CHAPTER 2

Hazards and Threats

Tunnel systems, in their design, have a safe environmental order and are capable of withstanding the assaults normally presented by everyday use. For example, below-grade tunnels are watertight, with proper water evacuation capability and safety systems to move air into and out of the tubes. The tunnel structure is designed and built to exist within the soil or seabed that it occupies. Mined tunnels similarly coexist within their surface environment to provide safe, smooth operation. Despite these and other safety features, however, damage or disruption to a tunnel, its operations, and/or occupants can result from the impact of hazards or threats.

The tables in this chapter consist of a list of major hazards and threats that may adversely impact the normal operation of a transportation tunnel and associated infrastructure. The transportation tunnel and associated infrastructure include all electrical and mechanical operations within the tunnel environment, such as ventilation and fire suppression. Hazards and threats to the tunnel environment also include actual or perceived physical hazards and threats affecting the users of the transportation system.

The primary criterion used for the analysis of safety hazards and security threats was the level of impact that a major hazard or threat would have on the tunnel system. All hazards and threats considered in depth are capable of closing a tunnel for an extended period of time (i.e., lasting more than 25 hours). These hazards and threats encompass potential incidents that have not been routinely encountered or planned for by a tunnel operator.

Because the standard literature discusses hazard issues, threats make up the major portion of the events examined in this report, particularly threats related to the introduction of a foreign item into the tunnel environment to disrupt the tunnel and its users. This analysis excludes completely the range of safety hazards that are routinely observed and handled by a tunnel operator—such as equipment breakdown, utility disruptions, minor criminal acts, and medical emergencies—because tunnel operators have years of experience in handling such issues. The experiences of tunnel operators in handling these minor incidents have been distilled into handbooks and readily available procedural reference materials. Where possible, notations for additional reference material concerning these minor hazards have been included in this report.

The focus of this guidance is, therefore, a combination of major hazards that are not likely and threats—principally acts of terrorism—that might be realized in a tunnel environment. Unlikely, extraordinary threats have been excluded. These include highly unlikely acts of terrorism that seem irrational or ineffective in a tunnel context (such as a nuclear detonation or airborne threats).

The hazards and threats discussed in this report have been assembled individually. With this format, the reader can first absorb the details of each potential scenario and then read the recommended actions to mitigate the hazard or threat.

The remainder of Chapter 2 discusses (a) the major hazards and threats that will adversely affect the normal operation of a transportation tunnel and its associated infrastructure, (b) the damage potential of these hazards and threats, and (c) possible hazard and threat scenarios.

2.1 Major Hazards and Threats

Table 1 presents a range of major hazards and threats that may adversely affect a tunnel and its associated features. The hazards and threats are expressed in terms of generic scenarios with potential to damage the normal operation of a transportation system, including specific tunnel components.

One of the concerns, "Fire," appears under the "Threat" heading as arson and under the "Hazard" heading as unintentional. This distinction is made because, although the

Table 1. Major hazards and threats to transportation tunnels and associated features.

Hazard or Threat	Vulnerable Tunnel Feature									
	Tunnel Construction and Engineering Feature						Tunnel System Feature			
	Immersed Tube	Cut-and-Cover	Bored or Mined	Vent Shaft	Portal	Station	Distribution Channel	Control Center	Substation	Utility Building
Hazard										
Fire (Unintentional)	√	√	√	√	√	√	√	√	√	√
Structural Integrity Loss by Natural Causes	√	√	√	√	√	√	√	√	√	
Introduction of Hazardous Materials	√	√	√	√	√	√				
Threat										
Introduction of Small IEDs	√	√	√	√		√	√	√	√	√
Introduction of Medium-Sized IEDs	√	√	√	√	√	√	√	√	√	√
Introduction of Large IEDs	√	√	√	√	√	√	√	√	√	√
Introduction of Chemical Agents				√		√				
Introduction of Biological Agents				√		√				
Introduction of Radiological Agents	√	√	√		√	√				
Cyber Attack								√		
Maritime Incident	√		√							
Fire (Arson)	√	√	√	√	√	√	√	√	√	√
Sabotage of MEC Systems	√	√	√	√		√	√	√	√	√

IEDs = improvised explosive devices.
MEC = mechanical, electrical, and communications.

effects of an intentional fire and an unintentional fire may be similar, the defenses to the two kinds of fire may differ.

There are three major hazards and 10 major threats. The major hazards are the following:

- Fire (unintentional),
- Structural integrity loss by natural causes, and
- Introduction of hazardous materials.

The major threats are the following:

- Introduction of small improvised explosive devices (IEDs): explosive materials delivered via one to five aggressors transporting the payload.
- Introduction of medium-sized IEDs: explosive materials delivered either by vehicle (car) or by multiple persons acting in concert to transport the payload.
- Introduction of large IEDs: explosive materials delivered either by vehicle (truck) or by multiple persons acting in concert to transport the payload.
- Introduction of chemical agents.
- Introduction of biological agents.
- Introduction of radiological agents.
- Cyber attack: a virtual aggression against the command and control systems of a tunnel system with the intent of disabling systems.
- Maritime incident: a waterborne incident affecting a tunnel shell from above and any exposed sides. Adverse

impacts may be due to sunken ships, misguided anchors, or explosives.
- Fire (arson): an intentionally set conflagration with the intent of causing physical harm or damage to property.
- Sabotage of mechanical, electrical, and communications (MEC) systems: the intentional impairment or destruction of MEC systems necessary to the safe, efficient operation of a tunnel system.

