Tunnel Operations, Maintenance, Inspection, and Evaluation Manual:
Operations

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This course was adapted from the Federal Highway Administration (FHWA) agency of the Department of Transportation, document "Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual – Chapter 2: Operations", which is in the public domain.

TOMIE MANUAL

CHAPTER 2

OPERATIONS

Chapter 2 – Tunnel Operations

2 Introduction

The operating requirements vary among tunnel facilities because of the traffic level, the feasibility of alternative routes, accessibility to existing utilities, availability of emergency responders, and other conditions specific to each tunnel. Functional systems within the tunnel must be integrated with operational procedures to include the mechanical equipment, electrical components, lighting fixtures, fire and life safety systems, signs and security equipment installed within the tunnel.

2.1 Scope of Chapter 2

Included in Chapter 2 are the essential roles and responsibilities of the tunnel staff, normal operating procedures, and emergency response guidelines for vehicle collisions, fires, explosions, floods and earthquakes.

2.2 Tunnel Facility Personnel

Highway tunnel agencies need to employ the appropriate personnel to operate the tunnel safely and provide reliable levels of service. Since tunnel operations differ among various facilities, the duties and responsibilities need to be organized to match requirements for each tunnel facility. An example of a tunnel organization with brief position duties is included below:

- **Tunnel manager** – This person manages the tunnel facility and is responsible for establishing an effective operating program that includes complying with applicable laws, regulations, and policies; managing budgets, payments, funding, and financing; maintaining tunnel facility records; approving contracts and major purchases; and hiring, organizing, and training personnel.

- **Facility engineer** – This individual leads the technical program for the tunnel facility and is responsible for establishing effective tunnel maintenance programs and leading capital improvement projects. This person performs basic engineering duties such as evaluating structural defects, safety concerns, and maintenance records; developing quality programs, performing life cycle analyses, prioritizing major repairs, recommending upgrades and replacements; specifying the performance requirements for tunnel systems; and negotiating contracts with contractors, consultants, and vendors.

- **Tunnel supervisor** – This individual is in-charge of the overall day-to-day operation and maintenance activities This person generates work assignments, issues work orders, schedules repairs and maintenance, orders spare parts and equipment, manages traffic and lane closures, responds to incidents, conducts quality reviews, approves the work of contractors and consultants, and communicates problems to the tunnel manager and facility engineer.

- **Tunnel operators** – These individuals manage tunnel operations by monitoring traffic, congestion, accidents, over-height vehicles, variable message displays and output from control signals. They monitor air contamination and ventilation, fan performance, electrical supply and power consumption, lighting intensity, weather conditions, water accumulation and pump operation. They are responsible for activating emergency systems and coordinating emergency response for serious incidents.

- **Tunnel forepersons –** Forepersons lead a small team of discipline-specific specialists and/or general laborers. The foreperson is the senior technical specialist for the group and serves as a resource to the tunnel facility in a specialized area of practice. This person is qualified through a combination of formalized education, on-the-job training, and relevant experience. The foreperson is responsible for such tasks as coordinating the duties of subordinate staff in their group, enforcing quality programs, checking the work performed, closing-out work orders, inventorying spare parts, and generating supply reorder lists.

- **Tunnel mechanical specialists –** The mechanical specialist performs tasks that are related to mechanical technology. Typically, this person has completed a certified program of formalized education and on-the-job training in mechanical technology. The specialist performs routine maintenance such as oil changes, filter changes, cleaning of blades, replacing belts, etc. This specialist works with different types of mechanical equipment to include ventilation fans, pumps, ducting, and air conditioning units. The mechanical specialist should also be able to diagnose routine mechanical problems and fully implement the designated quality measures during mechanical repairs.

