Oversight		
10	9/19/2016	Susan Fletcher	Director, Office of Program Management and Oversight		
TSA	10/6/2016	Chris McKay	Industry Engagement Manager/ Mass Transit and Passenger Rail	Ginny Long	

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