The right side of the table notes the affected vulnerable tunnel features, also referred to in this report as "assets." The vulnerable tunnel features have been divided into two types: tunnel construction and engineering features and tunnel system features.

Tunnel construction and engineering features include the type of tunnel facility constructed and the major engineered features, which are typically immovable. There are six categories of tunnel construction and engineering features:

- Immersed tube: employed to traverse a body of water. Tunnel sections, usually 300 to 450 feet (91 to 137 meters) long, are placed into a pre-excavated trench.
- Cut-and-cover: tunnel construction method involves braced, trench-type excavation ("cut") construction of structures and placement of fill materials over the finished structures ("cover").
- Bored or mined: bored tunnels are often excavated using mechanical equipment such as road headers or tunnel boring machines (TBMs), while mined tunnels may be excavated using manual or mechanical methods.
- Vent shaft: any at-surface or above-grade air intake or exhaust facility servicing a below-grade road, transit, or rail section.
- Portal: any engineered entranceway or boat section to a below-grade road, transit, or rail section.
- Station: any facility in regular use by nonemployees of a passenger rail or transit system. Unlike the other categories of construction and engineering features, this category is applicable to passenger rail and transit only.

Tunnel system features include the major components designed and installed to support the efficient operation and safe environment of a tunnel. Mechanical, electrical, ventilation, and communication systems are the major sections designed to support the tunnel system. These systems are capable of update or replacement over time. The categories of tunnel system features are as follows:

- Distribution channel: any conduit, sheath, piping, fiber optic, or metal line designed and installed to provide a source of power or method of communication between a tunnel system and a utility terminus.
- Control center: any facility designed, constructed, and equipped with systems intended to monitor and control the tunnel environment and the movement of vehicle and rail traffic over and through a tunnel section.
- Substation: any facility specifically designed to relay power, water, or sewer connections between the tunnel and the central utility building. The substation is connected to the utility building and the tunnel via distribution channels.
- Utility building: Any facility specifically designed to provide power to the tunnel system. This facility is operated continuously to achieve its mission and is connected to both substations and the tunnel through a distribution channel. A utility building may also be designed to provide water or sewer removal from the tunnel.

2.2 Damage Potential

The damage potential of hazard and threat scenarios—often a sequence of physical events (such as fire or flooding) and their secondary impacts (such as injuries, fatalities, or loss of function)—determines the key characteristics of countermeasures that can mitigate the impact of hazards and threats, if not prevent them. Table 2 presents the damage potential of the hazards and threats listed in Table 1.

Except for radiation, the types of damage listed in Table 2 and considered throughout this report are visible to emergency responders and the tunnel operator. All types of damage, including radiation, may be mitigated. Possible damage includes the following:

- Fire/smoke: any active conflagration or post conflagration condition of smoke and harmful vapors.
- Flooding: the condition of excessive water inflow to a tunnel area exceeding the pumping capacity of the tunnel systems and causing a hazard or threat to people and property.
- Structural integrity loss: any decrease in the fitness of the tunnel to carry passengers or freight that requires inspection by the tunnel owner and major repair prior to its reopening for beneficial use by the public.
- Contamination: the condition of being unfit for normal habitation due to the presence of radiation, biological agents, harmful chemicals, hazardous airborne particles, or sewage sufficient to require professional remediation.
- Utility disruption: loss of power, air, steam, water, or communication service for more than 25 hours.

Table 2. Damage potential of hazards and threats.

Hazard or Threat	Damage Potential						
	Fire/Smoke	Flooding	Structural Integrity Loss	Contamination	Utility Disruption	Extended Loss of Asset Use	Extended Public Health Issue
Hazard							
Fire (Unintentional)	√	√	√	√	√	√	√
Structural Integrity Loss by Natural Causes	√	√	√	√	√	√	√
Introduction of Hazardous Materials				√		√	√
Threat							
Introduction of Small, Medium-Sized, or Large IEDs	√	√	√	√	√	√	√
Introduction of C/B/R Agents				√		√	√
Cyber Attack						√	
Maritime Incident		√	√			√	
Fire (Arson)	√	√	√	√	√	√	√
Sabotage of MEC Systems	√	√	√	√	√	√	√

C/B/R = chemical/biological/radiological.
IEDs = improvised explosive devices.
MEC = mechanical, electrical, and communications.

- Extended loss of asset use: loss of the ability to safely move passengers or allow vehicular traffic for more than 25 hours.
- Extended public health issue: actual or potential ability to cause illness in a significant portion of the population sufficient to overwhelm the medical treatment capacity of the area.

2.3 Hazard and Threat Scenarios

Hazard and threat scenarios are profiles that include the hazard or threat, the mode of delivery, the path to the target, the tactical delivery device, and the location of the target. Table 3 provides basic hazard and threat scenarios. The assumptions made during the development of this table are based on past terrorist acts and current available intelligence. The scenarios are intended to include categories applicable to highway, rail, and transit tunnel systems. However, the needs, vulnerabilities, and points of access differ from mode to mode, as well as from tunnel to tunnel within a mode. The reader is encouraged to review the text to ascertain the applicability of the table to his or her own situation.

The following sections present hazard and threat scenarios, respectively, in relation to assets. Note that some scenarios, such as fire, may be the result of an intentional act (i.e., a threat) or an unintentional event or circumstance (i.e., a hazard).