- **Tunnel electrical specialists –** The electrical specialist performs tasks that are related to electrical technology. Typically, this person has completed a certified program of formalized education and on-the-job training in electrical technology. The specialist works on electrical control, power distribution, and electronic drive systems and performs functions such as changing batteries, operating motors, running generators, replacing or repairing lighting fixtures and ballasts, and checking various fire detection and suppression equipment, carbon monoxide detectors, and CCTV cameras. The electrical specialist should also be able to diagnose routine electrical problems and fully implement the designated quality measures during electrical repairs.

- **Tunnel electronics specialists** - The electronics specialist performs tasks that are related to electronics technology. Typically, this person has completed a certified program of formalized education and on-the-job training in electronics. The specialist works with low voltage power and communication equipment and support equipment and systems such as power switchgears and panel boards with amp meters, power meters and frequency meters, environmental control systems, programmable logic controllers (PLCs) and monitoring systems, fire alarm systems, HVAC control systems, lane control signals, variable message boards, and CCTV systems. The electronics specialist should also be able to diagnose routine problems and fully implement the designated quality measures during repairs.

- **Tunnel laborers –** Laborers serve as versatile workers that perform many tasks such as cleaning drains, washing structures, cutting grass, painting, unloading supplies, stocking parts, general housekeeping, and installing light bulbs. Laborers also support discipline-specific specialists (i.e., mechanical, electrical, electronic) by moving heavy objects, cleaning equipment, tightening bolts, etc. Laborers facilitate tunnel operations by directing traffic, placing barricades, clearing debris, shoveling snow, removing disabled vehicles, etc.

- **Safety officers –** The safety officers coordinate the emergency response with local fire departments, medical transport units, and police. These officers may have experience as emergency dispatchers, firefighters, or paramedics. Safety officers participate in disaster recovery planning and the development of response strategies for various tunnel specific hazards. Safety officers generally have some level of firefighting and rescue equipment on site that is appropriate for the tunnel facility. The safety officers conduct drills and training for emergency preparedness. These officers also serve as liaisons between the tunnel facility and emergency response to include firefighters, ambulance services, and medevac units.

- **Security officers –** The security officers respond to emergency situations, support emergency operations, patrol the facility, implement weather advisories, escort hazardous vehicles, inspect cargo, etc. Security officers participate in the development of response strategies for various tunnel specific threat scenarios. These officers may have experience in police or tactical units. They should receive specialized training in tunnel security. Security officers set up patrol vehicles and towing equipment on site and serve as liaisons between various police units and the tunnel facility.

2.3 Normal Tunnel Operations

Normal tunnel operations consist of routine tasks that ensure the safe and efficient flow of traffic through the tunnel facility. These tasks typically include:

- Monitoring traffic flows 24/7 using surveillance equipment and incident detection systems.
- Studying weather conditions and forecasts.
- Clearing roadway hazards (e.g., debris, ice, snow, and incidents)
- Inspecting critical areas to confirm that safe conditions exist (e.g., overhead equipment, roadway surfaces).
- Checking functional systems (e.g., ventilation, air quality monitors, pumping, lighting, CCTV).
- Servicing equipment and periodic exercising of all movable components (e.g., fans, pumps, emergency generators).
- Cleaning of tunnel facility, portal buildings, ancillary structures, and grounds.
- Maintaining vehicles and equipment.
- Completing daily logs and checklists.
- Processing work orders (e.g., initiating, scheduling, completing, closing).
- Checking information (e.g., lane signals, signs, and variable message boards).
- Evaluating sensors and meters (e.g., carbon monoxide, oxygen, explosive gases, and luminance).

2.3.1 Maintaining Traffic Flows

Traffic flows through the tunnel in a defined direction of travel. Unidirectional traffic refers to one-way traffic within a tunnel bore. Bidirectional refers to two-way traffic within a tunnel bore. Contra-flow refers to the temporary condition of changing from unidirectional traffic within a bore to bidirectional flow or the reversing of travel within the bore.

