CHAPTER 3

Case Studies

3.1 Introduction

This chapter consists of case studies of a variety of tunnel incidents that occurred between 1979 and 2004. Each case study includes a list of references.

After an incident similar to the incidents described herein, it is common practice for in-house or outside investigatory or oversight agencies to report on the incident. However, such reports are often unpublished and are rarely available to general readers. The information contained in these case studies came from published sources that were readily available in libraries or through the Internet, without any special access to the systems described. Although some published oversight reports were reviewed and included in the list of additional sources at the end of this report, most of the case study information presented herein came from newspaper accounts and after-incident analyses in magazines and academic journals. Because such sources can contain erroneous information, a piece of information was typically discounted if it differed radically from that found in the majority of other accounts. However, there may be facts or interpretations of facts that cannot be gleaned solely from published sources.

The case studies were selected for their applicability to the overall project. They represent sketches of a wide variety of types of emergencies. The incidents include willful acts of arson and bombings in transit systems, road and rail accidents in tunnels, fires in tunnels and transit stations, and an urban tunnel flood. Summaries, pre-incident and incident analyses, fatalities and injuries, fire and emergency response (including, in some instances, police response), damage and service restoration, and findings of the agencies involved in the incidents and various oversight groups are presented. Each case study ends with a list of references pertaining to it.

The chapter concludes with Table 4, which briefly summarizes each incident; a discussion of issues raised by the incidents; and Table 5, which shows the role of MEC systems in the case studies.

3.2 Case Study Descriptions

3.2.1 Moscow Subway Suicide Bombing

Location:	Moscow, Russia
Date:	February 6, 2004
Incident Category:	terrorist bombing
Tunnel Length:	N/A; subway train
Fatalities and Injuries:	39 fatalities, 100+ injured

Synopsis

A bomb, later linked to Chechen separatists, exploded inside a crowded Moscow subway train during the morning rush hour. The bomb destroyed the second car of the train as it left the Avtozavodskaya station in southeast Moscow while traveling toward the center of the city. The incident was one of three subway-related bombings attributed to Chechens.

Analysis of Pre-Incident Information and Events

The Moscow subway system, which carries an average of 8.6 million riders a day, is considered the world's busiest subway system. The February 6, 2004, blast was neither the first nor the last subway-related bombing, although it was the deadliest up to that time. A bombing in a subway car in June 1996 killed four people; a bomb blast on August 8, 2000, ripped through a Moscow underpass leading from an underground railway station at central Pushkin Square, killing 13 people and injuring at least 90; another bomb had injured about a dozen people in February 2001. The incidents were blamed on Chechen rebels, although the Pushkin Square bombing, according to police, may actually have been a turf battle between either rival businesspeople or criminal gangs. Regardless of motives, the bombings led to increased surveillance of riders, particularly those who appeared to be Chechens from the North Caucasus area, but the level of crowding in the system makes programmed or thorough surveillance impossible. In addition to police routinely stopping those who appear suspicious, there are security cameras throughout the system.

Analysis of the Incident

A bomb exploded at 8:45 a.m. in a crowded rush-hour Moscow subway train on the Zamoskvoretskaya Line (the Green Line), killing at least 30 people and wounding more than 130 passengers. The bomb, which was hidden in a backpack, exploded in the second car of the train as it left the Avtozavodskaya station traveling toward the center of the city. The train had moved 984 feet (300 meters) out of the station when the explosion occurred near the first door of the second car. The explosion shattered the train's windows, welded metal seats to the train, and hurled bodies and body parts out of the train. The third car was also damaged, and the blast shattered windows in other cars. The train traveled several hundred feet before coming to a stop.

Train operators initially had problems opening the car doors. Reports as to how the doors were opened differed; some survivors said that the operator was able to open the doors, but some survivors maintained that the passengers pried the doors open. Once the doors were opened, some survivors walked approximately 2 kilometers (1.2 miles) through the subway tunnel to the Paveletskaya station. Their walk took them under the Moscow River and closer to the Kremlin. At the Paveletskaya station, they were met by ambulances and firefighters.

Fatalities and Injuries

The fatalities and injuries all occurred on the train. Thirty-nine people were killed immediately in the blast. Of the approximately 135 passengers injured, the vast majority (estimates ranged from 113 to 122) required hospitalization.

Fire and Emergency Response

Firefighters, police, and emergency medical personnel responded to the incident in one of Moscow's deepest underground stations. Bodies and body parts were scattered along the tracks, and many bodies remained in the train, covered in blood and soot. More than 700 people were evacuated from the two stations, many transported from the scene by buses that were rerouted to assist in the evacuation to prevent further clogging of area streets. Police officers barricaded the streets nearest the two stations and stopped all train traffic on the subway line. Because of the reliance on public transportation by commuters, street-level traffic congestion was considerable.

Wounded passengers were brought up on stretchers on long escalators to the more than 50 ambulances that gathered outside the Avtozavodskaya station. Other ambulances gathered at the Paveletskaya station entrance, from which many of the survivors who were able to walk were evacuated. Some survivors were aided by police officers who were riding in the train two or three cars behind where the bomb went off.

Damage and Service Restoration

Both subway stations were reopened soon after the bombing. The Avtozavodskaya station was almost immediately turned into an impromptu memorial, with people laying flowers on the station platform.

Fear of additional explosions brought intensified security at subway and rail stations, airports, and other public places. One other subway station (Tekstilshchili), not far from the Avtozavodskaya explosion, was evacuated for part of a non-rush-hour Saturday afternoon and evening after an anonymous threat was called in by telephone.

Conclusions

The explosion was attributed to Chechen separatists who may have been attempting to influence the presidential election that took place on March 14, in which President Putin was reelected. The incident was the 13th terrorist attack of the year in Russia. The terrorist attacks were mostly suicide bombings and resulted in more than 260 people being killed. More than 60 of the deaths were in Moscow. Two previous bombings were in either a tunnel or subway station, including the August 8, 2000, bombing in a pedestrian tunnel near Pushkin Square, in which 13 people were killed and at least 90 injured, and the February 5, 2001, bombing of the Belorusskaya subway station, in which there were no fatalities but nine people were injured.

The incident resulted, as had the others, in enhanced security at public transportation facilities in Moscow and other major Russian cities. However, government officials reported there was little they could do to prevent bombings as long as the perpetrators were prepared to die along with those killed in the attacks. The problem in preventing such bombings was compounded by the conflicting reports as to whether the bomb was planted or carried. The conflicts stemmed from some investigators having viewed a videotape of what they believed were the suspected bomber and her alleged accomplice standing on the platform of the station before boarding the train. Others believed the explosion was caused by an unattended bag left in the car.

The difficulty of preventing a suicide attack in a subway station was reinforced a few months later. On August 31, a female suicide bomber set off a bomb outside a Moscow subway station, killing at least 10 people and injuring more than 50 others. The bomb exploded at about 8:15 p.m. near the Rizhskaya station in northeast Moscow, located near one of the city's major thoroughfares. Although it was after rush hour, the subway and surrounding area were busy because it was the last day of summer vacation and many people were returning home. Many subway passengers were also returning to their homes from the center of Moscow, thereby contributing to crowds at the station and in the area.

The explosion did not affect the subway directly, but two parked cars in the area were set on fire and passersby were injured by the metal fragments, the smoke, and shattered glass from shop windows. The explosive used in the bombing was Hexogen, which was the same explosive that had been used on August 24, 2004, to explode Russian civilian aircraft on domestic flights that originated in Moscow.

It was not determined whether the bomber had intended to detonate herself inside the subway, but there were reports that she had been walking toward the station and turned around when she saw two police officers near the entrance checking documents and searching bags. Instead, she set herself aflame in an area between the subway station and the Krestovsky department store and supermarket complex nearby. Lending credence to the view that the subway station had been her target, the 29-year-old Chechen woman who set the explosion was the sister of the woman suspected of detonating the blast on one of the two planes that were blown up on August 24, 2004.

The large number of bombings resulted in problems for Moscow's hospitals, which have become trauma centers on a continuing basis.

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3.2.2 Jungangno (Chungang-Ro) Subway Station Arson Fire

Location:	Daegu, Korea
Date:	February 18, 2003
Incident Category:	arson fire
Tunnel Length:	N/A; subway system station
Fatalities and Injuries:	198 fatalities, 147 injuries, 50+ missing

Note: Jungangno and Daegu are the preferred English spellings of the station and city name as translated by the City of Daegu and the Daegu Metropolitan Subway System.

Synopsis

At about 10 a.m. on February 18, 2003, a mentally unstable subway passenger trying to commit suicide threw flammable liquid inside a car of a Daegu, Korea, subway train that was carrying 600 people. Although passengers tried to stop the arsonist from lighting the liquid with a cigarette lighter, ignition occurred as the train pulled into the underground Jungangno station, four levels beneath Daegu's central city. The arsonist escaped through the closing doors just as the train burst into flames. The fire was fueled by flammable seats and other interior car furnishings. The system's control center allowed another six-car train traveling in the opposite direction to enter the tunnel moments after the first train burst into flames. The doors of the second train locked shut when its driver stopped the train in the tunnel and removed the master controller key, trapping passengers inside as the train cars filled with smoke and noxious fumes from the burning train.

Analysis of Pre-Incident Information and Events

Daegu is Korea's third largest city and has 2.5 million residents. It is a textile center in the south of the Korean Peninsula, about 200 miles (322 kilometers) southeast of Seoul. Construction of the 16-mile (25.7-kilometer), 30-station

Line 1 of the Metropolitan Subway began in 1992 and was inaugurated in two stages in 1997 and 1998. It was extended toward the southwest in 2002. The Jincheon-to-Jungangno segment opened to passengers November 26, 1997. The Jungangno-to-Ansim segment opened on May 2, 1998, and the 2,300-foot (700-meter) Jincheon-to-Daegok segment opened on May 10, 2002. Hanjin Heavy Industry manufactured the subway cars.

While the Daegu Metropolitan Subway prided itself on its incorporation of the latest in safety technology when it began construction, the Jungangno fire was one of five major incidents associated with the line since construction commenced in 1992. In January 1994, supporting equipment at a subway construction site collapsed, leaving one man injured. A gas explosion near another subway construction site injured 143 and killed 101 bystanders (including eight schoolboys) in April 1995; it was deemed the worst subway accident in the nation's history. Because of that accident, the Daegu government suspended construction of the system's Line 2 for several weeks. Another explosion in August 1995 resulted in four casualties. In January 2000, a subway section under construction collapsed, killing three people and closing part of the city's main road. In January 2002, a bus passing an intersection near a subway construction site killed and/or injured four people. The station where the arson occurred had passed a safety check approximately 5 months prior to the incident.

Analysis of the Incident

The incident began at 9:55 a.m. on February 18, 2003, on the fourth car of the six-car Train 1079 at the underground Jungangno station, four levels beneath the city. A 56-year-old man with a history of depression, Kim Dae Han, removed a plastic milk carton containing a flammable substance, most likely gasoline, from a black bag and attempted to light it with a cigarette lighter. As subway passengers tried to stop Han from flicking the lighter, some of the liquid spilled onto the floor of the car. Just as the car doors were closing for departure, the lighter ignited and the car caught fire. Han escaped through the closing doors and was seized by passengers, but the fire spread rapidly and black smoke rose. An ensuing power failure locked the doors, leaving passengers trapped in the burning car as well as in the five other cars in the subway consist.

The first reports of the fire were apparently generated within seconds of the doors closing on the burning car via cell phone calls from distraught passengers calling loved ones; however, official communication channels were not opened until at least 10 minutes had lapsed. Because of this communication gap, a six-car train (1080) traveling in the opposite direction entered the tunnel moments after the first train burst into flames. The driver of the second train had questioned train control as to whether he should enter the station, saying, "It's a mess. It's stifling. Take some measures please. Should I evacuate the passengers? What should I do?" The control center only advised the driver to drive carefully as he entered Jungangno station, since there was a fire. The driver approached the station, stopped the train in the tunnel, exited the cab, and removed the master controller key. This locked the doors shut, trapping passengers inside the train as its cars filled with smoke and noxious fumes.

The fast-moving fire was fueled by the train's seats and other interior products that were not fireproofed. This was, in part, because national safety standards for train interiors were not introduced until 1998, 1 year after revenue service began in Daegu. Prior to this date, Hanjin Heavy Industry used fire-retardant materials only in cars made for export.

Fatalities and Injuries

In August 2003, Daegu officials confirmed that 198 people had died in the fire, at least 147 were injured, and approximately 50 people were unaccounted for.

Fire and Emergency Response

In an eerie echo of the September 11, 2001, terrorist attacks in the United States, families reported receiving cell phone calls from loved ones trapped in the incident before officials were aware of it. This had also occurred during the Tauern Tunnel fire in Austria in 1999, when a truck loaded with paint collided with an oncoming car and many of those who were trapped used cell phones to contact those outside. In Daegu, emergency communications within the subway system did not register for more than 10 minutes after the incident began. This not only delayed emergency response but also led to the second train being permitted to proceed directly into the fire.

In addition to the communication failures, the subway's electrical systems also failed. This led to an absence of emergency lighting, the shut-down of the ventilation systems, and the inadequacy of any existing emergency evacuation procedures. Access to the station was also hampered because it is four levels below grade, with three levels of stairs between the platform and the surface.

All subway traffic was halted and officials also cut all power, fearing that the overhead cables would collapse and electrocute people. Because of the absence of emergency lighting and ventilation, firefighters from the more than 60 fire vehicles that responded to the scene were met with thick smoke and dense toxic fumes that prevented them from reaching the injured passengers. The station's sprinkler system was triggered, but it was not designed to suppress fire on the line itself. Therefore, it released water onto the platform and station passages, further inhibiting attempts to evacuate the station.

By the time firefighters discovered the remains of 70 people in one car, most had been reduced to ash and bones. Another 50 were discovered on the stairs of the station, apparently having choked to death as they attempted to flee the station. More than five hours after the fire started, firefighters with breathing apparatus were still hunting for survivors at the underground station.

Damage and Service Restoration

The fire was fueled by the train's vinyl interior, seat cushions, and flammable floor tiles and windows. Both of the six-car trains were demolished by the flames.

Subway Line 1 resumed normal business on February 26, 2003, except for the six stations around Jungangno.

Conclusions

Two days after the arson attack, South Korean President-elect Roh Moo Hyun declared the Daegu subway area a "Special Disaster Zone" so that it would be eligible to receive special administrative and financial aid for rescue work and restoration and for victims' compensation. Roh also ordered safety checks of the entire Daegu Metropolitan Subway System and said he would push ahead with the plan to establish a disaster control body to better cope with incidents like the arson attack. Investigators focused their probe into possible mistakes made by subway officials dealing with the emergency, concentrating on why the doors of the carriages of the two trains failed to open after the fire started.

Shortly after Roh's speech, subway officials promised to install emergency lighting, increase the number of exit signs, make car interiors flame resistant, and heighten security.

Kim Dae Han was apprehended 2 hours after the incident at a local hospital. He was transferred to Kyungpook National University Hospital to receive treatment for burns incurred during the incident. Police determined that Han showed signs of mental illness, for which he was treated between 1999 and 2002. He was a taxi driver who had become paralyzed on the right side of his body after what he considered faulty medical care. On the day of the incident, Han was determined to commit suicide in a crowded place. The Daegu District Court convicted him of arson and homicide on August 7, 2003, and sentenced him to life in prison. Although prosecutors had asked for the death penalty, the court showed leniency, saying that Han was repentant and mentally unstable when he committed the crime.