2.3.1 Hazard Scenarios in Relation to Assets

Fire (Unintentional)

Unintentional fire is more probable than intentional fire and has occurred in several tunnel systems. Fire may destroy any structure or vehicle and kill people if not controlled. A tunnel structure may be completely ruined by a conflagration. Fire sources may be disparate and triggered by any combination of flammable material and ignition. Fire occurs in nature and does not necessarily require human intervention to spread. Fire, or the danger of fire as a smoke condition, will immediately have a negative impact on all tunnel assets by inducing the evacuation of persons and equipment from

Table 3. Hazard and threat scenarios.

Hazard or Threat	Mode of Delivery	Path to Target	Tactical Delivery Device	Location of Target
Very Large IED	Ship	Waterway	Explosive Container (Depth Charge)	Top of Tunnel
Large IED	Vehicle	Tunnel Roadway	Truck	Liner
Large IED	Vehicle	Tunnel Roadway	Truck	Column or Wall
Large IED	Vehicle	Surface Roadway over Tunnel	Truck	Roof Slab
Large IED	Vehicle	Tunnel Roadway	Truck	Ventilation Building
Large IED	Vehicle	Surface Access Road	Truck	Ventilation Building
Large IED	Vehicle	Tunnel Roadway	Truck	C&C Center Above Tunnel
Large IED	Vehicle	Surface Access Road	Truck	Stand-Alone C&C Center
Large IED	Vehicle	Surface Access Road	Truck	Stand-Alone Substation
Large IED	Vehicle	Surface Access Road	Truck	Ventilation Shaft
Large IED	Vehicle	Surface Access Road	Truck	Station
Large IED	Vehicle	Surface Access Road	Truck	Ventilation Structure
Large IED	Rail or Transit Vehicle	Trackway	Locomotive or Freight/ Passenger Car	Liner
Large IED	Rail or Transit Vehicle	Trackway	Locomotive or Freight/ Passenger Car	Column or Wall
Medium IED	Vehicle	Tunnel Roadway	Car or Van	Liner
Medium IED	Vehicle	Tunnel Roadway	Car or Van	Column or Wall
Medium IED	Vehicle	Tunnel Roadway	Car or Van	Ventilation Building
Medium IED	Vehicle	Surface Access Road	Car or Van	Ventilation Building
Medium IED	Vehicle	Tunnel Roadway	Car or Van	C&C Center Above Tunnel
Medium IED	Vehicle	Surface Access Road	Car or Van	Stand-Alone C&C Center
Medium IED	Vehicle	Surface Access Road	Car or Van	Stand-Alone Substation
Medium IED	Vehicle	Surface Access Road	Car or Van	Ventilation Shaft
Medium IED	Vehicle	Surface Access Road	Car or Van	Ventilation Structure
Medium IED	Motor Vehicle or Foot	Surface Roadway over Tunnel	Truck or Multiple Backpacks	Roof Slab
Medium IED	Transit Vehicle	Trackway	Car or Engine	Liner
Medium IED	Transit Vehicle	Trackway	Car or Engine	Column or Wall
Medium IED	Rail Car or Foot	Trackway	Freight/Passenger Car, Engine, or Multiple Backpacks	Liner
Medium IED	Rail Car or Foot	Trackway	Freight/Passenger Car, Engine, or Multiple Backpacks	Column or Wall
Small IED	Foot	Tunnel Roadway	Backpack	Liner
Small IED	Foot	Tunnel Roadway	Backpack	Column or Wall
Small IED	Foot	Stations/Shops/ Tunnel Portals	Backpack	Column or Wall
Small IED	Foot	Stations/Shops/ Tunnel Portals	Backpack	Liner

Table 3. (Continued).

Hazard or Threat	Mode of Delivery	Path to Target	Tactical Delivery Device	Location of Target
Small IED	Foot	Tunnel Roadway	Backpack	Exposed Ductbank
Small IED	Foot	Surface Access Road	Backpack	Inside Ventilation Building
Small IED	Foot	Surface Access Road	Backpack	Inside C&C Center
Small IED	Foot	Surface Access Road	Backpack	Inside a Stand-Alone Substation
Small IED	Foot	Tunnel Trainway	Backpack	Exposed Ductbank or MEC Equipment
Small IED	Foot	Tunnel Trainway	Transit Vehicle	Station
Small IED	Foot	Surface Access Road	Backpack	Station
Small IED	Foot	Surface Access Road	Backpack	Inside Substation
Small IED	Foot	Surface Access Road	Backpack	Inside Ventilation Structure
Large Fire	Vehicle	Tunnel Roadway	Tanker	Liner
Large Fire	Vehicle	Tunnel Roadway	Tanker	Column/Wall/Roof Slab
Large Fire	Vehicle	Tunnel Roadway	Tanker	Portal
Large Fire	Vehicle	Tunnel Roadway	Tanker	Any Tunnel Location Adjacent to Critical Facility
Large Fire	Rail/Transit Car	Trackway	IED on Train	Liner
Large Fire	Rail/Transit Car	Trackway	IED on Train	Column/Wall/Roof Slab
Large Fire	Rail/Transit Car	Trackway	IED on Train	Portal
Large Fire	Rail/Transit Car	Trackway	IED on Train	Any Tunnel Location Adjacent to Critical Facility
C/B/R	Foot	Tunnel Air Supply System	Vial/Aerosol/Small Package	Tunnel Occupants and Surrounding Population
C/B/R	Foot	Surface Access Road to Tunnel Vent Intakes	Vial/Aerosol/Small Package	Tunnel Occupants and Surrounding Population
C/B/R	Vehicle	Tunnel Air Supply System	Vial/Aerosol/Small Package	Tunnel Occupants and Surrounding Population
C/B/R	Vehicle	Tunnel Roadway	Vial/Aerosol/Small Package	Tunnel Occupants and Surrounding Population
C/B/R	Vehicle	Surface Access Road to Tunnel Vent Intakes	Vial/Aerosol/Large Package on Truck	Tunnel Occupants and Surrounding Population
C/B/R	Vehicle	Surface Access Road to Tunnel Vent Intakes	Vial/Aerosol/Large Package	Tunnel Occupants and Surrounding Population
C/B/R	On Foot in Transit Car	Tunnel Roadway	Vial/Aerosol/Large Package	Tunnel Occupants and Surrounding Population
C/B/R	Transit Car	Tunnel Trainway	Vial/Aerosol/Large Package on Train	Tunnel Occupants and Surrounding Population
Hazardous Materials	Vehicle	Tunnel Roadway	Truck	Any Place in Tunnel
Hazardous Materials	Transit Car	Tunnel Trainway	Device on Train	Any Place in Tunnel
Cyber Attack	Digital	Virtual	Virus Code	C&C
Maritime Incident (Anchor Drag)	Ship	Water Above Tunnel	Passing Ship	Tunnel Shell