2.3.2 Tunnel Traffic Closures

Tunnels must sometimes be closed to traffic to conduct maintenance, repairs, rehabilitation projects, and inspections. Depending on the circumstances, a tunnel may be partially closed to traffic by shutting down a lane, or it may be fully closed by shutting down the entire bore. Typically, tunnel closures are made during off peak hours when practical for routine maintenance or inspections.

When closures for major repairs or rehabilitation are scheduled, public notification should be provided well in advance. The public may be informed a number of way such as using media announcements, web announcements, and variable message signs on roadways. Communication with police, emergency personnel, and utility companies is essential so all parties involved are prepared for incident management.

Traffic control devices are used in accordance with the latest version of *The Manual on Uniform Traffic Control Devices* published by the Federal Highway Administration.

http://mutcd.fhwa.dot.gov

2.3.2.1 Temporary Lane Closures

Lane closure procedures are influenced by the type of traffic flow in the tunnel and the number of traffic lanes. Lane closures involve:

- Regulated flow is a term used when alternating traffic flows must be managed by the tunnel operator. If this is a temporary condition of short duration, then traffic control can be managed by tunnel facility personnel or police officers. If it is a long-term closing, traffic lights are a good option.
- Restricted flow is a term used when a lane is shut down in a uni-directional tunnel with two or more traffic lanes.

2.3.2.2 Temporary Bore Closures

Full bore closures involve rerouting traffic to another bore or establishing a detour with an alternate route. If work is of a short duration, the operating personnel may simply stop traffic while the work is being completed such as when tunnel washing can be accomplished in a short period of time during off-peak hours.

Rerouting Traffic to Another Bore – When there are two or more adjacent bores, traffic can be rerouted through the other open bores, which might create bi-directional traffic. An assessment of the traffic control devices and emergency egress signs will be necessary.

Detours – When a suitable alternate route is available, the traffic can be detoured. The rerouting of traffic requires an assessment of the impacts to the neighborhoods and communities along the detour. Neighborhoods often bear significant social, economic, and environmental costs associated with traffic due to gridlock, noise, lights, fumes, repair work, and congestion; and the rerouting of hazardous materials through vulnerable communities are a concern.

2.4 Emergency Response and Incident Management

Incidents requiring immediate action can occur in tunnels. Emergency originate from fires, fuel spills, hazardous material releases, earthquakes, floods, rock slides, landslides, severe weather, and criminal acts. A thorough inspection of the tunnel damage should be conducted in accordance with the damage inspection procedures identified in Chapter 4 of the TOMIE Manual. These events often require partial or complete tunnel closure followed by the rerouting of traffic while the tunnel is repaired.

Procedures need to be established so that emergencies can be dealt with in a timely manner. Certain incidents may require immediate contact with emergency responders (e.g., fire, police, and utility companies). Other events may not be as severe and can be handled by tunnel facility personnel. Drills should be conducted periodically for conditions such as electrical blackouts, vehicle accidents, over height vehicle strikes, hazardous cargo releases, emergency evacuation, and other threat scenarios deemed appropriate for the tunnel facility.

2.4.1 Impacts and Collisions

Impact damage frequently occurs in tunnels from over-height vehicles near the portals. After an impact incident, traffic should be stopped at the tunnel entrance until the situation can be sufficiently assessed. If there are any injuries, emergency personnel should be immediately notified. Once the conditions are rendered safe by removing abandoned vehicles, removing damaged vehicles, clearing debris, repairing pavement, and inspecting for damage to the tunnel, the tunnel can be restored to service (See Figure 2.1).

Figure 2.1 – Collisions within tunnels.

2.4.2 Fires

Fire incidents often require emergency ventilation measures to exhaust the smoke, control superheated gasses, and provide tenable escape routes (See Figure 2.2). There are a number of ventilation concerns during a fire such as back-layering of smoke, fueling oxygen to the fire, exhausting superheated gasses, pressurizing escape routes to repel smoke and superheated gasses. In order to minimize potential ventilation errors during a fire event, written guidelines should be established for the operation of the mechanical ventilation system for various scenarios.