On February 24, 2003, police arrested 7 subway officials and announced that they were seeking 3 more warrants in connection with the arson. Among the 10 warrants, 9 were for subway officials and 1 was for the alleged arsonist. Among those who would be arrested that day and on March 4, 2003, for suspicion of professional negligence resulting in death and injuries was the driver of the original burning train and the driver of the second train who was suspected of pulling the master controller key out of the doors, trapping passengers inside the train as its cars filled with smoke and toxic fumes from the fire blazing in the other train. The charges were announced within weeks of a 63-year-old woman becoming the 198th fatality of the blaze when she died in an area hospital.

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3.2.3 St. Gotthard Tunnel Fire

Location:	Goeschenen and Airolo, Switzerland
Date:	October 24, 2001
Incident Category:	crash and fire (road tunnel)
Tunnel Length:	10.6-mile (17-kilometer) single-bore tunnel
Fatalities and Injuries:	11 fatalities, injuries not tallied

Synopsis

A head-on collision of two trucks—one carrying tires—about 1 mile (1.6 kilometers) from the tunnel's southern entrance sparked an explosion and subsequent fire. Additionally, part of the tunnel's intermediate ceiling collapsed over a distance of about 328 feet (100 meters). These two separate events combined to make the tunnel unapproachable because of temperatures as high as 1,832°F (1,000°C) and falling roof debris. Up to 40 cars and trucks were fused into a molten mass at the heart of the disaster zone. The incident resulted in 11 fatalities. Rescue efforts were hampered by the extreme heat and the risk that additional sections of the tunnel roof might collapse.

Analysis of Pre-Incident Information and Events

The St. Gotthard Tunnel is a 10.6-mile (17-kilometer) long, single-bore, two-lane tunnel linking the Swiss towns of Goeschenen in the north with Airolo in the south, approximately 10 miles (16 kilometers) from the Italian border. It holds two lanes of traffic in its 25-foot (7.8-meter) width, and when it opened to traffic in 1980, it was hailed as the safest of all the Alpine tunnels. Its safety features included a system of survival spaces at 820-foot (250-meter) intervals built to accommodate up to 70 people in an emergency; a safety corridor that parallels the tunnel length, allowing rescuers to quickly reach the scene of an accident (but too narrow for a rescue vehicle); and a state-of-the-art ventilation system that allowed a total air exchange every 15 minutes.

While approximately five fires per year had been reported in the tunnel, it was considered a safe route for motorists, especially after the March 1999 Mont Blanc tunnel fire. Traffic in the St. Gotthard tunnel had increased substantially after the March 1999 fire in the Mont Blanc tunnel that links France and Italy. At the time of the St. Gotthard incident, the traffic in the St. Gotthard tunnel averaged 16,497 vehicles daily.

In the wake of the Mont Blanc fire, prior to the St. Gotthard incident, safety campaigners had been saying that it was only a matter of time before such a disaster struck Switzerland. Safety advocates had demanded either a significant reduction in freight traffic or the construction of a second tube to the tunnel that would allow separation of the northbound and southbound traffic flows.

Analysis of the Incident

At approximately 9:45 a.m. on Wednesday, October 24, 2001, a southbound truck and a northbound truck that was carrying tires struck each other in a head-on collision at a spot located approximately 4,900 feet (1.5 kilometers) from the tunnel's southern end. Sparks from the collision ignited and spilled fuel from the trucks. Flames rapidly spread to the tires, resulting in thick black smoke that contributed to a zero-visibility level in the tunnel. The heat at the incident site rapidly climbed to 1,832°F (1,000°C), and it was later reported that explosions were heard as part of the ceiling collapsed from the intense heat.

Fatalities and Injuries

Both truck drivers involved in the initial accident were killed. There was speculation that one had been intoxicated and had questionable driving experience, but only one of the two bodies was in a condition sufficient to permit blood testing. Nine other people were killed, many seated in one of the 23 passenger vehicles involved in the accident. Some were burned to death as they called for help from their vehicles and others had most likely reached safety but returned to their vehicles to retrieve items left behind. Virtually all fatalities occurred within the "red zone," the 164-foot (50-meter) area nearest the seat of the fire. Vehicles were completely melted, and some were welded together.

Fire and Emergency Response

More than 300 people, including police, firefighters, and rescue workers, used five helicopters and 60 emergency vehicles in the rescue efforts, which were severely hampered by the extreme heat and the risk that additional sections of the tunnel roof might collapse. The fire smoldered for 24 hours and was finally put out more than 48 hours after it began.

Damage and Service Restoration

After the accident, police quickly closed the 10.6-mile (17-kilometer) tunnel. When Swiss President Moritz Leuenberger visited the site 24 hours after the incident, he described it as a scene of total destruction and expressed amazement that so many people had survived.

A team of 10 specialists spent the Monday following the incident combing through charred vehicles and rubble in search of victims in the "red zone." When the heat and smoke dissipated, crews began building metal supports to shore up the tunnel's weakened ceiling and walls. Police continued to check the tunnel to ensure there was no risk of the fire reigniting. Air quality checks were also conducted, and the experts were not allowed in until tests for poisons had been completed.

Later analysis found that safety systems worked well during the incident, with alerts sounding in four languages within minutes. Truck drivers, familiar with the tunnel, were reported to have directed other users to safety. In addition, approximately 656 feet (200 meters) of the tunnel were only superficially damaged and the primary concrete lining appeared unscathed. Regardless, the tunnel was closed for 2 months as engineers looked at every aspect of the infrastructure.

With the tunnel closed, Alpine communities that depended on traversing the Gotthard tunnel feared they would be cut off during the coming winter. To alleviate some of the tunnel traffic crisis, the Swiss federal railways increased the number of trains carrying trucks through the Alps by 20 to 30 percent. The number of trains carrying cars through the Lötschberg tunnel between the Swiss cantons of Bern and Valais were also increased.

The St. Gotthard tunnel reopened two months after the incident occurred, with a number of new safety rules in place, such as restricting the distances between trucks to 492 feet (150 meters) and abiding by an alternate one-way traffic system introduced to bring the St. Gotthard tunnel in line with other major tunnels in Switzerland. Two-way truck traffic was eventually reestablished, but a maximum of 60 to 150 trucks per hour are permitted through the tunnel at one time depending on the amount of traffic.

Swiss customs officials also began to hand out safety brochures to truck drivers, and the federal government worked with Swiss cantons to make tunnel safety part of truck drivers' training.

Conclusions

The St. Gotthard tunnel fire was the third major fire in 3 years in trans-Alpine, European tunnels. Although the safety level in the tunnel was considered quite high at the time of the incident, in its aftermath new safety rules were developed to reduce the number of trucks in the tunnel and their direction of travel from two-way to one-way, although two-way traffic has since been restored. By increasing the distances between vehicles and by ensuring that all vehicles traveled in the same direction, it was felt that the chances of head-on and rear-end collisions would be reduced, and therefore the chance of catastrophic fire in the tunnel would also be reduced.

The tunnel's ventilation system was also renovated to provide individually closeable and openable shutters.

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3.2.4 Howard Street CSX Tunnel Fire

Location:	Baltimore, Maryland
Date:	July 18, 2001
Incident Category:	derailment and fire

Tunnel Length:	single-track rail tunnel, 1.7 miles (2.7 kilometers) in length; approximately 4.8-percent upgrade
Fatalities and Injuries:	0 fatalities, 4 injuries

Synopsis

A 60-car freight train, of which eight cars in the rear half of the consist were carrying dangerous or hazardous materials, caught fire, probably because of a derailment in the Howard Street tunnel, located within the city of Baltimore. The train was stopped in the tunnel, and staff disconnected the three locomotives and escaped. There were no fatalities and only minor injuries, but the fire resulted in large quantities of smoke escaping the tunnel. The fire brought the city to a halt and resulted in a series of lawsuits by Baltimore against CSX.

Analysis of Pre-Incident Information and Events

The Howard Street tunnel opened in May 1895, when the Baltimore & Ohio (B&O) Railroad used it to carry freight through the city of Baltimore. The cost of the tunnel, known as the Baltimore Belt Line, drove the B&O into receivership in 1896, but the tunnel has been used ever since then as a major north/south freight route. Originally 1.4 miles (2.3 kilometers), an extension of 0.3 mile (536 meters) was added to the tunnel in the 1980s to accommodate parking for the Baltimore Orioles baseball stadium and a light rail station built at Camden Yards.

The tunnel, constructed mostly of concrete and refractory brick, is a single-track freight rail that travels for 1.7 miles (2.7 kilometers) through downtown Baltimore. It has vertical walls and measures 22 feet (6.7 meters) wide by 27 feet (8.2 meters) high, although the dimensions vary slightly along the tunnel's length. The tunnel's depth below grade varies from 3 feet (0.9 meters) to 60 feet (18 meters), and it has a 4.8-percent grade to account for the height difference of approximately 330 feet (100 meters) from the entrance to the exit at Mount Royal Station. At the time of the derailment, the train was moving in the direction of the upward grade.

Since the opening of Oriole Park Stadium and light rail at Camden Yards, the area has become a focal point for cultural and tourist activities. From July 13 to15, Artfest 2001 had drawn more than 250,000 people to the area. The area's popularity and its centrality to the vitality of Baltimore's business community played a large role in the traffic delays and loss of revenue that the derailment and fire caused in the city of Baltimore.

Analysis of the Incident

Shortly after 3:00 p.m. on Wednesday, July 18, 2001, CSX freight train L421216 derailed in the Howard Street Tunnel in Baltimore. The 60-car train was pulled by three locomotives and was traveling at 17 mph (27 kilometers per hour), below the speed limit of 25 mph (40 kilometers per hour). The train was halted by the emergency brake, indicating an air brake loss of pressure, which is designed to prevent the engineer from restarting the train until the air sensor on the last car detects sufficient pressure. The air hose, which runs the length of the train, was either severed or disconnected and caused the train to stop about half a mile (800 meters) from the northern end of the tunnel.

The train's crew, consisting of an engineer and a conductor, attempted to contact a CSX dispatcher, but their radio would not transmit inside the tunnel. One member of the crew used his cell phone to contact the CSX dispatch center in Jacksonville, Florida. The crew members then dismounted the locomotive and, as policy required, attempted to walk the length of the train to locate the problem. They were unable to do this because of the heavy black smoke that limited their visibility and made breathing difficult. The crew followed training and emergency procedures, shutting down the two lead locomotives and uncoupling the third from the train so they could exit the tunnel. Sensors indicated that they left the tunnel at 3:27 p.m. and called CSX to describe the emergency and report what they had done.

The train, traveling from Hamlet, North Carolina, to Oak Island, New Jersey, had 31 loaded and 29 empty cars. Eleven of the cars were derailed, including a tank car carrying about 28,600 gallons (108,000 liters) of liquid tripropylene, a lubricant similar to paint thinner. Fire officials believed that the derailment caused this car to rupture and fuel the fire. The train was also transporting tank cars that contained hydrochloric acid (a metal cleaner), glacial acetic acid (a flammable glass solvent), fluorosilicic or hydrofluoric acid (a noncombustible but corrosive acid used to fluoridate water), and ethyl hexyl phthalate (a combustible used to make a variety of flexible products, including piping). None of these chemicals were believed to have caught fire. The extreme smoke conditions were also attributed by Baltimore's fire department to wood products that the train had been carrying. This assessment was reinforced by air quality tests, which revealed mostly steam and hydrocarbons, common in wood fires.

Fatalities and Injuries

There were no fatalities; two firefighters were hospitalized after complaining of chest pains, and two workers were treated and released from the hospital for heat-related injuries on the day of the fire. Four emergency workers, two of whom were CSX employees, were rescued by fire personnel when one of them complained that his oxygen supply was running out.

Fire and Emergency Response

The response of Baltimore's fire department was delayed by the inability of the CSX crew to contact the dispatcher. The crew made contact with the dispatcher at 4:04 p.m., about an hour after the train had stopped in the tunnel and the crew had discovered smoke. The fire department arrived on the scene at 4:18 p.m. not in response to a report from CSX, but after receiving calls from the public reporting black smoke coming from either end of the tunnel and up through sewer covers.

One hundred and fifty firefighters worked to extinguish the fire, which by 5:15 p.m. had been raised to five alarms. Those who responded first tried to fight the fire by entering the tunnel from either end on vehicles with special rail wheels, but the intense heat and lack of visibility made this impossible. Instead, they lowered large-diameter hoses from the street above into the tunnel and were able to reach the burning cars after 10:00 p.m. To combat the smoke and heat, they used oxygen masks and air tanks and entered the tunnel on a sports utility vehicle outfitted with train wheels.

Firefighting efforts were complicated by the rupture of a 40-inch (100-centimeter) water main running directly above the tunnel; this rupture was reported at 6:25 p.m. The rupture resulted in the collapse of a number of city streets. It also flooded nearby buildings, halted electricity to about 1,200 customers of Baltimore Gas and Electric, and interrupted a major Internet cable line and an MCI WorldCom fiber optic telephone cable.

At about 5:45 p.m., the city had activated civil defense sirens to warn citizens of danger from the fire and the hazardous materials. A number of key local streets were shut down, including Howard Street between Pratt and Mount Royal streets, and parts of Lombard Street, a major downtown thoroughfare that collapsed following the water main rupture. All major highway entrances into Baltimore were closed by city officials, and baseball games at nearby Camden Yards were postponed because of the smoke emanating from both ends of the tunnel and through the sewer covers, which caused a black cloud over parts of the city.

The Baltimore City Police Department, assisted by the Baltimore Department of Public Works, controlled traffic on surface streets and closed highways I-395 and I-83 and US-40 into the city to preclude greater traffic congestion. As was mandated, notification of the presence of hazardous materials on the train was given to the Maryland Department of the Environment's Emergency Response Division. Within 2 hours of the start of the fire, the U.S. Coast Guard closed the Inner Harbor, which is a few blocks from the derailment location, to boat traffic. The Maryland Department of the Environment set up booms to minimize any possible contamination from the chemicals escaping from the rail cars involved in the fire.

The city's fire department was assisted by the Anne Arundel County Fire Department, which sent a dozen firefighters, two engines, and a truck to cover south Baltimore stations in the event of secondary emergencies.

In addition to CSX, the Maryland Transportation Authority (MTA)—which includes local bus, commuter bus, MARC, Metro subway, and light rail—became involved in emergency response. MARC personnel initiated bus service in the area when trains were unable to pass through. The MTA's Central Light Rail Line, which runs above the Howard Street tunnel, was disrupted, as was MTA bus service, which also runs along Howard Street. Also affected was the Metro, the MTA-managed subway system, which passes below Howard Street and the Howard Street tunnel.

On the third day, CSX contractors began pumping acid from two of the cars and replacing the 800 feet (243 meters) of track at the south end of the tunnel that had been damaged while removing the railcars. The fire burned for an additional 2 days; it was not fully out until 5 days after the derailment.

Damage and Service Restoration

It took 5 days for the fire to be totally controlled and for all rail cars to be removed from the Howard Street tunnel. Recovery efforts continued for 55 days. The final work was the completion of road repairs on September 10, 2001.