C&C = command & control.
IEDs = improvised explosive devices.
MEC = mechanical, electrical, and communications.

within the structure and surrounding areas. Fire and smoke will decrease visibility to unsafe levels, precipitate collision of vehicles and equipment, and cause personal injury. A fire controlled by firefighting may still result in smoke and water damage at a level sufficient to render a tunnel unfit for use or occupancy. The related assets are the following:

- **Tunnel structures.** A fire may cause damage to the integrity of a structure and its engineered support bracing. The heat of a flame may distort all standard tunnel materials sufficient to require closure for repair. The damaging effects of a fire are consistent across bored, cut-and-cover, and immersed tube tunnel construction.
- **Portals.** Smoke and flame damage may threaten engineered works to weaken a portal. Damage or destruction may also be inflicted on monitoring equipment situated at the portal to a tunnel such as over height detection units, heat sensors, carbon monoxide detectors, and closed-circuit camera units.
- **Vent shafts.** Fire, heat, and water damage may affect air intake and exhaust towers, machinery, and required air filtering equipment. The damage would require replacement.
- **Stations (passenger tunnels only).** A fire may damage or destroy wood, metal, and masonry structures that are necessary for normal human occupancy. Certificates of occupancy are routinely revoked when a fire causes damage to a structure. A small conflagration, with flame and smoke, may render a station unfit for occupancy and disallow its use by persons, vehicles, and equipment; it will be unfit until environmental abatement is complete and repairs are made to meet regulatory code. A station unfit for occupancy eliminates its primary function within the system, which is the transfer of passengers to railcar.
- **Distribution channels.** The destructive path of flame and smoke may melt sheathing, iron piping, polyvinyl chloride (PVC), and metal conduit, thereby damaging the contents beyond repair. Pipes carrying water could serve as conduits for burning oil. Water used in firefighting efforts may have a destructive effect on power and communication lines. The loss of a utility in or near the tunnel structure will deny service to the surrounding areas, including any businesses, homes, or schools. Utilities may also facilitate the flow of water and other materials along their pathways and in entry and exit locations.
- **Control centers.** Flame and smoke may destroy the physical structure and all mechanical equipment of a control center and endanger the lives of personnel assigned to that facility. Water damage to equipment and structure may also occur in firefighting efforts. The loss of a control center would severely affect the ability of a transportation system to operate. The impact would be particularly severe on rail systems that rely on remote monitoring and sensors to control movement.
- **Substations.** Fire may damage or destroy the physical structures containing utility equipment and connections. A fire may also sever the power feed and monitoring systems of a substation, thereby rendering the station unfit for use. Equipment rendered unusable by the effects of a fire will need to be replaced prior to the operation of a tunnel to maintain the ability to evacuate water and provide power. Substations may also be adversely impacted by firefighting techniques that may send soiled water and debris into the plenums, thereby jamming lines and pump rotors.
- **Utility building.** Fire may damage the utility terminus structures, rendering them unusable.

Structural Integrity Loss by Natural Causes

Despite the best efforts of engineering and maintenance, the potential danger of structural integrity loss to tunnels and supporting infrastructure from unforeseen circumstances will always exist. There is no known method to guarantee that a structure will never fail or deteriorate. Proper design, construction, and maintenance may drastically reduce the likelihood of a sudden failure. However, unseen geotechnical or aquatic forces may go undetected by asset owners. Inconsistencies and lapses in the design, construction, and maintenance of a tunnel may collude to create the conditions for a sudden structural integrity loss.