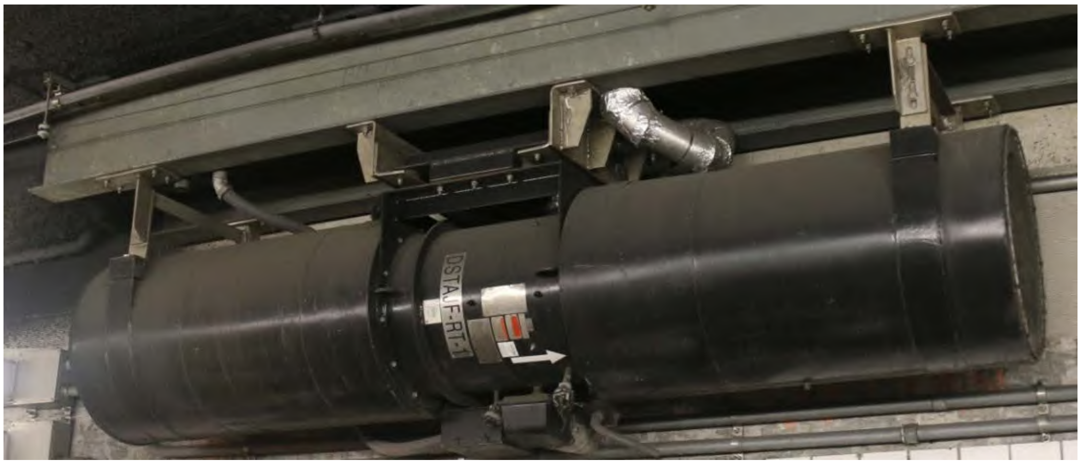

Figure 2.2 – Emergency ventilation fan.

Tunnel fires can be very difficult to extinguish; and these fires can produce large amounts of toxic smoke and dangerous heat that can fill the tunnel (See Figure 2.3). The tunnel operator has a responsibility to protect the tunnel occupants. Rapid detection is essential in this safety chain, and surveillance equipment, fire and smoke detectors, and Supervisory Control and Data Acquisition SCADA systems play a major role in the rapid detection of fires (See Figure 2.4). Modern tunnel facilities are protected by fire extinguishers, sprinkler systems, and deluge systems (See Figure 2.5).

Figure 2.3 – Tunnel fires can be extremely dangerous.

Figure 2.4 – Incident detection systems facilitate a rapid response to the emergency.

Figure 2.5 – Fire protection equipment and accessible escape routes.

Fire support personnel and other first responders should be notified immediately; however, emergency responders may not always arrive at the scene in time to assist with the evacuation. In the period before the emergency responders arrive on the scene, self-rescue should be encouraged. The vehicles in front of the accident site should be directed to exit out of the tunnel in the direction of travel. The tunnel occupants trapped behind the fire and debris generally must evacuate on foot.

Intuitive wall signage, audible messages, and lights that direct escapees to designated cross passages, portals, escape routes, and areas of refuge help increase survivability. Signs that display the direction and distance to the nearest emergency exit have been shown to be most effective. Information is available from the Permanent International Association or Road Congress (PIARC) and American Association of State Highway and Transportation Officials (AASHTO), which are conducting studies on the influence of user behavior on sign effectiveness under simulated emergency conditions.

Tunnel personnel should respond in accordance with established protocols, training, and drills. Traffic should be stopped in all adjacent bores since the crossovers might be used for evacuation and emergency response purposes. Fuels and other combustibles can drastically increase the severity of a fire. Spilled fuel may also flow to collection points in the drainage system or be transported to other parts of the tunnel. Some drainage systems may discharge to locations outside of the tunnel. Monitors should be evaluated to gauge the explosive gas levels after a crash at various collection points in the drainage system.