Because of the central location of the fire and the concern that hazardous materials might explode, rail and other transportation modes in Baltimore and beyond were disrupted. Within Baltimore, street closures in the Howard Street area cut traffic to the central business district and to the Inner Harbor tourist area. Passenger cars, commercial traffic, and buses were also affected. Howard Street was reopened to traffic on July 23 except in the area of the water main break, which was not completely repaired until July 29.

The MTA Metro's State Center Station (which was the closest station to the fire) was closed because of the smoke, although trains maintained their schedules without other service disruptions. The station reopened on July 20. The MTA light rail service was disrupted because of the water main break; bus service was initiated within an hour of the discovery of the water main break to move passengers around the disrupted stations. All bus routes that crossed Howard Street were turned back or diverted. While some of the diversions and delays were of short duration, others persisted for lengthy periods. For instance, full service on the MTA's light rail line was not restored and substitute bus service was not discontinued until September 8, which was 56 days after the derailment and fire.

The closing of the Howard Street tunnel affected freight moving between Chicago and the east coast, some of which was rerouted via Selkirk, New York, and South Kearny, New Jersey. CSX also used tracks owned by Norfolk Southern to minimize delays.

Much of Baltimore's business area was affected by the incident. In October 2001, CSX paid the city $1.3 million to cover some of the costs, primarily the overtime for police, firefighters, and public works department employees. The payment did not include the costs of cleaning up the chemical spill, investigating the incident, replacing the ruptured water main, or repairs to damaged roads. CSX's insurance adjuster accepted claims from 25 merchants on Howard Street for damages and lost business and paid $20,000 to a business improvement district operating in the area. CSX also paid $15,000 to volunteer groups that served meals to rescue crews responding to the incident.

The Baltimore Orioles baseball organization was also affected. A double-header was being played at Camden Yards Stadium at the time of the incident. The second game was cancelled, and all Orioles personnel and fans were evacuated. The next day's game was cancelled because of the smoke and traffic disruptions in the area. The team postponed four games scheduled in the following 3 days; no scheduled game was played until July 21. An Orioles' official estimated that the postponed games resulted in a financial loss to the team of $3 million.

An unusual side effect of the incident caused problems for the state of Michigan's campground and harbor reservation system when a Department of Natural Resources cable and telephone system located in Cumberland, Maryland, discovered that callers to 800-44-PARKS were either getting a busy signal or were forced to endure far longer waits for an operator than usual.

Conclusions

This incident presented three interrelated problems to all the emergency responders, but particularly to the Baltimore City Fire Department, which committed the largest number of people to the emergency response effort and had direct responsibility for fighting the fire that the derailment caused. The fire department worked closely with the department of public works to contain the water main break that occurred directly above the fire. In addition to having to fight a fire in a tunnel that was too dark and smoky for them to enter, the firefighters were faced with the presence of hazardous materials and with the weakened structural integrity of the water main and surrounding areas. The tunnel remained intact throughout the incident and was reopened to rail freight traffic once debris was cleared away.

Based on a model created after the fire, it was estimated that peak temperatures in the tunnel had reached approximately 1,832°F (1,000°C) in the flaming regions and approximately 932°F (500°C) when averaged over a length of the tunnel equal to three or four rail car lengths. Because of the insulation provided by the brick walls of the tunnel, the calculated temperatures within a few car lengths of the fire were relatively uniform, similar to an oven or a furnace. The peak wall surface temperature reached about 1,472°F (800°C) where the flames were directly impinging and averaged 752°F (400°C) over the length of three to four rail cars. Firefighters attempting to enter the tunnel lost all vision within 300 feet (91 meters) of the entrance; the use of self-contained breathing apparatus (SCBA) became essential when gas masks and air-purifying respirators (APRs) were found to be useless.

Despite the emergence of a number of issues—including tunnel access, the presence of hazardous materials, freight and other transportation delays, and the need for environmental monitoring—most analyses of the emergency response were positive. The potential for disaster was great; the fire department was not advised of the fire for an hour after it occurred, and the water main break could not have been anticipated, but once agencies were notified, they worked well together. The delayed notification by CSX to the fire department doubtlessly added to the financial cost of the incident, but the fire department was aided by CSX employees at the scene, who had a complete waybill that identified the location and contents of all cars and that was immediately shared with the fire incident commander on the scene.

The city agencies were able to work together and rely on mutual aid pacts that had been developed earlier. CSX also worked closely with the city agencies, contracting for a private firm to conduct air and water monitoring and providing all other information as needed. Response by fire department personnel was aided by a drill that had recently been conducted in one of the city's Amtrak tunnels using a MARC train and by previous drills in a Metro tunnel. Although these training exercises were intended to practice response in the event of a passenger train accident, they acquainted fire personnel with the environment of a railroad tunnel, which helped them in their response to a somewhat similar freight incident.

The major criticism of the handling of the incident pertained to information access, attributed to the failure to designate a public information officer during the initial stages and to the problematic internal and external communications by CSX.

On January 5, 2005, the National Transportation Safety Board's (NTSB's) recommendations R-04-13 and -14 indicated that CSX maintain historical records documenting inspection and maintenance activities affecting the tunnel and that the corporation take whatever steps necessary to exchange information with the city of Baltimore on maintenance and construction activities within and in the vicinity of the tunnel. Recommendations R-04-15 and -16, issued the same day to the city of Baltimore, reiterated the need for better cooperation and information exchange between CSX and the city and called on the city to update its emergency preparedness documents to include information on hazardous materials discharge response procedures specific to tunnel environments and to include infrastructure information on the Howard Street tunnel.

On January 13, 2005, the NTSB reported that it was unable to determine the cause of the incident. The report concluded, however, that according to a finite element analysis, the 40-inch (100-centimeter) water main above the tunnel broke after the train had derailed, as a result of the thermal expansion of the tunnel caused by the postaccident fire within the tunnel. Although the report was approved unanimously by the five members of the board, two board members were critical of the length of time the investigation took and the lack of attention to the security implications of shipping hazardous materials.

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3.2.5 Kitzsteinhorn Tunnel Cable Car Fire

Location:	Kaprun, Austria
Date:	November 11, 2000
Incident Category:	fire
Tunnel Length:	2.2 miles (3.5 kilometers); 45-degree inclination; single-bore tunnel designed for cable conveyance; very small cross-sectional area (108 square feet [10 square meters])
Fatalities and Injuries:	155 fatalities (152 of the total 167 passengers), injuries not tallied

Synopsis

The cable car’s rear driver’s cab caught fire at the bottom of the tunnel immediately after departure, causing a fire that engulfed a cable train packed with skiers in a tunnel on the 2.4-mile (3.9-kilometer) mountain. The fire caused the cable car to halt 1,970 feet (0.6 kilometers) inside the tunnel. Lights went out, and initially the doors would not open. Some doors were eventually opened, but the narrow 11.8-foot (3.6-meter) width left little space for evacuation. The steep (45-degree) incline turned the tunnel into a chimney, blocking the escape route.

Analysis of Pre-Incident Information and Events

The Kitzsteinhorn glacier, which rises to 2.4 miles (3.9 kilometers) in the Austrian Alps, is a popular international ski resort accessed via the city of Kaprun, 50 miles (80 kilometers) southwest of Salzburg, Austria. It is a 3-hour drive from Munich, Germany. Access to Kitzsteinhorn’s ski trails is mostly via a circa 1976 funicular (i.e., cable) railway that originates at the Kaprun Valley station, climbs the slope, and enters a tunnel pass before emerging at the Kitzsteinhorn ski slopes. Access to the 2,900-inhabitant town of Kaprun is via one main road. The cable railway was modernized in 1994, adding two state-of-the-art cars and ancillary technology. At the time of the fire, the cable railway could transport about 1,500 people per hour up to the Alpine center on the glacier.

Several other incidents occurred in Alpine tunnels or to Alpine trains prior to the Kitzsteinhorn fire. These included the 1999 Mont Blanc Road Tunnel fire that killed 41 people; a 1999 fire in the Tauern motorway tunnel that killed 12 people and injured 50 people; and a 2000 accident in Germany in which two trains collided near the Zugspitze, injuring more than 60 people. After the Mont Blanc incident, inspectors visited 25 of the continent's biggest road tunnels and found that nearly a third had poor safety features.

The day of the accident—Saturday, November 11, 2000—was the first official day of the ski season. The funicular had undergone safety checks by an outsourced inspection agency 2 months prior to opening day. The last inspection by the government's Ministry of Transport had been in 1997.

Analysis of the Incident

On November 11, 2000, the Kitzsteinhorn funicular departed its base station in Kaprun with 167 passengers (near its 180-person capacity) and ski and snowboard gear en route to the Kitzsteinhorn glacier ski slopes. Before the cable car entered the 2.2-mile (3.5-kilometer)-long and 11.8-foot (3.6-meter)-wide tunnel, which had an average incline of 45 degrees, passengers and the driver noticed smoke emanating from the driver's cab. Although the driver reported the blaze to his base station, the train continued into the tunnel, stopping 1,970 feet (600 meters) from the entrance.

The fire continued and the steep tunnel acted like a giant chimney, sucking air in from the bottom and sending toxic smoke billowing upwards. Despite an alarm signal and contact with the base station instructing the driver to open the doors, the train stayed at the location with its doors sealed. Later investigation revealed that this was the immediate cause of death of most of the passengers.

A few passengers were able to knock out the windows to flee, but they were trapped between the fire below them and the smoke-filled tunnel ahead of them, with no clearly marked emergency exits. Of those who apparent climbed out of smashed windows and ran downhill, away from the smoke, only 12 survived. Others who fled uphill were overcome by smoke and fumes, most likely because of the small (approximately 108-square-foot, or 10-square-meter) cross-sectional area.

Fatalities and Injuries

One hundred and fifty-five fatalities were reported, 152 of whom were passengers on the funicular and 2 of whom were passengers overcome by smoke inhalation while waiting in an area outside the tunnel, and one who was a cable car attendant traveling in an empty car in the opposite direction. Those who tried to escape upwards were caught by smoke and warm gases and died inside the tunnel. The 12 people who survived escaped the train at an early stage through a broken window and fled downward in the tunnel. Recovery efforts were slowed by falling rock and toxic fumes.

Fire and Emergency Response

A massive rescue operation was mounted with approximately 13 helicopters and more than 200 emergency workers, including teams of police, doctors, and Red Cross workers. Rescue helicopters carrying firefighters with special equipment were also flown in from Bavaria. The Red Cross assembled a team of 40 psychologists to help relatives cope with their grief.

It took at least 3 hours to extinguish the fire, but fumes and smoke continued to emanate through the night. Rocks also fell from the tunnel walls, hampering rescue efforts throughout the incident.

Damage and Service Restoration

The cable cars and ski lifts at Kitzsteinhorn resumed operation on December 7, 2000, but the funicular Gletscherbahn Kaprun 2 remained out of order. During the month-long closure, an estimated $140 million in tourist revenue and local income was lost, since 80 percent of the area's jobs depend on tourism. Upon reopening the alternative means to the ski slope, revenues ran 40 percent less than prior to the funicular closing because 40 percent fewer skiers could be transported via alternative means.

The ÖBB, the Austrian Railways, received a court order on December 29, 2000, to save the wreck of the destroyed cabin. The process cost about 7 million Austrian Schillings (ATS) and was completed in early March 2001. The wreck was shipped to a laboratory, and all aspects of the analysis were filmed for the investigation.

Sixteen people—including cable car company officials, technicians, and government inspectors—were arrested and charged with criminal negligence. On February 19, 2004, the Austrian court acquitted all 16, but prosecutors immediately appealed the verdicts. Lawyers for the families said they would continue civil proceedings in the United States and Germany, seeking millions of dollars in compensation. These cases are still pending.

Conclusions

The official results of the investigations on the accident became known on September 6, 2001, when experts announced their belief that the fire was started by an electric heating ventilator illegally installed in the driver's cabin. On the day of the accident, the ventilator overheated, most likely at the lower station. A leaky tube of hydraulic oil came into contact with the glowing heater, nearby wooden panels, and isolation materials. These things became soaked with oil and caught fire, either in the departure station or on the way up the mountain.

Austrian investigators found that the ski train suffered technical problems before it entered the tunnel. They based their analysis on plastic-like debris found on the rails near the tunnel mouth that indicated that a fire could have broken out before the train went into the tunnel.

Investigators also pointed out that a larger cross-sectional area might have given the passengers more time for evacuation.

Officials in ski resorts throughout Austria shut down five similar train systems for safety checks following claims that the Kitzsteinhorn train was not properly fitted with safety devices, such as a sprinkler system, and did not have enough emergency exits or fire extinguishers. An allegation was made that an evacuation drill had never been carried out. In direct response to the incident, the French government announced that it would institute immediate safety checks on all its funicular railroads.

The incident had parallels with the 1987 King's Cross Tube Station fire in London, where the escalator shaft at the center of the fire had a 30-degree incline that, like the Kitzsteinhorn tunnel fire, created a chimney effect. The Kitzsteinhorn blaze moved faster than the King's Cross fire because of an even steeper incline.

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3.2.6 Mont Blanc Tunnel Fire

Location:	Chamonix, France/Courmayeur, Italy
Date:	March 24, 1999
Incident Category:	fire
Tunnel Length:	7.3 miles (11.6 kilometers); single-bore, reinforced concrete; two traffic lanes; 28-foot (8.6-meter) width
Fatalities and Injuries:	39 fatalities, injuries not tallied

Synopsis

A truck carrying margarine and flour entered the 7.3-mile (11.6-kilometer)-long Mont Blanc Tunnel from France, caught fire, and stopped in the tunnel, where it burst into flames. The fire, which was fueled in part by the margarine, reached temperatures of 1,832°F (1,000°C), trapping approximately 40 vehicles in dense and poisonous smoke.

Analysis of Pre-Incident Information and Events

The Mont Blanc Tunnel is a major Alpine automotive tunnel connecting the cities of Chamonix in Haute-Savoie, France, and Courmayeur in Valle d'Aosta, Italy. Situated under the highest mountain in Europe, the Mont Blanc massif, the tunnel was notable for its approach to ventilation and was the first large rock tunnel to be excavated full face, with the entire diameter of the tunnel bore drilled and blasted. It was operated by two separate agencies, the Autoroutes et Tunnels du Mont Blanc (ATMB) in France and the Società Italia per l`Esercizio del Traforo del Monte Bianco (SITMB) in Italy. Although ventilation and safety systems existed on both sides and were operated by French and Italian personnel, the systems differed in a number of ways and there was little consultation between the two agencies.

Begun in 1957 and completed in 1965, the tunnel is a major trans-Alpine transport route, particularly for Italy, which relies on the tunnel to ship as much as one-third of its freight bound for northern Europe. For the French, it is a passage for exports to Italy and a tourist route to the south. It was designed to carry 450,000 vehicles per year, but by 1997 it was being used by 1.1 million vehicles per year. In 1974, one person was injured in a truck fire that lasted about 15 minutes; in 1990, two people were injured when a fire occurred in a truck loaded with cotton.

Lay-bys are located every 300 meters, alternating on each side of the carriageway, and numbered 1 to 36 from France to Italy. In front of each one, a gallery makes it possible for heavy-goods vehicles to do U-turns. Shelters supplied with fresh air and protected from the tunnel by a wall with a 2-hour fire rating are located every 600 meters.