Structural integrity loss may be sudden or slow acting. The scope of this damage may be minimal, such as a crack in the wall requiring remediation or a pavement ripple requiring the temporary relocation of traffic. Integrity loss may also be catastrophic, resulting in total collapse or flooding of a structure, wreaking widespread loss of assets, and loss of life. The related assets are the following:

- **Tunnel structures.** Loss of structural integrity threatens to collapse the bore, tube, or constructed below-grade area wholly or partially. A whole or partial collapse will force the closure of the asset for an undetermined amount of time. Minor integrity losses also drastically increase the opportunity for water inflow, thereby inducing a progressive loss of material strength. Loss of integrity directly affecting a rail bed or track may unsettle the transit area of the tube. Disturbances to only the transited area will slow road traffic until repair; these disturbances will likely halt rail traffic because of the deflection of the rail.
- **Portals.** Portal construction is subject to the same stresses as the tube areas. Whole or partial collapse will force a closure of the transit areas and nearby access paths.
- **Vent shafts.** Loss of structural integrity may destroy air intake and exhaust plenums, shafts, and towers. A shift in the support of a vent shaft area can alter the load-bearing capability to support heavy machinery necessary for air

purification. The absence of fresh air delivery into the below-grade structure can detrimentally impact that facility's ability to support life and safety.

- **Stations (passenger tunnels only).** A passenger station may be made partly or wholly unsafe by a structural integrity loss. Falling debris, unsettled steps and walkways, and uneven road or rail surface contribute to an unsafe environment.
- **Substation.** A substation may be disturbed or made nonfunctional by a loss of structural integrity. Machinery or piping may be made uneven, thereby interrupting the designed flow of the station. Power brought in by hard wire may be interrupted by the movement or decay of the structures on which they are tethered.
- **Control centers.** Control centers lose functionality when a loss of structural integrity occurs in a tunnel system. Sensors, cameras, alarms, radio signals, and detectors are normally hard wired inside a tunnel system and tethered to a wall, shaft, plenum, or stairway system. The partial collapse of a support for one of these remote communication systems would disable the unit and eliminate its use to a control center.
- **Distribution channels.** Similar to the operation of a control and detection system, distribution channels would be interrupted or impaired by the whole or partial loss of the structures that they monitor or are attached to. Buried utilities, located within the footprint of the tunnel structure or in nearby corridors, may be affected by the geotechnical alteration subsequent to a whole or partial collapse. Utilities connected by piping or hard wire may be severed or cracked. The collapse may allow water to intrude on soft wire networks such as fiber optic to corrode connectors. Power utilities may also experience water intrusion that may result in surges, overloads, and possibility of electrocution.

Introduction of Hazardous Materials

A tunnel system may be threatened by the accidental discharge of hazardous materials into the confined space of the tunnels or the stations. Hazardous materials can take a liquid, solid, or gaseous form. Even minimal quantities of some materials can cause serious injury to tunnel system users. Hazardous materials can range from common industrial cleaners used by tunnel workers to a canister of pepper spray set off by a commuter. In both circumstances, it is unlikely that the maintenance worker or the commuter entered the tunnel system with the intent of discharging hazardous material into the air. Materials may also include hazardous liquid, debris, or waste product moved into the tunnel system by a vehicle, truck, or rail car.

Public vehicular tunnel systems may forbid the transport of dangerous materials through below-grade areas, but these injunctions alone cannot stop private vehicles and trucks from attempting to transport them. Hazardous materials will enter the tunnel systems in varying quantities, and many will exit the system without incident or release. Through driver error or unfortunate circumstance, hazardous materials may leak or be released into the tunnel. Many hazardous materials require specialized remediation that will close a road or transit tunnel to allow processing. The related assets are as follows:

- **Tunnel system and structure.** The introduction of hazardous materials into a tunnel system constitutes a hazard to the safe use of the tunnel and requires immediate remediation. When a material is identified as potential or actual hazardous material, the area containing the hazard must be taken out of service for remediation. This closure adversely affects the use of the tunnel system and disrupts traffic flow. The tunnel as a system is adversely disrupted. The structural integrity of the tunnel may also be damaged by the introduction of certain hazardous materials, thereby requiring heavy repair under closed conditions.
- **Portals.** Hazardous material introduction may have the same adverse impacts to a portal as to the tunnel structure. Certain hazardous materials require remediation, and remediation may require full or partial closure of the road or rail line. Closures will affect flow through the portals.
- **Stations (passenger tunnels only).** The introduction of hazardous materials may constitute an immediate safety hazard and require the partial or full evacuation of the station to commence remediation efforts. Any evacuation would be an adverse impact.

2.3.2 Threat Scenarios in Relation to Assets

Introduction of Small IEDs

Explosives are materials capable of violent decomposition, which often takes the form of extremely rapid oxidation (i.e., burning). Explosions are the result of sudden and violent release of gas during the decomposition of explosive substances.

Small IEDs are defined as explosive or incendiary production materials or devices small enough to be easily concealed. Compact or small devices are easily concealed among a person or personal belongings and may only be detected by deliberate use of equipment, processes, or close observation. The destructive pattern of any explosive device has the potential to damage every object within its blast radius. A small conventional explosive has the capacity to kill or injure anyone within its blast radius. The related assets are as follows:

- **Tunnel structures.** A hand-carried IED will damage the portion of the tunnel located within the blast radius. The portion of the structure damaged may be relatively small or extensive. The hand-carried IED will cause the temporary closure of the tunnel for evacuation and repair.