2.4.3 Floods

Flooding occurs due to water entering at the portals from heavy rainfall, overflowing rivers, rising water levels and increased wave heights, dam or levee breaches, and water main ruptures. To prevent flooding from water and sewer supply lines, the utilities near the tunnel should be inspected periodically. Most tunnels have pump systems that help prevent flooding, but flooding may still occur when the water rapidly enters the tunnel. Some tunnels also have flood gates installed at their portals to seal out flood water from extreme weather events (See Figure 2.6). If flooding is anticipated, the tunnel should be closed ahead of time to prevent endangering any motorists using the tunnel.

Figure 2.6 – Tunnel flood gates (left) and photograph of a flooding event taking place (right).

Tunnel facility personnel should be prepared to respond quickly to a potential flood event, which will help to minimize the damage to the tunnel equipment and systems. After a flood event, the embankments and slopes around the tunnel should be checked because they may become unstable due saturation with water. The functional systems must be checked to ensure that they are working as intended. Electrical systems can be ruined by floodwaters, especially if they are exposed to saltwater in the process. The potential for electric shock also needs to be evaluated prior to reentering the tunnel.

2.4.4 Earthquakes

Seismic events occur without warning; and vehicles may be present in the tunnel when the earthquake strikes. Depending upon the magnitude of the seismic event and the design of the tunnel to withstand certain seismic forces, motorist may be at risk and the tunnel might be severely damaged (See Figure.2.7). This damage could range from movements at joints and cracks to detachment of materials to severe damage to equipment and supports. Large quantities of water may also penetrate through tunnel cracks and joints that widen during the shaking of the ground.

Figure 2.7 – Earthquake damage to tunnels.

Depending upon the event, the tunnel may need to be closed until earthquake aftershocks have diminished. It is also advised to be aware of tsunamis in low lying areas after a seismic event. As with other emergency events, service should be restored safely and as quickly as possible, following a thorough safety inspection.

2.4.5 **Security Events**

Tunnels are complex infrastructure with unique challenges from a security perspective (See Figure 2.8). Tunnels contain a number of vulnerabilities unique to the particular tunnel as well as those common to most tunnels. Security risks to highway tunnels range from threats of terrorism to minor criminal vandalism. Tunnels also house utilities and communication lines. With some exceptions, mitigating highway tunnel security risk involves many of the same measures described for fire, flood, and impact from other incidents. Explosions generate many of the same deleterious effects as fire and impact; however, the shockwave caused by an explosion can potentially do much more extensive damage to the tunnel structure. Explosions can be accidental or they can be deliberate acts. Accidents can be caused by increased use of alternative fuels in private and commercial vehicles, spilled fuel accumulated in drainage sumps, and explosive gasses leached from certain rock formations with inadequate ventilation.

Figure 2.8 – Police escort through tunnel to mitigate safety concerns.

Quantitative methods can be used to evaluate security risk to tunnels that include threats, vulnerabilities, and consequences. One method developed for the Transportation Security Administration by the US Army Corps of Engineers (**See Appendix A**) evaluates risk in two distinct areas: Operational Risk and Casualty Risk. This is a component-level methodology that evaluates mitigated and unmitigated threats. The tunnel owner can evaluate the effectiveness of strategies to minimize damage, limit loss of life and function, and allocate resources. The Operational risk analysis allows an owner to select an "Operational Loss of Service" damage level and then evaluate the current and mitigated threat sizes relative to the specified damage level. The Casualties Risk Analysis uses a scenario-based procedure to select a threat size and location. From this information, the current and mitigated casualties are evaluated. This risk process is used for new and existing designs to develop mitigation strategies and to effectively reduce costs. By using the quantitative risk assessment, the multi-hazard concept of operations can be developed.

Threats considered in this model include explosives (e.g., vehicle borne and hand-emplaced), fire, cutting devices, impact, and chemical spills. Each threat should be evaluated based on location and its impact on vulnerable components. By understanding the vulnerabilities and using risk based assessment, tunnel security can be enhanced. The process for tunnel vulnerability assessment should be a methodical and a logical basis for action that incorporates expert analysis, organized risk calculation processes, evaluation of baseline tunnel vulnerabilities and risk using qualitative and quantitative analysis, and re-evaluation of risk to determine mitigation effectiveness.