Analysis of the Incident

Wednesday, March 24, 1999, was a day with average traffic flow in and out of the tunnel. Between 9:00 and 10:00 a.m., about 165 vehicles drove from France to Italy. This traffic translated to roughly four vehicles per minute entering the tunnel and traveling at 50 mph (80 kilometers per hour), with an average of 980 feet (300 meters) between vehicles. Weather conditions were normal; rain clouds had cleared and the warm southern wind called die Föhn blew from the Italian side of the tunnel. A medium wind blew, as usual, inside the tunnel from south to north.

One of the trucks that entered the tunnel from the French side was a Volvo FH12 tractor-trailer driven by Gilbert Degraves, a 57-year-old Belgian trucker with 25 years of experience. He was hauling a refrigerated trailer loaded with nine tons of margarine and 12 tons of flour. Although nothing abnormal was visible to the driver, later investigations estimated that the fire started about 10:46 a.m. and was fueled by the 145 gallons (550 liters) of diesel in the truck's tank.

At 10:53 a.m., Degraves was alerted that something was wrong when he noticed that oncoming cars were flashing their headlights at him. Through his rearview mirror, he saw white smoke on the right side of his truck, and stopped at Mile 3.8 (Kilometer 6.2). After allowing a truck coming from the opposite direction to pass, he exited his vehicle. He stated later that he had tried to reach the fire extinguisher under the left seat to extinguish a fire between the cab and the trailer, but flames had burst out on both sides of the cab.

Other truckers noticed white smoke swirling toward the tunnel's ceiling at 10:56 a.m. At about the same time, automatic video cameras detected cars turning into Lay-By 22. People on foot were also visible there. Between the time the Belgian truck entered the tunnel and the time it was closed to traffic 9 minutes later, 1 motorcycle, 10 passenger vehicles, and 18 trucks had also entered the tunnel. Four trucks passed the burning truck after it had stopped, and 26 vehicles were trapped.

At 10:54 a.m., the Italian control room was informed by phone that smoke had been detected on the video monitors between Lay-Bys 16 and 21. The siren on the French side went off at the same time. A minute later all traffic lights in the direction from France to Italy turned red and a truck backed up to yield to emergency vehicles, although two other vehicles continued into the tunnel.

The obscuration detector in Lay-By 18 set off a visual and audio alarm at the French control station. The operator at the control station acknowledged the alarm. Observation of cameras in Lay-Bys 16, 17, 18, and 19 indicated that smoke had surrounded the truck.

Although the French fire detection system in the tunnel had heat sensors every 26 feet (8 meters) programmed to sound when temperatures rose over 122°F (50°C), it did not sound an alarm while the burning vehicle was moving. The first French alarm sounded at 11:13 a.m. from Lay-By 19. By then, temperatures were estimated to have been higher than 1,832°F (1,000°C). The Italian detection system relied on 230- to 260-foot (70- to 80-meter) sealed tubes containing a special gas. The system had been prone to false alarms, and, because the tubes at Lay-By 21 (where the truck stopped) had given false alarms the night before, they were off and could not signal any fire.

The smoke changed almost immediately from white to black, and the fire quickly entered the cab. The trailer, which was constructed of flammable isothermal foam, caught fire later. The cargo of margarine was transformed into a combustible liquid as it melted and ran out of the trailer and spread onto the road.

On the Italian side, the drivers of the eight trucks that had stopped before Lay-By 22 left their cabs when they observed black smoke. The tunnel is too narrow for trucks to make a U-turn, so the drivers fled on foot. All escaped, possibly because the airflow from Italy to France was blowing the smoke away from them. Drivers on the French side left their vehicles and ran back toward the French entrance. They died, probably of toxic smoke, between 660 and 790 feet (200 and 240 meters) from the fire. The majority of drivers on either side further away from the fire stayed in or near their vehicles; 27 were found dead in the wrecks, nine were found outside their vehicles. It took no more than 10 minutes for the tunnel to fill with combustion gases.

Fatalities and Injuries

Thirty-nine people died, including one firefighter. Post-incident analysis determined that most died within 15 minutes of fire detection. Of the 38 nonfirefighters who died, 27 stayed in their vehicles, 2 took refuge in another vehicle, and 9 died outside their vehicles. Of these 9, a motorcyclist and a car driver died in Shelter 20 near the fire zone.

Fire and Emergency Response

Emergency response was provided by tunnel employees and fire departments from France and Italy. A French employee coming from Italy drove past Lay-By 22 and crossed a thick wall of smoke that filled the whole cross section for a distance of 330 to 660 feet (100 to 200 meters). He reached within 33 feet (10 meters) of the burning truck as an Italian employee came from the opposite side. This Italian employee on the French side at 10:56 a.m. likely drove a motorcycle into the tunnel, where he encountered people fleeing on foot. He advised them to keep to the side with the fresh air outlets and he continued to drive wearing a breathing device. He got within 23 feet (7 meters) of the Belgian truck and saw a burning cab and lamps and cables tumbling down from the ceiling. He returned to the French side to report this, and then reentered the tunnel to help more people. He reportedly saved at least 10 people from death but was unable to save himself; he died at Shelter 20 along with a driver from a passenger car.

Fire department responses began 11 minutes after the fire, when, at 10:57 a.m., a pumper engine with four firefighters, extinguishers, and breathing devices; a rescue vehicle with additional equipment; and an ambulance entered the tunnel from France. When the French Central Alarm Center was alerted to the fire at 10:58 a.m., it forwarded the alarm to the Main Rescue Center in Chamonix at the same time that an alarm was pulled at Lay-By 21. At the time, the four French firefighters, who were 1,100 yards (1,000 meters) from the burning truck, reported zero visibility. They were ordered to take shelter in Shelter 17. Although the shelters can hold dozens of occupants, the bunkers were designed to resist heat and toxic fumes for only about 2 hours.

The Italian side initially dispatched eight motorcycle patrols and a multi-use fire vehicle with three extinguishers staffed by a driver. Italian firefighters were alerted to the fire at 11:02 a.m. and arrived at 11:10 a.m. The Italian fire detection system lost all transmission data in Lay-By 19, although Italian firefighters arrived at the portal on their side. At Lay-By 22, they were stopped by heavy smoke. Although they tried to continue on foot, the extreme heat and low visibility forced them to retreat.

Approximately 30 minutes later, a second engine arrived at the French portal, but was unable to rescue the first group of firefighters because of the smoke condition. The fire engines could not be removed from the tunnel until 3 days later; at that time, one engine was found totally burned and the other badly damaged. About 3 hours into fighting the fire, the French commander raised the alert to red (the highest level possible) to permit a higher level of firefighting machinery to be employed. Both nations' firefighting efforts were hampered when, by 11:01 a.m., the lighting equipment, the French sprinkler system, and the Italian exhaust dampers failed in the tunnel.

At just short of 8 hours into the incident, French firefighters rescued six people in Shelter 17. This was the final rescue that firefighters were able to mount.

Although the tunnel originally was constructed with a full transverse ventilation system, by the time of the fire the system was transformed into semi-transverse ventilation that was limited to exhausting air. The change had been made to accommodate the increased truck traffic in excess of what had been anticipated at the time of construction, since the traffic mix called for a greater amount of fresh air.

When the Italian operator saw people fleeing on foot, he judged that it was preferable to introduce oxygen to give those people a chance instead of switching the ventilation to maximum extraction. The added oxygen helped the flames spread rapidly and created a strong blow of toxic smoke towards the French side. The French extraction capacity was insufficient to get rid of this air, so it blew right through the tunnel. Since no one was injured on the Italian side, the decision may have saved some people, although it probably added to the deaths on the French side. Nature also played a role: As the incident unfolded, an air stream (Föhn) blew from the Italian to the French side.

Investigators later reported that the tunnel operators knew of deficiencies in the ventilation system but had done little to correct them. The problems were exacerbated by gases that were present in the tunnel, the foam insulation of the trailer that produced nitrogen oxides, and the burning margarine; all of these things were worsened by a lack of oxygen, which led to the production of more toxic gases.

Damage and Service Restoration

It took more than 50 hours for the fire to be completely extinguished; it required a spray mist to cool the interior sufficiently for entry to move the concrete, burned installations, and truck cargo that blocked access to the center of the tunnel. The shelters near the incident were also severely damaged. In addition, nearly 1,100 yards (1 kilometer) of the tunnel lost virtually all its ceramic tiles.

As a result of the fire, the tunnel was closed for 3 years while numerous safety features were installed.

There was local opposition to the tunnel's reopening based on claims of danger from truck exhaust fumes and concerns that truck traffic polluted the Alpine region. Protesters blocked the first heavy freight truck trying to use the tunnel and set fire to its contents when they found a television crew aboard the largely empty Belgian truck. After three cancelled openings, the tunnel reopened in stages: to cars in March 2002, to trucks with up to four axles and weighing less than

19 tons in May 2002, and to all trucks in July 2002 (despite a July 26, 2002, environmental protest against reopening the tunnel to heavy goods vehicles).

Conclusions

The inquiry into the 1999 Mont Blanc fire led to a radical reassessment of safety needs, a redesign/rebuilding of the tunnel, and a restructuring of the tunnel management. Investigators determined that communication between the French and Italian sides of the tunnel had been very limited and that almost no coordinated efforts had been made in any area. Neither the Italian fire service nor the French fire service had ever mounted a full exercise inside the tunnel. Two joint safety exercises had been held in 25 years, and neither had involved live practice inside the tunnel. No joint fire drills had been held in the 10 years prior to the incident. The investigation also determined that both nations' emergency plans—the French plan from 1994 and the Italian plan from 1995—were inadequate and lacked any redundant or failsafe systems.

A significant management change resulted from the fire. Now, one company that includes both French and Italian interests manages the entire tunnel, with one active control room and one incident commander. The general manager changes every 30 months and alternates between countries. Full-scale, videotaped safety training exercises are conducted every 3 months to improve organization and cooperation among the rescue services, including firefighters, paramedics, and police from both countries. A typical exercise includes 100 emergency response personnel, 40 vehicles, and 30 people with simulated injuries. Participants do not know the specifics of the simulated incident beforehand.

Numerous other safety measures emerged from the court inquiry that were intended to detect abnormal situations, provide protection and evacuation routes for tunnel users, provide access for rescuers, and assist in the self-protection of tunnel users and firefighters. To achieve these goals, the tunnel authorities made numerous improvements:

- Installing lay-bys and turning bays every 1,970 feet (600 meters) on both sides of the tunnel to allow heavy goods vehicles to stop and to allow maintenance and rescue vehicles to operate in the tunnel.
- Situating concrete-lined emergency shelters on one side of the tunnel at 980-foot (300-meter) intervals to protect occupants from the atmosphere of the tunnel. Each shelter is pressurized and fitted with a fireproof, airlock door. The shelters are also equipped with telephones, closed-circuit TV cameras, video links to one of three command posts, and public address systems.
- Adding 116 smoke extractors, one every 328 feet (100 meters), and creating 76 new fresh air vents.
- Adding fire-resistant sheeting to the tunnel's walls.
- Installing more traffic lights and flashing warning signs along the tunnel.
- Installing new heat sensors at both ends of the tunnel to detect overheated trucks before they enter the tunnel.
- Adding 120 video cameras to monitor traffic at all times.
- Locating firefighting facilities at each portal and one close to the tunnel's midpoint.
- Restricting truck travel to one direction through the tunnel. Trucks traveling in the opposite direction must use the Frejus Tunnel some 55 miles (90 kilometers) to the south.

On January 31, 2005, a criminal trial to establish responsibility for the fire began in France. Sixteen people and companies were named as defendants in the manslaughter case, including the Belgian driver of the truck that caught fire; Volvo, the truck's manufacturer; both the Italian and French companies that managed the tunnel; safety regulators; and the mayor of the town of Chamonix. The French court found 12 individuals and four companies guilty of manslaughter. The head of tunnel security received a 6-month jail term plus a 24-month suspended sentence; the president of the French operating company received a 2-year suspended jail term plus a fine; and the driver of the truck received a 4-month suspended jail term. Seven other people, including the tunnel's Italian security chief, were handed suspended terms and fines. Three companies were fined up to $180,000 each. The charges against Volvo were dropped.

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3.2.7 Channel Tunnel Fire

Location:	Folkestone, England/Sangatte, France
Date:	November 18, 1996
Incident Category:	fire
Tunnel Length:	32-mile (50-kilometer) twin-bore steel and concrete underwater tunnel with access to a service tunnel every 1,230 feet (375 meters)
Fatalities and Injuries:	0 fatalities, about 30 injuries

Synopsis

A freight truck on Train 7539 traveling from France to Great Britain caught fire in the Channel Tunnel. The train continued at normal speed (120 kilometers per hour) for about 10 minutes before it stopped next to an exit to the adjoining service tunnel, where it became impossible to disconnect the burning part of the train. The heavy fire damaged the power catenary quickly once the train stopped. The fire then spread rapidly to adjoining cars. The smoke moved quickly because of other trains moving in the tunnel; this smoke also hampered evacuation. Train staff and truck drivers evacuated through a door leading to the service tunnel, but overpressure from that tunnel door created a fresh air bubble when the door was opened. All crew and passengers were rescued via the adjoining service tunnel; structural damage was considerable.

Analysis of Pre-Incident Information and Events

The Channel Tunnel is a 32-mile (50-kilometer) rail tunnel hundreds of feet beneath the English Channel that connects the United Kingdom with France. It is the world's longest undersea tunnel. Despite the tunnel's length, it is possible to travel through the tunnel in about 20 minutes because trains may operate at speeds up to 100 mph (160 kilometers per hour). Construction began in 1988; by the time the tunnel was completed in 1994, it had cost more than $21 billion to complete, making the tunnel the most expensive construction project undertaken at that time. Also called EuroTunnel, Eurotunnel, or the Chunnel, it is actually three tunnels. Two of the tunnel tubes are full size and accommodate rail traffic. Between these tunnels is a smaller service tunnel that was planned as an emergency escape route. There are also crossover passages that allow trains to switch from one track to the other.

Each running bore has a walkway on the side nearest the service tunnel that was designed specifically for the evacuation of passengers and crew in an emergency. The running tunnels are connected by cross passages to the service tunnel at about 1,230-foot (375-meter) intervals. The passages have fire-resistant, air-lock doors on each side.

Although the Eurostar train, the passenger service through the tunnel, received most of the early publicity, the Channel Tunnel is primarily a conduit for freight. In the first 5 years of the Channel Tunnel's operation, trains using the tunnel carried 28 million passengers and 12 million tons of freight.

Trains carrying freight through the Channel Tunnel are different from U.S. trail vans, where freight vans are loaded onto flatbeds and carried solely by the train to an unloading yard. Although the Channel Tunnel provides a rail-only link, drivers of trucks load their vehicles onto specially designed carriers and then leave their trucks to ride in coaches that are usually located next to the locomotive and away from the trucks, which are generally at the end of the train. When the train arrives at its destination, the trucks are unloaded from the train and the drivers retrieve their trucks and proceed to their destinations.

This fire was not the first fire in the tunnel. About a year after it opened, the Channel Tunnel was the scene of a fire that broke out in a train going from France toward England, as was the case in the November 18, 1996 fire.