- **Portals.** Similar to the tunnel structure, the portal may be damaged if it is within the blast radius of the hand-carried IED. The portal will be closed temporarily for repair.
- **Vent shafts.** Similar to the tunnel structure, the vent shaft may be damaged if it is within the blast radius of the hand-carried IED. The shaft or intake structure will be closed temporarily for repair.
- **Stations (passenger tunnels only).** A hand-carried IED set to detonate in a passenger station will likely cause more damage to persons than to property. A device set to explode in a passenger station will have been intended to harm or frighten people. The relative space difference between a station and a tunnel will allow a greater physical area to absorb the blast, thereby lessening the physical damage to the station. A mass casualty incident will likely lead to the closure of the station for an extended period, but not permanently.
- **Substation.** Similar to the tunnel structure, the system's substation may be damaged if it is within the blast radius of a hand-carried IED. The substation will be closed temporarily for repair.
- **Control centers.** Depending on the placement of an explosive device, the blast may throw the facility off line or threaten the facility's ability to safely hold persons and equipment. A control center located many miles from the scene of an explosion may be physically unaffected but still see a loss in monitoring capacity to the affected area. A control center located at the site of an explosive blast may be directly affected, evacuated, and possibly destroyed.
- **Distribution channels.** A small blast will damage or destroy wiring, piping, or vents located within the blast zone. Loss of these distribution channels may force the closure of the tunnel system for repair.
- **Utility terminus building.** A building may be partially closed for repair as the result of the successful delivery of a small IED. Loss of a utility may have a cascading effect on downstream systems, thereby debilitating service in the tunnel system.

Introduction of Medium-Sized and Large IEDs

Medium-sized and large explosives typically rely on a mobile delivery system, such as a car, truck, or rocket, or are stealthily placed in a chosen area prior to detonation. The power of a medium-sized or large explosive is wholly destructive to persons and property. In the confined atmosphere of a tunnel system, the force of a blast will be absorbed by the components of the tunnel system, causing casualties and destruction. Large quantities of explosives require efforts at interdiction prior to their placement or delivery. Vehicle-borne delivery systems are noticeable to defenders. The related assets are as follows:

- **Tunnel structures.** A vehicle-borne explosive will damage a significant portion of the tunnel located within the blast radius. The vehicle-borne explosive will cause a long-term closure of the tunnel for evacuation and repair. A well-placed large explosive may cause the tunnel structure to collapse and require rebuilding. A large explosive may also cause a mass casualty incident.
- **Portals.** Similar to the tunnel structure, the portal may be damaged or destroyed if it is within the blast radius of the vehicle-borne explosive.
- **Vent shafts.** Similar to the tunnel structure, the vent shaft may be damaged or destroyed if it is within the blast radius of the vehicle-borne explosive. The shaft or intake structure may require reconstruction.
- **Stations (passenger tunnels only).** A vehicle-borne explosive set to detonate in a passenger station will cause significant damage to persons and property. A mass casualty incident will likely lead to the closure of the station for an extended period, if not permanently. Reconstruction of the station will need to occur.
- **Substation.** Similar to the tunnel structure, the substation may be damaged or destroyed if it is within the blast radius of a vehicle-borne explosive. A substation will require reconstruction if the damage is significant.
- **Control centers.** Depending on the placement of a vehicle-borne explosive, the blast may throw the facility off line or threaten its ability to safely hold persons and equipment. A control center located many miles from the scene of an explosion may be physically unaffected but still see a loss in monitoring capacity to the affected area. A control center located at the site of an explosive blast may be directly affected, evacuated, or possibly destroyed.
- **Distribution channels.** Any explosive blast will damage or destroy life safety and monitoring systems located within the blast zone. Interconnected distribution channels will be severed, thereby limiting or destroying their usefulness to another part of the tunnel system not directly affected by the blast. Systems will need to be reconstructed.
- **Utility building.** Utility lines and connectors may be damaged or destroyed if they are within the blast zone. Loss of a utility will have a cascading effect on downstream systems, debilitating service in the tunnel system and adjoining areas.

Introduction of Chemical Agents

According to the Federal Emergency Management Agency (FEMA), as promulgated in *Emergency Response to Terrorism Job Aid* (which is available online at http://www.usfa.dhs.

gov/downloads/pdf/publications/ert-ja.pdf), there are five classes of chemical agents, all of which produce incapacitation, serious injury, or death:

- **Nerve agents** damage the nervous system of a person and are extremely effective in small doses. Exposure is achieved through the respiratory tract and the skin. Nerve agents are deadly and fast acting, and symptoms include difficulty breathing, seizures, headaches, and salivation. All nerve agents require handling and treatment with extreme care. Well-known nerve agents include sarin (GB), soman (GD), tabun (GA), and V agent (VX).
- **Blister agents,** also known as vesicants, include phosgene and mustard gas. Vesicants are absorbed through the eyes, skin, and lungs. They attack tissue and cause severe blistering. They may lead to seizures, blindness, and pulmonary edema. Blister agents are treatable and were first introduced during World War I.
- **Blood agents** quickly diminish the ability of the body to absorb oxygen into the bloodstream, thereby depriving the organs of oxygen. Common types of blood agents include hydrogen cyanide and arsine, both of which are used in industrial applications. Blood agents enter the body through the skin or the respiratory tract and provoke cherry red lip color convulsions, nausea, and respiratory arrest. Affliction by a blood agent is treatable.
- **Choking agents** interfere with the breathing process and, if left untreated, may induce asphyxiation. Choking agents include common compounds such as chlorine, ammonia, hydrogen chloride, and phosphorous. Common symptoms include coughing; shortness of breath; and a burning sensation in the eyes, nose, and throat. There are no known antidotes to choking agents, but successful medical treatment is available.
- **Irritant agents** are agents designed to temporarily incapacitate a person. They generally do not have long-term effects or induce death. Common irritants include pepper spray, mace, and tear gas, all of which will induce tearing eyes, coughing, and throat irritation. These effects are temporary and treatable.