The National Cooperative Research Program and the National Cooperative Highway Research Program (2006) jointly produced a report on making transportation tunnels safe and secure to include discussions on possible hazards and threats, case studies, tunnel elements and vulnerabilities, countermeasures, and system integration. It also provides recommendations for future research.

2.5 Preparation of Plans and Procedures

The operation of each highway tunnel is a function of the age of the facility, the ventilation, electrical, and lighting equipment; location and geometry of the tunnel; availability of emergency support; and the sophistication of equipment, tunnel systems and operation center. Each tunnel facility should develop site-specific operation protocols and staffing requirements for both normal and emergency operating conditions.

2.5.1 Emergency Response Plan (Site Specific)

Emergency response plans and mitigation strategies should be developed based on the "buy-in" of multiple stakeholders including the tunnel management and operation team, firefighters, police, other emergency responders, security professionals, and owners of co-located assets. Each tunnel should have an emergency response plan tailored to meet the demands of the appropriate threat scenarios. The following are examples of actions in a site-specific emergency response plan:

- Assess the location and severity of the emergency.
- Close the tunnel roadway to nonessential vehicles; Note that emergency vehicles may still need access into the tunnel.
- Close adjacent tunnel since evacuees might need to escape through crossover passageways and use the adjacent tunnel. Evaluate whether emergency vehicles need to use the adjacent tunnel to carry out the emergency response.
- Adjust ventilation output as necessary for fire and smoke control.
- Notify first responders: Fire, police, emergency medical personnel, management, and others.
- Prior to first responders arriving at the site, the motorist should be encouraged to perform self-rescue as conditions permit.
- Initialize warnings on variable message boards and other communication devices.
- Assist in safely clearing vehicles from the tunnel.
- Perform an inspection after the event is resolved and the conditions are safe to do so.
- Clear the tunnel of debris.

2.5.2 Training and Drills

An effective emergency response ensures that all responsible personnel receive training and participate in drills with firefighters and other first responders. The frequency and nature of the training and drills should be described in each tunnel's concept of operations. Since all tunnels have features that require unique protocols, the concept of operations should be tailored for each tunnel. Among the items to be considered are: ventilation control for various scenarios, traffic management (e.g., how to close the tunnel quickly), impact on adjacent bores, communication among first responders and between the tunnel operation center, communication with tunnel users, and how to safely and quickly evacuate users who are at risk. Training should be provided for new tunnel personnel and periodically thereafter, i.e. refresher training for experienced workers.

2.5.3 Pedestrian Evacuation Route Signage

Some countries have enhanced the exit doors of tunnel by incorporating flashing LED lights and audible messages to help evacuees locate the exit or safe room when smoke engulfs the tunnel. A scan of European tunnels reported widespread use in Europe of clear and consistent signs for emergency escape. The findings and details are in an FHWA report from June 2006: *Underground Transportation Systems in Europe: Safety, Operations and Emergency Response*.

(http://international.fhwa.dot.gov/uts/)

A current study is underway at the National Cooperative Highway Research Program to evaluate signs, markings and auditory messages in order to develop guidelines for use in the United States. An example of the type of sign that is under consideration is shown in Figure 2.9.

Figure 2.9 – Proposed sign for emergency escape route**.**

2.6 Summary

It is paramount that the operation of a highway tunnel be based on the safety of the traveling public. The tunnel should also provide reliable levels of service. Since tunnels are resource intensive, they should be operated by competent staff with well-defined areas of responsibility. The operating procedures should be appropriate for all of the requirements of the tunnel facility. The emergency response for the tunnel facility should address various appropriate scenarios taking into full account the ramifications of possible tunnel closure. It is important that health and safety plans be developed for the tunnel.

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