Analysis of the Incident

A truck carrying expandable polystyrene (EPS) caught fire on Train 7539 traveling through the Channel Tunnel from France to the United Kingdom on November 18, 1996. It was one of 29 trucks on the train, which was about 11 miles (18 kilometers) into the tunnel when the fire was discovered. EPS, which is saturated with the expanding agent pentane, is flammable and is shipped in the form of beads in large bags or drums that are frequently transported by truck. Although most hazardous substances are prohibited from transport through the tunnel, EPS was not among the banned substances.

The fire, which began near the end of the train, where the loaded trucks were located, filled the tunnel with smoke and reached temperatures of 1,832°F (1,000°C), which resulted in a number of the truck-bearing railcars being welded to the track.

The train driver was unable to follow Eurotunnel's primary safety option of proceeding through the tunnel in an emergency. The passenger carriage and front locomotive should have automatically uncoupled from the train, but a power failure prevented this automatic uncoupling from occurring. This failure forced the train crew to lead the passengers off through the central tunnel. The rescue effort was estimated to have taken about 20 minutes. From the center tunnel, the evacuees were put on a train that traveled through the second tunnel tube to safety.

The tunnel was busy at the time; in addition to the train that caught fire, other vehicles in the tunnel included two Eurostar passenger trains, two tourist shuttles, and two other freight shuttles (or lorry shuttles, as they are called in Great Britain). Once the fire was confirmed by the command center, one of the tourist shuttles in the non-incident tube was ordered to stop at one of the fire doors to evacuate 26 passengers and the engineer of Train 7539.

Fatalities and Injuries

The 29-car train was carrying 31 passengers and a crew of three; people who were injured suffered smoke inhalation, mostly while being evacuated through the service tunnel. Nineteen people were treated at hospitals, and two were seriously injured. Others received medical attention at the scene.

Fire and Emergency Response

It took firefighters from both countries almost 14 hours to contain the blaze, which damaged about 1,970 feet (600 meters) of the tunnel. In addition, the concrete lining was scorched, miles of power cable were destroyed, and a section of the track buckled. The fire also destroyed the rear locomotive and nine trucks.

Damage and Service Restoration

Partial restoration of service took place on November 21, three days after the fire occurred, but the United Kingdom–bound tube, where the fire occurred, was not reopened to passenger trains until about a month after the incident.

Conclusions

Although safety procedures called for a train to speed through the tunnel if fire broke out, the train stopped in this instance. Additionally, although procedures called for the emergency ventilation system to be switched on, the system was not activated. Despite the sophisticated ventilation system built into the Chunnel to pull smoke from the running tunnels and to provide air to the service tunnel, the system did not work as designed during the fire. Three problems were later determined to have prevented the system from activating; two were caused by equipment and one by human error. The first mechanical problem occurred when the heavy steel doors used to close off the tunnel crossovers remained in the open position during the incident. The second mechanical problem occurred when one piston relief damper did not close as it should have. These problems led to the large amount of smoke in the non-incident tunnel, and that amount of smoke was increased when the variable-pitch fans were left at zero pitch, making them useless for several minutes. Once this problem was corrected, the fans helped to remove smoke from the tunnel quickly.

There was extensive damage to the tunnel's concrete lining, about 1,970 feet (600 meters) of which was scorched by the fire and spalled under the intense heat. Similar damage did not occur in other tunnel fires, and this difference led to considerable study of the materials used and the heat-resistant qualities of tunnel liners.

Firefighters and some safety experts voiced concern about the design of the railcars that carry the trucks through the tunnel. The railcars are considered semi-open and are lighter than the closed railcars that carry passenger vehicles and small trucks. The semi-open railcars permit a free flow of air that may spread a fire. Since drivers do not remain with their trucks, it may be some time before a fire is observed and its exact location noted. Conversely, those who remain in passenger cars for the trip are considered to be in danger of car fires from electrical mishaps.

The absence of fatalities in the Channel Tunnel fire, when compared with fires at Mont Blanc (linking France and Italy), Tauern (linking Austria and Italy), and Kaprun (in Austria), have been attributed to the Channel Tunnel's being a three-tube tunnel while the others are single-bore tunnels. With multi-tube tunnels, the non-incident tubes can be used to shuttle equipment and staff to the accident site; this emergency response pattern does not exist in single-bore tunnels. But both the geography of a tunnel's location and the construction costs play a role in the decision of whether to construct a single- or multi-bore tunnel. At the time it was built, the Channel Tunnel was the most expensive construction project planned, and it eventually cost more than $21 billion to complete. The time from start to completion (1988 to

1994) and the costs may preclude similar construction of multi-bore tunnels in all but a few locations.

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3.2.8 Subway Sarin Gas Attack

Location:	Tokyo, Japan
Date:	March 20, 1995
Incident Category:	gas attack
Tunnel Length:	N/A; attacks were in the subway
Fatalities and Injuries:	12 fatalities, 5,000 to 6,000 exposed to chemical gas

Synopsis

The Aum Shinrikyo religious sect released five canisters of diluted sarin, an extremely toxic chemical, disguised in lunch boxes and soft drink containers on five separate trains during the Tokyo subway system's morning rush hour. Twelve people died, and between 5,000 and 6,000 people may have been exposed to the chemical.

Analysis of Pre-Incident Information and Events

Aum Shinrikyo was unknown to the public, especially outside Japan, until the March 20, 1995, attack. The leader of the group, Shoko Ashara, was a half-blind former acupuncturist who had turned to religion and mysticism. Born in 1955, he was known as Chizue Matsumoto before he changed his name. In 1984, he founded the Aum Shinsen Club and recruited 15 followers. Membership swelled into the tens of thousands in Japan, in the Soviet Union, and then in Russia and the newly independent republics that had been part of the Soviet Union. Around 1987, the group changed its name to Aum Shinrikyo, which means "supreme truth," and members began to view Ashara as their god. At its peak, the group was believed to have had close to 40,000 members in six countries.

Ashara developed the group's primary aim of overthrowing the Japanese government. The group experimented with a range of chemical agents, including variants of nerve agents, such as sarin, tabun, soman, and VX. The group also explored using hydrogen cyanide, phosgene, and mustard agents. The group was believed to have settled on sarin primarily because it is relatively easy to manufacture. Group members working in Kamikuishiki, Japan, made the gas used in the attacks.

Group members made several attempts to use chemical weapons before their attacks on the subway system, initially targeting rival religious and cult leaders. On July 27, 1994, Aum Shinrikyo released sarin gas using a truck-mounted dispersal system located outside an apartment complex at Matsumoto, a city about 93 miles (150 kilometers) northwest of Tokyo. The gas traveled through the open windows into the building, where occupants were sleeping. Seven people died, and 600 were sickened by the attack, which was intended to assassinate judges who were expected to decide a land dispute that would have been injurious to group members.

Despite a massive investigation, police were unable to trace the chemical agent to the group. Police later learned that the group had tested sarin on animals in Australia and had used the Matsumoto attack to further test weapons. The police were still investigating Aum Shinrikyo at the time of the subway attacks.

Analysis of the Incident

The attack occurred at the height of rush hour and used approximately 1.9 gallons (7 liters) of high-grade sarin. Occurring on a Monday morning on one of the world's busiest commuter transport systems, the attack was intended to affect hundreds of thousands of people and garner worldwide attention. Millions of people are transported on Tokyo's subway; during rush hours, the trains are often so crowded that it is virtually impossible for passengers to move.

Ten male group members, working in two-man teams, were able to release sarin on five different subway lines that merged at the Kasumigaseki station, which is the closest station to the Tokyo police headquarters. Five of the group members released the gas, while the other five served as getaway drivers. The sarin was packaged in plastic bags and was activated when each bag was punctured with an umbrella.

Sarin packets were dropped on the Chiyoda line by a group member wearing a surgical mask typically worn on cold days. He punctured his bag of sarin at a station in the central business district, killing two people and seriously injuring 231. The second sarin packet was released on the Marunouchi line. Despite passengers being removed from the train, the train continued to another station with the third car soaked with sarin. New passengers boarded the train and were affected until the train was taken out of service. One person died, and 358 were seriously injured. The third release, also on the Marunouchi line, was less successful, but when the train reached its destination at 8:30 a.m., searchers evacuated it but failed to find the sarin packets and allowed the train to remain in service. The train was not taken out of service until 9:27 a.m. In the fourth attack, a group member boarded the first car of the 7:59 a.m. train on the Hibiya line. Three stops after he punctured his packets, passengers began to panic. Although some passengers were removed and taken to the hospital, the train continued in service with the empty first car. One person died, and 532 were seriously injured.

In the last attack, also on the Hibiya line, the group member boarded the third car of the 7:43 a.m. train and released his three packets of sarin (all other attackers had only one packet each) two stops later. It is possible that passengers were affected immediately because he released more sarin than the others did. At the next station, a passenger kicked the sarin onto the platform, resulting in four deaths at the station. Sarin remained on the train, which continued on its route until a passenger pressed the emergency stop button at 8:10 a.m. Because the train was in a tunnel, it proceeded to the next stop. When the doors were opened, several people collapsed and the train was taken out of service. The train made five stops after the sarin was released, killing eight people and seriously injuring 275.

Although all the actions surrounding the attack took place on the subways, the group members had hoped that releasing the gas on these particular trains would cause deaths in police headquarters and other government buildings in the immediate area.

Fatalities and Injuries

Victims left the trains and staggered onto platforms, vomiting and foaming at the mouth. Hundreds were dazed and blinded by the gas. In addition to the fatalities on the specific train lines, people affected by the sarin had a variety of respiratory problems. They also suffered convulsions, paralysis, uncontrollable trembling, and high fevers.

Sarin is an extremely deadly gas. The small number of deaths (twelve) was attributed to the chemical being heavily diluted. Two people died immediately after admission to the hospital; the last death related to the incident occurred on June 12, 1996, when a 52-year-old victim died in a Tokyo hospital.

Long-term disabilities have continued to affect many of the injured, who report suffering disturbed sleep and nightmares, sensitivity to light and other vision problems, loss of memory, and post-traumatic stress disorder, for which many are expected to be treated for the rest of their lives. Others suffered permanent mental retardation and loss of motor control.

Fire and Emergency Response

Among the dozen victims of the attack, several were subway employees who tried to save others by removing the sarin bags and were poisoned during their efforts. One of the victims was an employee of the Teito Rapid Transit Authority who was working at one of the stations that the trains passed through. Despite these efforts, the incident exposed a lack of coordination among Japan's police departments and other authorities that was similar to the problems that have become common at major disaster sites.

Despite the efforts of individual employees, all emergency responders, including police, fire, and ambulance services, were criticized for the handling of the sarin attacks. The subway authority was severely criticized for failing to halt trains despite reports of injured passengers. Some hospitals turned away victims, and one was censured for failing to admit a victim for almost an hour. The media were criticized because some who were reporting the story hesitated when asked to transport victims to the hospital. Some of the confusion was attributed to lack of knowledge about sarin poisoning.

Criminal Justice System Response

Because the crime was premeditated rather than accidental, the police response was a large part of the incident aftermath. The police raided Aum Shinrikyo locations and seized a large amount of chemicals normally used in the manufacture of sarin and mustard gases, VX, and other biological agents. There was also evidence that group members had been attempting to manufacture assault rifles based on the design of the Russian-made AK-47.

Between the time Japanese authorities learned of Aum Shinrikyo and late 2004, more than 400 members of the group were arrested. About 100 have been convicted of crimes, including attempted murder, kidnapping, wiretapping, and possession of illegal weapons. On February 27, 2004, Shoko Asahara was found guilty and was sentenced to death by the presiding judge in Tokyo District Court. Forty-eight years old when sentenced, Asahara, whose trial began in 1996, was found guilty of 13 charges, one each for the 12 deaths that occurred and one additional charge. He was the twelfth member of the group to be sentenced to death. Throughout the trial he refused to answer questions and made only confusing statements about the incident. On May 28, 2004, another group member, who had originally escaped the death penalty, had his life sentence changed to the death penalty by a judge who ruled that the group member's role as a coordinator of the attack made him as guilty as those who had actually released the gas in the subway system. The group member's appeal to the Supreme Court of Japan is expected to take years to resolve.

The group was forced to release its property to pay victims' claims. This forced release of property was one reason for the group's diminished membership and name change. Despite attempts to force the group to disband under a 1952 anti-subversion law originally passed to outlaw communist groups, a government commission ruled in 1997 that Aum Shinrikyo no longer presented a threat to the public. After parliament passed a law in December 1999 permitting close police scrutiny of organizations that had committed mass murder, the group changed its name to Aleph. Aleph claims to have renounced violence and is primarily involved in yoga and meditation. It also maintains a website to publicize it beliefs.

Damage and Service Restoration

Although Aum Shinrikyo had enough sarin to kill 4.2 million people, only 12 people were killed in the attacks. The efficiency of the air filtering systems in the subway network was credited with keeping the number of fatalities low.

The subway system has permanently removed garbage cans to prevent terrorists from placing bombs or nerve gas canisters there, but few other security measures have been undertaken by the transit system or in government buildings.

The attack occurred less than 3 months after the Kobe earthquake; many economists thought the two events would have a serious negative effect on what had been seen as a rising economy. The two events also led to emotional questioning within the country, because many of the leaders of Aum Shinrikyo had attended top universities and were viewed as elite members of a society in which status and position are difficult to achieve.

Conclusions

Government studies of the incident found that the response to the disaster lacked coordination. A major reason for this lack of coordination was the vertical structure of Japan's society, where each agency that responded (police, fire, hospitals, and other governmental units) acted independently under its own chain of command. This finding led to the formation of a Severe Chemical Hazard Response Team to preclude a lack of coordination and to encourage information sharing.

Because the attacks were unique in their use of lethal gas, many of the post-analyses have focused on medical response to the incident. Typical sarin poisoning symptoms are convulsions, vomiting, loss of balance, double vision, and slurred speech. Hospitals treated the victims with drug inhibitors and antidotes, primarily atropine and two-pan chloride. The drugs were found to be in short supply, and only the most severe cases could be treated with the antidote serum.

A review of the incident response also determined that decontamination procedures were lacking. Of the 1,364 emergency medical technicians dispatched to the incident, 135 were secondarily affected. Twenty-three percent of the medical staff at the hospitals where the injured were transported later complained of symptoms and signs of secondary exposure.

The incident highlights the potential for creating mass terror by an attack in a public transit system. The ease with which the sarin was released and the problems isolating the sarin, halting train movements, and handling large numbers of injured and hysterical patrons cannot be easily dismissed. A transit system can never fully prepare for such incidents. Current efforts to create and place sensors to recognize chemical or biological weaponry may prevent some attacks, but the terrorists will always seek to devise new ways of bypassing sensors or using chemicals not yet detectable.

Since the sarin gas attack, more cities with mass transit systems have become involved in cross-agency and cross-jurisdictional pre-incident planning and training. In addition, transit agencies have become more receptive to placing anti-tampering devices on their ventilation systems; closing off open, nonpublic areas or public areas during nonpeak periods; formalizing policies and procedures for stopping trains and taking them out of service; and launching passenger education and awareness campaigns to help recognize suspicious items or behaviors. Although these precautionary efforts are worthwhile, it is unlikely that any of the awareness campaigns would have prevented the sarin attacks on March 20, 1995.