The agents' means of affliction and effects are outlined in *Emergency Response to Terrorism Job Aid* and in the succinct Department of Health and Human Services's *Terrorism and Other Public Health Emergencies: A Reference Guide for Media* (which is available online at http://www.hhs.gov/emergency/mediaguide/PDF/00.pdf).

The related assets are as follows:

- **Vent shafts.** Similar to a biological agent, air intake facilities may be the point of introduction for a chemical agent. By introducing a chemical agent into a vent shaft, an aggressor would be able to introduce the agent into the ventilation system. This method may also dilute the concentration of the chemical agent. An affected vent shaft would need to be quarantined, decontaminated, and likely decommissioned due to damage, public fear, or use as evidence in a criminal investigation.
- **Stations (passenger tunnels only).** Stations would be the likely scene of both introduction of the chemical agent and the mass casualty. The means to introduce a chemical agent into a station is relatively unsophisticated. An aggressor could enter the station with a vial, bag, or other carrier and open it on the platform, thereby exposing the tunnel users to the chemical agent. The station would be designated as out of service; it would become a mass casualty treatment area, crime scene, and site of an infected structure requiring decontamination. Upon decontamination and release as a crime scene, partial or full reconstruction may be necessary.

Introduction of Biological Agents

The introduction of a harmful biological agent into a tunnel transportation system is a threat of high damage potential and low probability. There is little historical data on the use of biological agents in the United States as a threat against tunnel transportation systems.

Biological agents are weaponized versions of organisms that occur in the natural environment. Bacteria, viruses, and toxins can be manipulated to cause widespread contagion and infection among a targeted population. Biological agents can be released into the air of a tunnel system and provoke either an immediate or delayed response from the affected individuals.

Biological agents are very difficult to manufacture, handle, and deliver. Their effectiveness is impacted by wind, moisture, and air removal systems. Well-known biological agents include botulism, smallpox, and anthrax. Symptoms of a biological agent vary, but may include increasing fatigue or flu-like symptoms. Victims may suffer localized paralysis, swelling, rashes, or fever. Treatment is possible for many, but not all, biological agents.

Introduction of a biological agent into a transportation tunnel would likely cause a delayed medical treatment situation. Travelers would begin seeking medical treatment hours or days after the exposure. Damage to the tunnel infrastructure would be contained to directly affected equipment and areas, all of which would require complete decontamination. During the period of decontamination, all equipment must be quarantined and replaced.

The related assets are as follows:

- **Vent shafts.** Air intake facilities may be the point of introduction for a biological agent. By introducing a biological agent into the air shaft, an aggressor would be able to introduce the agent into the ventilation system. This method may also dilute the concentration of the biological agent. For a persistent agent, an affected vent shaft would need to be quarantined, decontaminated, and likely decommissioned due to damage, public fear, or use as evidence in a criminal investigation.

- **Stations (passenger tunnels only).** Stations would be the likely scene of both the introduction of the biological agent and the mass casualty incident. The means to introduce an agent into a station is relatively unsophisticated. An aggressor could enter the station with a vial, bag, or other carrier and open it on the platform, thereby exposing the tunnel users to the biological agent. Once identified as contaminated, the station would be designated out of service; depending on the speed of onset of symptoms, it could become a mass casualty treatment area, crime scene, and infected structure site requiring decontamination. Upon decontamination and release as a crime scene, partial or full reconstruction may be necessary.

Introduction of Radiological Agents

A radiological attack would have a destructive impact on a tunnel transportation system, nearby environments, and the user community. Radiological contamination disrupts the cell structure of a victim, causing sickness and death. A victim may experience delayed symptoms and may mistake the cause of the symptoms for a flu-like illness. Radiological material is difficult to manufacture, handle, and deliver. It can be as deadly to the attacker as to the victims.

Facilities and equipment would both be placed out of service and possibly abandoned. Extensive decontamination efforts would be required to restore them to use. The related assets are as follows:

- **Tunnel structure.** A successful radiological attack would adversely affect the tunnel structure. Damage may be immediate (resulting from the explosive used in the delivery) or long term (resulting from the contamination of the structure with radiological material). Immediate blast damage may affect the integrity of the structure, including supports, braces, and engineered works that withstand water intrusion. The long-term effects of radiological contamination might require lengthy remediation, including replacement of sections or construction of alternative routes. These scenarios would require a long-term closure of that area of the system or abandonment.
- **Portal.** The portal would be similarly impacted as the tunnel structure. Depending on the placement of the explosive delivery device, the portal may become unsteady and contaminated. Damage may require reconstruction, long-term closure, or abandonment. The effect of a radiological threat successfully executed on an occupied passenger station would be a mass casualty event and would lead to closure of the station for an extended period for abatement and reconstruction. Severe contamination or severe damage from the explosive delivery could result in abandonment. The impact to the system could be drastic. The station might not be used as a transit way, entry point, or egress point for a considerable amount of time.

A Note about Biological, Chemical, and Radiological Attacks: Biological, chemical, and radiological attacks may not be readily apparent at the site of introduction within the tunnel system. The introduction of these agents may be discernable only later, when victims seek medical treatment and the origin of their problems are traced to the use of a common tunnel. The effect of an attack would remain consistent with the descriptions provided, yet the discovery of the attack would be different than other primary hazards and threats described. An extended discussion of chemical, biological, and radiological agents and transportation system response options is presented in *NCHRP Report 525, Vol. 10: A Guide to Transportation's Role in Public Health Disasters*.