The attacks continue to have political repercussions in Japan. Pointing to the large financial payouts Americans received after the September 11, 2001, attacks, protestors have argued that the Japanese government should pay a larger price for not having taken the threat of Aum Shinrikyo seriously enough. Taking the threat seriously enough might have resulted in actions that would have prevented the sarin attacks.

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3.2.9 Chicago Freight Tunnel Flood

Location:	Chicago, Illinois
Date:	April 13, 1992
Incident Category:	flood in unused, underwater, and underground freight tunnel
Tunnel Length:	50 miles (80 kilometers)
Fatalities and Injuries:	0 fatalities, 0 injuries

Synopsis

A piling driven into the Chicago River bottom caused a leak in the underground freight tunnel. The inrush of water spread through much of the system's 50 miles (80 kilometers) of tunnels. Although there were no deaths or significant injuries, the disruption caused flooding to more than 50 buildings, most of which had to be evacuated. The disruption flooded stores and halted utility service throughout Chicago's Downtown Loop area. More than 250,000 people were evacuated from some of Chicago's busiest and most famous buildings, including the Sears Tower, the Merchandise Mart, and Marshall Field's Department Store. Declared a local, state, and federal emergency, the flood was estimated to have cost Chicago $40 million for the five and a half weeks it took to pump the water from the tunnel and as much as $2 billion in lost revenue, tax assessment losses, and damage to the city's infrastructure.

Analysis of Pre-Incident Information and Events

The Chicago freight tunnel system was constructed between 1899 and 1904, originally for a telephone system that was never created. The tunnel system was used to deliver coal, remove ash, and deliver freight directly by railroad transfer or by trucks that delivered merchandise at street level. The merchandise was then transported on rail cars for unloading at specific stores' underground sidings. A 2-foot-gauge, mine-type electric railway operated in the tunnels, connecting to major railroad and port facilities. Over the years, the 62 miles (100 kilometers) of tunnel had shrunk to about 50 miles (80 kilometers) because of construction by the Chicago Transit Authority (CTA) of the State Street subway, the Dearborn Street subway, and the Kennedy Expressway. At the time of the flood, the tunnel ran under many important buildings in downtown Chicago and criss-crossed under the Chicago River at a dozen locations.

Although the tunnel system was unknown to most residents after it was abandoned in 1959, it was equipped with a 24-inch (61-centimeter)-gauge track on which at least one engine and four cars that hauled ash remained intact at the time of the flood. At the time of the flood, telephone companies, cable television companies, and light and power companies (e.g., Commonwealth Edison and Peoples Gas) rented tunnel space from the city to run lines and store equipment. Because the responsibility for the tunnels had been transferred among a variety of city agencies over time, the existence of the tunnels had been virtually forgotten and little oversight was exercised.

Some of the tunnel system's statistics give an indication of its size and complexity. When described in 1928 (considered accurate at the time of the flood), the tunnel, which measured 6 by 7.5 feet (1.8 by 2.3 meters), encompassed 734 intersections and sidings, had 96 elevators (not all operable), 266 telephones that once connected to the Chicago Tunnel Company's central station dispatchers, 540 pumps, 63 sumps, and almost 4,000 lights. The average distance of the tunnel below street level was 40 feet (12 meters).

Providing an indication of its importance to early commerce, there were 26 private merchandise connections for freight delivery, 40 connections for picking up and delivering coal and cinder, 16 connections for cinder only, three coal receiving stations, and four universal public stations. At the public stations, anyone could have dropped a shipment to be routed through the tunnels via any of the 49 railroad connections.

Analysis of the Incident

At about 5:30 a.m. on April 13, a slow leak that had probably been in existence for the previous 7 months began to flood the tunnel system. The flood was discovered by a boiler room engineer working at the Merchandise Mart, north of the Loop, who heard the sound of running water. He was located in the lowest basement of the Mart, about 30 feet (9 meters) below the level where the Chicago River was flooding into the tunnel. The Chicago fire department was notified at 5:57 a.m. Shortly after 6:00 a.m., the Chicago Emergency Preparedness and Disaster Service, part of the fire department, activated the city's emergency operation plan and sought to locate the source of the water, which was initially thought to be a sewer or water main that had burst.

By 6:30 a.m., after a citizen reported seeing a whirlpool in the Chicago River's North Branch near the Kinzie Street bridge, it was determined that the source of the water was a hole in the tunnel near the bridge. The hole was later determined to have been caused by a bridge piling that had been inadvertently pounded into the side of the tunnel exactly where the whirlpool was observed.

Between 7:00 and 8:00 a.m., flooding was reported in five more buildings, including Marshall Field's Department Store. By 9:00 a.m., 11 feet (3.3 meters) of water had filled the lowest of City's Hall's three basement levels. Shortly thereafter, City Hall was evacuated, power was shut down by Commonwealth Edison, and additional buildings were evacuated. At about 9:00 a.m., water was discovered in the subway tunnels and the CTA stopped all service. At 11:00 a.m., the entire downtown Loop area, from the Chicago River south to Taylor Street and from Canal Street east to Michigan Avenue, was shut down. The evacuation involved about 250,000 people.

By noon, 23 buildings had been flooded. Although quick-dry concrete had been poured into the area around the hole by Kenny Construction Company, a private firm employed by the city, about 250 million gallons (946 million liters) of water, containing fish and debris from the river, continued to flood the basements of more than 50 buildings in the Loop.

Fatalities and Injuries

There were no fatalities and no injuries reported as a result of the incident.

Fire and Emergency Response

The Chicago fire department was notified at 5:57 a.m., less than a half hour after the leak was observed. Shortly after 6:00 a.m., the Chicago Emergency Preparedness and Disaster Service, a part of the fire department, activated the city's emergency operations plan. Despite this effort, the source of the water, initially thought to be a sewer or water main break, was discovered inadvertently to be the Chicago River leaking into the old Chicago freight tunnel.

By early the first day of the incident, the Illinois Emergency Management Agency (IEMA) and the American Red Cross were involved. Both Chicago Mayor Richard M. Daley and Illinois Governor Jim Edgar declared emergencies, and a joint command center was established for all emergency workers near the breach site. On the evening of April 14 (the second day of the incident), Mayor Daley contacted the White House to request assistance from FEMA. The request was approved and received the following day. Despite disputes between the city and the state over financial responsibilities, on April 18 (five days after the incident), the U.S. Army Corps of Engineers was assigned to seal the breach in the tunnel and then to remove the accumulated water from the freight tunnel system and other affected areas.

The dewatering process continued until May 22; work associated with sealing the tunnel continued until June 30, 1992.

Damage and Service Restoration

Although service was restored within 3 days, it took five and a half weeks to pump water out of the tunnel system at a cost of $40 million. It took additional months for the Loop area to return to its previous state. The cost in lost business was estimated at almost $2 billion. Nine employees of the city of Chicago, including the acting transportation commissioner, lost their jobs after it was determined that they had ignored reports months earlier that the tunnel was leaking. At that time, about 7 months before the flood, the estimated cost of repairing the leak had been less than $10,000.

Illinois Bell activated and maintained its 24-hour emergency operations center from the first day of the flood until the 31st day (May 13). Call volume on the first day was estimated at about 150,000 per hour, three times the usual volume. Increased volume was also recorded for days in directory assistance calls and requests for call forwarding. Cables were submerged, and fiber optic equipment had to be replaced. Electrical power was restored to about half the buildings in the Loop on April 17.

Beginning the day of the flood, small boats were barred from passing through the Kinzie Street bridge area of the Chicago River. While some traffic was permitted use of the area on April 30, the river was not completely reopened until May 21.

On April 18, the Kennedy Expressway, used by about 200,000 vehicles per day, was closed for fear that it would flood. It remained closed for 10 days, which impacted the transportation system, particularly in light of the continuing subway closures.

The two affected CTA subway lines also incurred costs and service delays. The State Street subway did not reopen until May 1 (the 19th day). On May 7 (the 25th day), the Dearborn Street subway reopened.

Conclusions

Subsequent to the incident, it was learned that the flood might have been prevented had the initial crack in the tunnel under the Chicago River been repaired for less than $10,000. This crack had been reported to at least one city agency by the company that installed the pilings, but the report was ignored. Forty million dollars was spent on pumping and plugging the leak, and an estimated $2 billion was spent on overall costs of the incident.

The structural stability of many buildings had to be ensured; there were numerous safety issues involving asbestos and polychlorinated biphenyls (PCBs) in water-damaged buildings. Insurance coverage, evacuation plans, and safe storage of business records were affected.

Among the recommendations to mitigate similar hazards were surveying the freight tunnel system, including documentation of conditions and locations of access shafts, bulkheads, floodgates, building closures, and utilities; preparing a comprehensive map of Chicago's underground infrastructure; and surveying all buildings with subbasements adjacent to the tunnel system. This last effort was intended to chart the existence of bulkheads and test their effectiveness in preventing a similar incident.

Other recommendations pertained to correcting existing installations of flood monitoring equipment, providing uniform specifications for bulkhead and floodgate designs for all buildings with subbasements adjacent to the tunnel, and encouraging individual buildings to either assign space for utilities above the flood level or require water-tight splices for below-flood-level telephone cables.

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3.2.10 London Underground (the Tube) King's Cross Station Fire

Location:	London, England
Date:	November 18, 1987
Incident Category:	fire in escalator in Tube station
Tunnel Length:	N/A; Tube station
Fatalities and Injuries:	31 fatalities, injuries not tallied

Synopsis

A fire that started in one of four escalators in the London Underground King's Cross station, one of the busiest stations in the system, spread throughout the station and into a ticket hall at about 7:30 p.m., at the end of the evening rush hour. The draft created by train movements, the steep incline of both the escalator and the station itself, and the old paint on the ticket hall walls contributed to create a fast-moving inferno that engulfed the station and thousands of patrons, resulting in 31 deaths.

Analysis of Pre-Incident Information and Events

At the time of the incident, King's Cross was the busiest station in the London Underground system. Five lines (the Metropolitan, Circle, Piccadilly, Northern, and Victoria) operated on four different levels. The station was built on five levels, including passageways, shafts, and tunnels, and during its busiest rush hours, 2,000 passengers per minute moved through the station. The station has been described as a labyrinth of passageways, shafts, and tunnels, including the subway, which connected the Piccadilly and Victoria platforms to the Midland City station. This connection was closed off with locked gates when the incident began.

The escalators where the fire began were installed in 1939, and there had been a history of fires occurring in their mechanisms. Because of this history, the escalators had been fitted with water fog equipment, which basically consisted of water sprays that were located under each escalator and manually operated by valves on a landing inside the access door to the upper machine room. Three access staircases were also located in the area—one between Escalators 4 and 5, another between Escalators 5 and 6, and a third under Escalator 5.

Analysis of the Incident

The incident began at 7:29 p.m., when a fire was reported by a passenger coming up Piccadilly Line Escalator 4 (one of four escalators in the station). The passenger noticed the fire one-third to halfway up the escalator and informed a ticket office clerk, who telephoned the station inspector on the Victoria Line platform. Within a minute, another passenger who had come up the same escalator pressed the stop button and shouted a warning to passengers to disembark the escalator. A British Transport Police (BTP) officer in the ticket hall's control room heard the commotion and responded to the incident.

Although the fire above the escalator seemed small, the BTP officer determined that there might be a more serious fire under the escalator. At 7:33 p.m., he left the scene to go above ground to advise the BTP control room of the fire. He left because his portable radio was inoperable underground. The London Fire Brigade was alerted to the fire by the BTP control room at 7:34 p.m., and fire units were dispatched 2 minutes later. The fire was still small, described in size as similar to a fire created by a large, burning cardboard box. However, by 7:45 p.m., the fire had spread rapidly to the ticket hall at the top of the escalators, where it quickly turned into an inferno that destroyed the ticket hall. All but one of the deaths occurred in the period immediately following the spread of the fire.

Fatalities and Injuries

Thirty-one people, including one BTP employee, were killed. There were a large number of serious injuries. One of the victims remained unknown until January 2004, when 72-year-old Alexander Fallon, of Scotland, was identified through forensic evidence.

Fire and Emergency Response

Before the fire units arrived at 7:42 p.m., the Piccadilly Line escalator had been stopped and taped off by BTP employees and officers who had arrived in response to the initial officer's radio message to central control. They directed passengers from the Northern and Piccadilly Lines via the cross passage up the Victoria Line escalator. People entering the station were directed down the Victoria Line escalator. At about 7:40 p.m., just prior to arrival of the fire brigade, police decided to evacuate the station and to request that trains no longer be allowed to stop at King's Cross. Until then, some passengers and Underground staff had been evacuated by train, and trains continued to run through the station, stopping to discharge passengers.

When the fire units arrived, the fire at Escalator 6 was still small. Firefighters at the top of Escalator 4 thought it was a more significant fire, but not one that would rapidly engulf the entire area. Yet by 7:45 p.m., the fire spread quickly and with great velocity up the escalator and into the ticket hall and surrounding subways, preceded or accompanied by thick black smoke. Despite the size and speed of the fire, the incident ended quickly. The fire was deemed under control by 9:48 p.m.

Damage and Service Restoration

Since service was restored to King's Cross station, work on the facility has been almost constant. Total renovation is scheduled for completion in 2007, including extensions and refurbishments that are not directly related to the fire, but are rather in response to changing travel patterns and what is expected to be an increase to 82,000 passengers using the station during the morning rush hour.

Conclusions

The King's Cross fire was only the third incident investigated under the 1871 Railway Act; the previous two incidents were the Tay Bridge disaster in 1879 and the Hixton Level Crossing accident in 1968. A formal investigation, announced on November 25 by the Secretary of State for Transport, was headed by Desmond Fennell. His final report led to legislative initiatives to include fire safety standards for underground railway stations under Section 12 of the Fire Precautions Act, which at the time applied only to offices, shops, factories, and hotels.

The absence of interoperable communications played a role in both the fire and the emergency response. The first police officer at the scene was forced to leave to communicate with central control because of the inoperability of his radio underground. Train service might have been curtailed earlier had there been more explicit communications between BTP and the fire units. People trapped during the fire were in telephone communications with BTP line controllers, the headquarters central controllers, and the BTP controllers, but there was no direct communication with those fighting the fire on the surface, who remained unaware of the people trapped in the station.

The situation was exacerbated by the firefighters' lack of knowledge of the station. Two examples of this occurred when, at 8:17 p.m., two BTP officers evacuated an injured passenger via the Midland City subway, but did not communicate with the firefighters, who were unaware of the existence of that subway. At 9:05 p.m., the BTP incident officers arrived via the Midland City subway and went above ground to meet with the fire officer in command, but they did not inform the fire officer that they had arrived via subway. Firefighters were finally dispatched underground via the Midland City subway at 9:15 p.m., an hour and a half after the fire began and only about half an hour after the fire was declared under control.

Simulations of the flow of gases following the fire concluded that a trench effect was responsible for the rapid spread of the fire; this conclusion contradicted the original theory that the rapid spread was due to train movements. The fire started about 70 feet (21 meters) from the top of Escalator 4, although there was also damage to Escalators 5 and 6.

The rapid spread of the fire when it reached the ticket hall was later attributed less to the draft created by train movements than to factors in the hall. The floor area of the ticket hall, excluding the ticket office, was approximately 5,700 square feet (530 square meters); the height from the floor to the suspended ceiling was 8 feet (2.5 meters). The 138-foot (42-meter) length, the small 23-foot (7-meter) internal diameter, and the steep angle (30 degrees) of the escalator also contributed to the intensity of the fire. The inferno created in the hall was caused by the suspended ceiling, which had been constructed from fire-resistant panels containing asbestos. Many panels fell during the fire, allowing flames to penetrate and burn any combustible materials, including electrical wiring. In addition, wooden and aluminum-based components were burned and charred, resulting in fumes and hot gases that spread through the stairways and tunnel system. The layers of old paint, many of which predated rules pertaining to fire resistance, also contributed to the speed with which the ticket hall was engulfed in flames.

The Fennel Report, which included 157 recommendations that were accepted by London Underground and other organizations involved in underground system emergency oversight and response, highlighted the lack of staff training, cuts in expenditures on cleaning, and the absence of a program to replace the wooden escalators. It specifically mentioned a lack of concern about station maintenance and hygiene. This lack of concern led to acceptance of debris and refuse, including cigarette butts, collecting at the base of the escalators. It was also policy not to contact the fire brigade unless a fire appeared serious; this policy resulted in a work culture where small fires were treated casually by Underground staff.

Despite the number of fatalities and injuries, the public location of the fire and the large number of evacuees resulted in many more eyewitness accounts than usual in tunnel and/or transportation facility incidents. The Fennel Report heard evidence from many eyewitnesses and compared their statements to the logs of the control centers of the fire brigade and the BTP. This effort created a rare qualitative description of the events to compare with the official chronology, which raised questions about the value of such accounts in situations where visibility is low and the level of panic is extremely high.

The Fennel Report led to passage of the Sub-Surface Railway Stations Regulations of 1989 (referred to as "the Regulations" because they were actually introduced under Section 12 of the 1971 Fire Precautions Act). The Regulations mandated replacement of all wooden escalators on the Underground system, installation of automatic sprinklers and heat detectors in escalators, fire safety training for all station staff twice a year, and improvements in communications and liaison among agencies expected to respond to any Underground emergency. The scope of the requirements meant that full compliance with the safety changes was not expected until late 2004, and requirements for safer station exits was not anticipated to be met until 2007. In 2004, a move in Parliament to repeal some of the requirements through the proposed Regulatory Reform (Fire Safety) Order 2004 passed. However, support for the regulations by unions and rider advocacy groups resulted in the House of Commons' Regulatory Reform Committee recommending in October 2004 that both the 1989 and 1971 laws remain in effect.

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3.2.11 Bay Area Rapid Transit (BART) Transbay Tunnel Fire

Location:	San Francisco, California
Date:	January 17, 1979
Incident Category:	fire
Tunnel Length:	3.7-mile (5.9-kilometer) twin-bore tunnel with service tunnel
Fatalities and Injuries:	1 fatality, 58 injuries (including 19 firefighters)

Synopsis

During the evening rush hour on Wednesday, January 17, 1979, a fire broke out in a circuit breaker in the fifth and sixth cars of a seven-car westbound BART train about two miles (3.2 kilometers) into the Transbay Tunnel. The train was stopped by the emergency brake and could not be restarted. An unsuccessful attempt to disconnect the burning cars delayed the evacuation of passengers by about 30 minutes, during which the tunnel filled with smoke despite activation of the ventilation system. Rescue efforts involved taking the passengers out through the service tunnel, although smoke entered both the service and the other main tunnel.

Analysis of Pre-Incident Information and Events

BART is a rapid transit district serving the San Francisco Bay area that includes mainline rail service between San Francisco and Oakland via the two-bore Transbay Tunnel tube. The tube sections resemble huge binoculars in cross section, 24 feet (7.3 meters) high and 48 feet (14.6 meters) wide, with trackways in each bore to carry trains in each direction, and separated by an enclosed central corridor called the gallery. The gallery is divided into two chambers; the lower one serves for pedestrian and maintenance access as well as for distribution of various electrical and safety systems, and the topmost chamber serves as an air duct for the ventilation system pioneered by BART.

BART officials were optimistic about the ventilation system's design and ability to safely handle a fire under the Bay, but San Francisco's assistant fire chief had voiced concern that fighting a fire in the tunnel would be like entering a 3-mile (4.8-kilometer)-long high-rise building that was lying on its side and had no windows. Everyone had agreed that smoke would be the major problem should a fire occur; they were all correct.

A few hours prior to the incident, at 4:45 p.m. on January 17, a westbound train had stalled in the tunnel for about 20 minutes. Passengers later reported that there had been sparks, explosion-like sounds, and flashes that seemed to warn of a fire. Even closer to the time of the incident, at 5:15 p.m., patrons at the Embarcadero station on the San Francisco side of the tunnel reported seeing smoke coming from the west side of the tunnel. Problems prior to the stalling of the 6:06 p.m. train that caught fire were acknowledged by BART, but the system officials said there did not appear to be any connection between the earlier reports and the incident that closed the tunnel.

Analysis of the Incident

On January 17, 1979, at about 6:00 p.m., a fire occurred in the fifth and sixth cars of a seven-car train (Train No. 117) traveling from Oakland to San Francisco in the Transbay Tunnel Tube Bore A. The train was stopped, passengers were moved into the forward cars to avoid the fire, and the exhaust fans in both vents located at each end of the tube were activated to draw the smoke out of the tunnel tube.

The last cars of the train were uncoupled from the train, but attempts to move the rest of the train were unsuccessful. The NTSB later determined that the uncoupling system malfunctioned because of a short in the train's control circuit. At the same time, personnel from BART and from both the Oakland and San Francisco fire departments entered the tunnel to rescue staff and passengers.

There were numerous miscommunications almost as soon as the incident began. San Francisco fire department tapes showed a call from BART dispatchers at 6:00 p.m., but the dispatchers stated that they had reached a wrong number and were disconnected. At 6:09 p.m., BART contacted the Oakland fire department, which dispatched one unit of about 10 firefighters. These firefighters proceeded to the Oakland West station to board a special train, while a second unit of firefighters entered the tunnel walkway on foot. The San Francisco fire department was not officially contacted until 6:34 p.m., 25 minutes after Oakland was notified and 34 minutes after the first call made to the department was disconnected.

Indecision about the rescue train led to BART dispatching an eastbound train filled with rush-hour passengers to act as the rescue vehicle. The decision to send a train with passengers from the Embarcadero station was based on the view that it would have taken at least 10 minutes to order the approximately 1,000 passengers off the train. When the train stopped in the tunnel to pick up the passengers stranded from the disabled train, passengers in the rescue train were told only that they would be stopping for other passengers but were not told that there was a fire in the other tunnel tube. The rescue train remained in the adjacent tube for about 45 minutes, during which there were no lights or fresh air on that train, and some passengers smelled smoke coming from the other tunnel.

Intense smoke minimized visibility and hampered rescue efforts. It was later found to contain toxic materials attributed to combustion of the train's polyurethane seats. The material had previously been identified as a potential fire hazard; BART had received a $2.5 million federal grant for replacement with less flammable materials. At the time of the incident, BART was preparing to secure bids for replacement seats and had estimated that it would take at least a year for new seats to be obtained and installed.

The fire was declared under control at about 10:45 p.m., although it took more time for the fires in the rear-end cars to be fully extinguished. They were then pulled from the tunnel by a diesel engine. Their windows and roofs were missing, and they were described as crumpled like pieces of tin foil. About 24 hours after the original incident, Oakland firefighters arrived at BART's storage yard to douse a small fire that flared in the gutted train.

Fatalities and Injuries

The single fatality (Oakland firefighter William Elliott, 50, who died of a combination of smoke inhalation and flue gas poisoning) and the injuries to passengers and firefighters were caused primarily by gases from the combustion of plastics.

Fire and Emergency Response

Fire personnel from the San Francisco and Oakland fire departments responded to the incident, which occurred about a mile (1.6 kilometers) from the Oakland end of the tunnel tube. The fire started small and was originally recorded by the Oakland fire department as a two-alarm fire. Although the tunnel's ventilation system was working, it did not expel smoke quickly enough and allowed smoke to fill the tunnel. The dense smoke limited visibility to almost zero and impeded rescue efforts; it took almost 40 minutes for Oakland firefighters to reach the train. By that time, passengers, many of whom had panicked, had crawled along the train's floor in an effort to escape the fire by entering the more forward cars.

Once firefighters were able to reach the passengers, the passengers were removed via a narrow trackside catwalk through emergency doors to the gallery ways between the eastbound and westbound tunnel tubes and onto an eastbound train that took them to the West Oakland station. Paramedics treated many people at the scene, where ambulances waited to take the more seriously injured to hospitals.

Of the injured people, 24 passengers, 19 firefighters, and three BART employees were sent to three Oakland hospitals and one San Francisco hospital. Most, with the exception of the firefighter who died, were treated for smoke inhalation and noncritical injuries. Because of the thick smoke and the time it took firefighters to reach the wreck, a number of the firefighters reported running out of oxygen. Despite the heavy smoke, a few of them were able to make it completely through the tunnel. Some of the Oakland firefighters walked the entire length of the tube and emerged at the San Francisco end; they were among the seven firefighters taken to San Francisco General Hospital.

Damage and Service Restoration

Damage to the gutted BART cars was estimated at $800,000. No other monetary damage figures were publicized.

Although BART intended to restore service within days of the incident, criticism by California Public Utilities Commission (PUC) investigators and Oakland and San Francisco fire officials prevented this from occurring. The fire departments criticized BART officials for not giving firefighters what they called "ultimate authority" during the incident. San Francisco's fire chief announced that his department was planning to conduct its own investigation of events surrounding the fire.

BART had been running test trains through the fire-damaged tunnel prior to the meeting of the PUC. However, within 3 days of the incident, the PUC ordered BART to keep the Transbay Tunnel closed until a number of safety improvement actions had been taken, including the following:

- Present sworn testimony that both tunnels were structurally sound and operationally safe, and have the testimony verified by either Caltrans or the California Department of Industrial Safety.
- Develop a plan to keep smoke from a burning train out of the gallery that separates the two tunnel tubes.

- Provide appropriate rescue equipment (e.g., emergency vehicles, golf carts for moving in the walkway, and breathing apparatuses for emergency responders) and improved communications.
- Revise rescue procedures so that the fire chief of either Oakland or San Francisco, depending solely on where the fire occurred, was in charge of operations.
- Change the doors to the gallery to enable people inside to get out as easily as people outside to get in.
- Receive approval from the Oakland and San Francisco fire chiefs on the new fire rescue procedures.

Conclusions

Both fire departments had practiced tunnel emergency procedures in drills that involved entering the tunnel tubes and the central corridor, or the gallery that connects them. Firefighters were trained that the gallery was the place to flee to during a fire or smoke condition because panic doors every 100 feet (30 meters) were programmed to open as soon as they were touched. Although this worked during drills, in the actual incident the gallery filled with smoke, thus becoming a dangerous location. When firefighters tried to exit the gallery and enter the relative safety of the eastbound (unaffected) tube, they were unable to find the keyholes in the doors. The firefighter who died was trapped in the smoke-filled gallery.

The incident was attributed to lack of communication between the train operator and central operations, poor coordination, and errors of judgment, all of which made the incident a key factor in the development of National Fire Protection Association transit industry guidelines (NFPA 130) on responses to fire incidents [Ref. 2].

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3.2.12 Port Authority Trans-Hudson (PATH) Evacuation under the World Trade Center

Location:	PATH rapid transit station under the World Trade Center
Date:	September 11, 2001
Incident Category:	terrorist bombing of buildings above the rail station
Tunnel Length:	N/A; rail station under bombed building
Fatalities and Injuries:	None in this portion of the incident

Synopsis

Two planes flown by terrorists struck the World Trade Center’s (WTC’s) twin towers during the morning rush hour on September 11, 2001, resulting in fire and heat that caused the buildings to collapse. This case study does not discuss the overall incident, but looks specifically at the successful evacuation of employees, passengers, and trains from the PATH rapid transit station under the WTC.

Analysis of Pre-Incident Information and Events

PATH was acquired in 1962 by the Port Authority of New York and New Jersey from the bankrupt Hudson and Manhattan Railroad. The system and its tunnels linking New York and New Jersey, which had been built in 1908, were the first passenger rail connections between the two states. Prior to September 11, 2001, the PATH rapid transit system of 13 stations carried approximately 260,000 weekday passengers, about 67,000 of whom boarded PATH at the WTC station located about 70 feet (21 meters) below the WTC towers.

When the first plane hit the WTC at 8:46 a.m., the PATH rush hour was not quite over. Yet within 5 minutes, despite the surrounding chaos, a train dispatcher at the station had the presence of mind to ask his control center what he should do about passengers he had just unloaded and those who had just entered his train on Track 4. He was told to immediately take his train and passengers out of the station and back to New Jersey. Although tapes released later indicated that at least one conductor did not think he would be able to reverse his train to get out of the 14th Street station, passengers at Manhattan stations were boarded or reboarded onto trains that traveled under the Hudson, returning them all to safety in New Jersey.

The only train that was unable to leave the WTC station was found later on Track 4 with debris covering four of its seven cars. However, there were no fatalities because all occupants had fled the station before the buildings collapsed.

Analysis of the Incident

Within minutes of the first plane striking the north tower of the WTC at 8:46 a.m., at least four PATH employees individually contacted the PATH control center at Journal Square in Jersey City to report that an unexplained explosion or fire seemed to have occurred at the WTC. None were aware of the magnitude of the event. Based on instructions from a PATH deputy director who was at the WTC, by 8:52 a.m. the system's trainmaster began to issue instructions to conductors and operators to avoid the station. Had it not been for these prompt instructions, trains would have continued to arrive at the station at 3- and 5-minute intervals, unloading passengers directly into buildings that would soon collapse. This would undoubtedly have resulted in a far larger number of deaths in conjunction with the WTC attack.

Staff aboard a train from Newark that was carrying about 1,000 passengers announced that passengers should reboard; the staff then moved the train out of the station and to the Exchange Place station in Jersey City. The passengers who had not reboarded were evacuated from the Trade Center by Port Authority police officers and other operations personnel. A second train originating in Hoboken, New Jersey, and also carrying approximately 1,000 passengers was scheduled to arrive at the WTC station just after the Newark train. The crew was ordered by the trainmaster to keep its doors closed, move through the WTC, and loop around and proceed to Exchange Place. A third train scheduled to leave the Exchange Place station for the WTC station was directed to discharge all passengers at Exchange Place and to proceed to the WTC to evacuate any stranded passengers and Port Authority personnel. That train, which left the station at about 9:10 a.m., was the last to leave before all city-bound trains were halted in New Jersey. The timely decision to evacuate trains from the WTC station and to halt those heading toward it resulted in no trains being trapped in the tunnels when the towers collapsed and no passengers or staff being left in the station.

Fatalities and Injuries

There were no fatalities or injuries in this portion of the incident.

Fire and Emergency Response

Fire and emergency response was not involved for this portion of the incident.