Cyber Attack

Closed-circuit television (CCTV), air quality testing, and traffic algorithms are commonplace to ensure the smooth, safe use of a tunnel. The deployment of a concerted effort to deny the use of digital technology to the tunnel operator is a threat. The venue to attack the computer network of a tunnel operator is remote and virtual. The introduction of a virus into a remote network is commonplace in today's environment. Minimal technology is needed to launch a cyber attack. The related asset is as follows:

- **Control centers.** Technology is crucial to the monitoring and safe operation of a tunnel. Control centers remotely view, test, and monitor a tunnel environment using digital transmission and other technology.

Maritime Incident

The occurrence of a maritime incident, specifically a ship sinking over a subaqueous tunnel or dropping a depth charge on the tunnel, is a threat to the safe operation of a water tunnel. Subaqueous tunnels located under navigable waterways are potentially at risk. A maritime incident may result from a navigational error or mechanical defect aboard the ship. A maritime incident may also result from an intentional act by an aggressor.

An intentional maritime incident may be part of a more elaborate attack designed to simultaneously inflict damage on multiple assets. For example, the use of a sunken vessel to damage the tunnel shell will cause a great amount of first responder resources to be devoted to mitigating the waterborne disaster. An aggressor may take advantage of the concentration of resources at that site and strike another area deemed to be the higher-value target. In this example, the sunken vessel only serves as a delivery mode for an explosive to reach the tunnel shell. A quantity of explosives detonating outside the shell would damage the shell. The extent of damage will be determined by the exact placement of the explosive and the quantity deployed. All explosions occurring from the outside on the tunnel shell will cause the closure of the tunnel to users for a period of time while the damage is inspected and mitigated. Efforts will also be expended to evacuate any tunnel users in harm's way.

The related asset is as follows:

- **Tunnel structures.** Subaqueous tunnels may suffer damage or collapse if struck by a ship of sufficient size. The damage or collapse may allow sufficient water inflow to flood the tunnel, thereby endangering lives, property, and the use of the tunnel.

Fire (Arson)

Arson is the criminal act of enacting a conflagration on property. The act is intended to inflict injury to persons and damage to property. Arson that is intended to damage or destroy property may also recklessly endanger the safety of tunnel users and first responders. An occurrence of arson could inhibit the ability of the tunnel operator to open the tunnel for a period of time. A 341 million British thermal units (MBTU) per hour (100 MW) fire is the maximum design fire currently used globally for most road tunnels and is the maximum size fire that can be controlled by the majority of road tunnel ventilation systems. In typical transit and rail tunnels, the maximum design fire size is much lower, in the neighborhood of 68.2 to 170.5 MBTU per hour (20 to 50 MW). Any fire larger than 341 MBTU per hour (100 MW) will not be controllable in any tunnel and, therefore, could be a major catastrophic event. Therefore, this project considered only fires larger than 341 MBTU per hour (100 MW).

Sabotage of MEC Systems

A premeditated, intentional disruption of tunnel MEC systems presents a threat to all nearby below-grade tunnel structures. Loss of system function may alter the effectiveness of safety and operational systems, thereby presenting a tunnel condition unfit for general use. Systems designed for the evacuation of water, delivery of power, provision of fresh air, or monitoring of traffic may be made unusable for an extended period. Replacement of the sabotaged system may incur great costs and lengthy installation times. Significant loss of MEC systems may cause tunnel operations to be suspended. The related assets are as follows:

- **Tunnel structures.** A disrupted utility may cause the suspension of tunnel system operations due to unsafe conditions. Power loss in a tunnel system will likely trigger a closure of the underground area and evacuation of standing populations. Water or sewer inflow will trigger an immediate suspension of tunnel operations or severe restrictions on travel through the system.
- **Vent shafts.** Exhaust and air intake machinery may suffer a loss of function due to a loss of power or a sudden water inflow.
- **Stations (passenger tunnels only).** Sabotage of MEC systems may adversely impact a passenger station due to power loss, which cripples lighting, ventilation, and safety systems. Disrupted sewer, steam, and water lines allowing material to enter the station could create an unsanitary condition, thereby precipitating injury and evacuation.
- **Substation.** Facilities containing connections for pumps and feeder machinery may suffer a loss of function due to a loss of power.
- **Control Centers.** Monitoring capabilities of a control center are diminished or negated by a loss of power. Staffed control centers are also subject to evacuation because of unsafe or unsanitary conditions that may be found with a disrupted water, steam, or sewer pipe.
- **Distribution channels.** Piping, wiring, conduit, and shafts to control fire control, ventilation, smoke detection, carbon sensor, and video monitoring equipment may suffer a function loss due to a power loss or intentional damage.
- **Utility terminus building.** This facility may be the direct target of an aggressor determined to damage or interrupt MEC systems within a tunnel system. Loss of the utility terminus building would require intensive repair efforts.

2.4 Conclusions

To varying degrees, the hazards and threats presented in this chapter have occurred in the United States. They will likely present themselves again. Their capacity to close a tunnel system, however briefly, is proven. Although their detrimental effects on the tunnel system, equipment, and users may be mitigated, the more consequential security threats may have unprecedented consequences in terms of major tunnel damage and indeterminate service impacts.