Damage and Service Restoration

An important part of damage control that pertained specifically to the PATH portion of the events of September 11, 2001, involved securing the basin under the collapsed towers to ensure that the PATH system was not flooded beyond the immediate event. A 60-foot (18-meter)-deep cavern that became known as the "bathtub" formed the foundation and side walls of the basement levels of the WTC and kept out water from the Hudson River. If the bathtub had given way, water would have rushed into what had been the basement levels of the WTC and subsequently into the two PATH tubes under the river. Although some water damage occurred at the Exchange Place station in Jersey City, had the water not been contained it could have reached the PATH terminus at West 33rd Street and Sixth Avenue in midtown Manhattan, and from there flooded adjoining New York City subway tunnels. Further flooding was prevented, and it was eventually determined that much of the water in the PATH tubes was not from the bathtub, but from broken water mains, firefighters' hoses, and rainwater.

On November 23, 2003, PATH service linking lower Manhattan and New Jersey was restored at the temporary WTC PATH station. The station, which opened 1 month ahead of schedule, was the final part of Port Authority's $566 million program to restore the rail service into lower Manhattan that was severed on September 11, 2001. It was the first public space to re-open within the WTC site since the terrorist attacks. Although the temporary station cost $323 million to build, the station lacks many of the amenities of the original station, including heating, air conditioning, and features necessary to comply with the federal Americans with Disabilities Act (ADA). It is planned that these features will be included in the permanent station.

In addition to the cost of the temporary station, $106 million was spent by the Port Authority to restore the PATH tunnels under the Hudson River. The interior of some tunnel sections had to be stripped, and equipment damaged by the collapse of the towers and subsequent flooding (such as tracks, electrical wiring, and train signals) had to be replaced. The $106 million also included restoration and enhancement of the Exchange Place station in Jersey City.

The WTC temporary station is slated to be replaced with a proposed $2 billion permanent WTC Transportation Hub that will include underground pedestrian connections to more than a dozen New York City subway stations and an additional connection to the Metropolitan Transportation Authority's proposed Fulton Street Transit Center.

Conclusions

Based on normal ridership patterns, it is estimated that as many as 3,000 PATH passengers were prevented from detraining directly into the WTC station. The immediate decision to halt trains into New York City prevented these passengers and the trains carrying them from being stranded in the station or rail tunnels.

The ability to bring all passengers to safety, including those who were quite literally right under the twin towers, was attributed to a combination of a culture in which workers are encouraged to think independently and act in an emergency without waiting for authorization from higher levels of management and to an independent communications system that allows dispatchers and train operators to communicate freely. The PATH communication system worked throughout the emergency because it was not located on top of the WTC even though both the WTC and the PATH system are components of the Port Authority of New York and New Jersey.

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3.3 Summary of Case Studies

Table 4 shows the details of each case study at a glance. In total, the case studies represent 10 rail incidents and 2 road incidents, taking place in Asia, Russia, western Europe, Great Britain, and the United States. All intentional violent acts occurred on passenger transit systems:

- Moscow terrorist bombing (2/6/2004),
- Daegu arson fire (2/18/2003), and
- Tokyo chemical attack (3/20/1995).

Passenger transit incidents resulted in the largest numbers of casualties and injuries:

- Moscow terrorist bombing (2/6/2004): 39 fatalities, 100+ injuries;
- Daegu arson fire (2/18/2003): 198 fatalities, 147 injuries, 50+ missing;
- Kitzsteinhorn cable car fire (11/11/2000): 155 fatalities, injuries not tallied;
- Tokyo chemical attack (3/20/1995): 12 fatalities, 6,000 exposed to sarin gas;
- King's Cross Station fire (11/18/1987): 31 fatalities, injuries not tallied; and
- BART Transbay fire (1/17/1979): 1 fatality, 58 injuries.

One incident did not result in fire or explosion: Chicago freight tunnel flood (4/13/1992).

3.4 Conclusions

3.4.1 Pinpointing Vulnerabilities

Passenger transit tunnels and stations present a high potential for large numbers of fatalities and injuries, for worldwide media coverage, and for creating public fear. While some transit tunnel incidents can be characterized as accidents, many are intentional acts in which the initiators of the incident are suicidal or seeking to kill or injure large numbers of people. Even when there is little or no intent to cause chaos or mass casualties, the possibilities for such outcomes are strong.

Road tunnel fires are closely related to truck accidents. These accidents frequently result in fires, and the fires are often exacerbated by the goods being carried. Even when the materials being transported are not flammable or hazardous, serious side effects of fires may be toxic fumes or residue. Freight and motor tunnel incidents hamper economic arrangements by altering patterns for the transport of goods and may lead to long-term damage from flammable cargo or the release of hazardous materials.

3.4.2 Lessons Observed

All the case studies point to a need for better safety management and for better communications. In a number of the incidents, no one person or office was responsible for system safety, sometimes because the organizational culture minimized the importance of working safely and of maintaining a clean and safe system.

There is also a need for better planning of emergency systems and of estimations of overall tunnel usage. Many of the

Table 4. Case study summary.

Section Number	Incident	Date	Fatalities and Injuries	Brief Description
3.2.1	Moscow Subway Suicide Bombing	Feb. 6, 2004	39 fatalities, 100+ injuries	A bomb, later linked to Chechen separatists, exploded inside a crowded Moscow subway train during the morning rush hour. The bomb destroyed the second car of the train as it left the Avtozavodskaya station in southeast Moscow; the train was traveling toward the center of the city. The incident was one of three subway-related bombings attributed to Chechens.
3.2.2	Jungangno (Chungang-Ro) Subway Station Arson Fire	Feb. 18, 2003	198 fatalities, 147 injuries, 50+ missing	A subway passenger threw flammable liquid inside a subway car of a train carrying about 600 people. The liquid ignited as the train pulled into the underground Jungango station, beneath Daegu's central city. A train traveling in the opposite direction entered the tunnel moments after the first train burst into flames. The death toll increased when the doors of the second train locked shut after the driver stopped in the tunnel and removed the master controller key. The passengers were trapped inside as cars filled with smoke and noxious fumes.
3.2.3	St. Gotthard Tunnel Fire	Oct. 24, 2001	11 fatalities, injuries not tallied	A head-on collision of two trucks about 1 mile (1.6 kilometers) from the tunnel's southern entrance sparked an explosion and subsequent fire. Part of the tunnel's roof collapsed over a distance of about 328 feet (100 meters). These two separate events combined to make the 10.6-mile (17-kilometer) tunnel unapproachable due to temperatures as high as 1,832°F (1,000°C) and falling roof debris. Up to 40 cars and trucks were fused into a molten mass at the heart of the disaster zone. The incident resulted in 11 fatalities, including the two truck drivers involved in the accident. Rescue efforts were hampered by the extreme heat and the risk that additional sections of the tunnel roof might collapse.
3.2.4	Howard Street CSX Tunnel Fire	July 18, 2001	0 fatalities, 4 injuries	A 60-car freight train, of which eight cars in the rear half of the train were carrying dangerous or hazardous materials, caught fire, probably due to a derailment in the tunnel. The train was stopped and staff disconnected the locomotives and escaped. There were no fatalities, but the fire resulted in large quantities of smoke escaping the tunnel. The fire brought the city to a halt and resulted in a series of lawsuits by Baltimore against CSX.
3.2.5	Kitzsteinhorn Tunnel Cable Car Fire	Nov. 11, 2000	155 fatalities, injuries not tallied	A cable car packed with skiers caught fire at the bottom of a tunnel on the 2.4-mile (3.9-kilometer) mountain. The cable car halted inside the tunnel; lights went out and initially the doors would not open. The narrow, 11.8-foot (3.6-meter) tunnel width left little room for evacuation. The steep (45-degree) incline turned the tunnel into a chimney, thereby blocking the escape route.

(continued on next page)

Table 4. (Continued).

Section Number	Incident	Date	Fatalities and Injuries	Brief Description
3.2.6	Mont Blanc Tunnel Fire	Mar. 24, 1999	41 fatalities, injuries not tallied	A truck carrying margarine and flour entered the 7.3-mile (11.6-kilometer) Mont Blanc Tunnel from France, caught fire, and stopped in the tunnel, where it burst into flames. The fire, fueled in part by the margarine, reached temperatures of 1,832°F (1,000°C); it trapped approximately 40 vehicles in dense and poisonous smoke.
3.2.7	Channel Tunnel Fire	Nov. 18, 1996	No fatalities, about 30 injuries	A truck on a freight train traveling from France to Great Britain caught fire, which made disconnecting the burning part of the train impossible. When the train stopped, the fire damaged the power catenary and spread to adjoining cars. The smoke moved quickly because of other trains moving in the tunnel, which also impeded evacuation. Train staff and truck drivers evacuated through a door leading to the service tunnel, but overpressure from that door created a fresh air bubble when the door was opened. Staff were rescued via the adjoining service tunnel; structural damage was considerable.
3.2.8	Subway Sarin Gas Attack	Mar. 20, 1995	12 fatalities, 5,000 to 6,000 exposed to the gas	The Aum Shinrikyo religious group released canisters of diluted Sarin on five separate trains during the Tokyo subway system's morning rush hour. As many as 6,000 people may have been exposed to the chemical; 12 people died. A review of the response highlighted a lack of coordination. Each agency (police, fire, hospitals, and other governmental units) acted under its own chain of command. This finding led to formation of a Severe Chemical Hazard Response Team.
3.2.9	Chicago Freight Tunnel Flood	April 13, 1992	0 fatalities, 0 injuries	A hole in the wall of one of the Chicago freight tunnels, 40 feet (12 meters) under the Chicago River, resulted in flooding that knocked out power throughout the Loop, forced the shutdown of the subway system, caused damage to numerous businesses, and resulted in the evacuation of about 250,000 people from the area. The flood was estimated to cost as much as $2 billion in lost revenue, tax assessment losses, and damage to the city's infrastructure.
3.2.10	London Underground (the Tube) King's Cross Station Fire	Nov. 18, 1987	31 fatalities, injuries not tallied	King's Cross station, then the busiest station in the London Underground system, is the convergence point where five Tube lines operate on four levels. There is also a ticket office below street level. A fire started in one of the four escalators linking the platform levels. The fire grew rapidly when it reached the ticket office. (The fire's rapid growth was later attributed in part to old paint and the draft created by train movements). The length and steep angle of the escalator also contributed to the fire's intensity.

Table 4. (Continued).

Section Number	Incident	Date	Fatalities and Injuries	Brief Description
3.2.11	BART Transbay Tunnel Fire	Jan. 17, 1979	1 fatality, 58 injuries	After a fire broke out in a circuit breaker in the fifth and sixth cars of a seven-car train, the train was stopped by the emergency brake and could not be restarted. An unsuccessful attempt to disconnect the burning cars delayed passenger evacuation by about 30 minutes, during which the tunnel filled with smoke despite activation of the ventilation system. Rescue involved taking the passengers out through the service tunnel. The fatality (a firefighter who died from flue gas poisoning) and injuries were caused primarily by gases from the combustion of plastics. The accident was attributed to lack of communication between the train operator and central operations, poor coordination, and errors of judgment, all of which made the incident a key factor in the development of National Fire Protection Association transit industry guidelines on responses to fire incidents [Ref. 2].
3.2.12	PATH Evacuation under the World Trade Center	Sept. 11, 2001	No fatalities, No injuries	Within minutes of the first plane striking the WTC, multiple Port Authority employees contacted the PATH control center to report that an unexplained explosion or fire had occurred. Based on direction from a PATH deputy director who was at the WTC, within 6 minutes the system's trainmaster was issuing instructions to conductors and operators to avoid the station. Had it not been for this prompt response, trains would have kept coming in at 3- and 5-minute intervals, unloading passengers directly into buildings that would soon collapse. This prompt response undoubtedly saved many lives.

older systems hadn't been upgraded since they opened. In the case of the European road tunnel accidents, inadequate planning led to traffic volumes far in excess of those anticipated. The excessive traffic volumes may have weakened the effect of the life safety and ventilation systems and contributed to post-incident problems.

The vast majority of incidents displayed communication gaps. Because all the incidents involved responses from a number of jurisdictions and agencies, the absence of advance planning and of emergency drills contributed to post-incident problems. Responses to the incidents were hampered by either an absence of procedures to follow or the failure of system employees to follow the established procedures and guidelines. The absence of preplanning of communications and emergency response, along with the lack of guidelines on whom to notify and when to notify them, added to the loss of life in some of the incidents and to the damage incurred in almost all of them.

The problems were apparent in the two primary areas of concern: prevention and mitigation. It was difficult to measure prevention because, in some cases, there did not appear to be anticipation of potential danger. It is impossible to plan to prevent or mitigate something that no one considers might occur.

The case studies demonstrate the need for the following:

- Interoperable communications networks;
- An empowered safety management team;
- An understanding of risk and vulnerability to realistically address prevention and mitigation issues;
- Pre-incident procedures, real-time emergency guidelines for operational personnel, and post-incident debriefing standards;
- Planning, upgrading, and testing of emergency systems on a regular basis;
- Inter- and intra-agency cross-training, tabletop exercises, onsite training, drills, and exercises; and
- An understanding of human factors.

The case studies also demonstrate the following realities:

- Absolute safety does not exist in tunnels.
- The highest priority must be given to securing escape routes and passages.
- The probability of accidents can be minimized through tunnel design and materials.
- The damage potential of accidents and fires can be reduced by installing emergency facilities and constructing fire-resistant tunnel structures.

Table 5. Role of MEC systems in case study incidents.

Section Number	Title	Ventilation	Life Safety Systems	Power Distribution	Command and Control	Communications
3.2.1	Moscow Subway Suicide Bombing	–	–	–	–	–
3.2.2	Jungangno (Chungang-Ro) Subway Station Arson Fire	U	U	U	–	U
3.2.3	St. Gotthard Tunnel Fire	–	F	–	–	F
3.2.4	Howard Street CSX Tunnel Fire	–	–	–	–	U
3.2.5	Kitzsteinhorn Tunnel Cable Car Fire	–	U	–	U	–
3.2.6	Mont Blanc Tunnel Fire	U	–	–	U	U
3.2.7	Channel Tunnel Fire	U	–	U	–	–
3.2.8	Subway Sarin Gas Attack	F	–	–	U	U
3.2.9	Chicago Freight Tunnel Flood	–	–	–	F	F
3.2.10	London Underground (the Tube) Station Fire	–	–	–	U	U
3.2.11	BART Transbay Tunnel Fire	U	U	–	U	U
3.2.12	PATH Evacuation under the World Trade Center	–	–	–	F	F

A "U" indicates that a particular system or operation played an unfavorable role in the incident, and an "F" indicates that a system played a favorable role. A dash indicates that the accounts do not say anything specific about the particular system.

- There is a need to change or direct tunnel user behavior.
- Tunnel operators must become more aware of four key areas:
  - Operations (ventilation and smoke extraction);
  - Infrastructure (direction of traffic, communication between tubes, and length of tunnel);
  - The sizes, types, and numbers of vehicles allowed within tunnels; and
  - Tunnel users (drivers' escape route and communications equipment).

3.4.3 Role of MEC Systems in Case Study Incidents

Although it is extremely subjective, Table 5 relates the case studies to the MEC tunnel systems that are discussed in Section 4.5. A "U" indicates that a particular system or operation played an unfavorable role in the incident, and an "F" indicates that a system played a favorable role. A dash indicates that the accounts do not say anything specific about the particular system.