Fire Early Warning Mechanism and Evacuation-Rescue Model for Large-Scale Subway Stations (Postprint)

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Abstract

Subway stations are deeply buried underground with complex and unique structures. In the event of a fire, they often result in substantial casualties and property damage. How to effectively prevent and reduce casualties in fire scenarios, particularly to avert major safety incidents such as mass casualties, has become a focal point and priority in fire safety research both domestically and internationally. To enable timely and effective response to fire incidents at stations, minimizing both the impact scope and losses, this paper analyzes the characteristics of fires in large subway stations, systematically introduces fire early warning systems and associated mechanisms for subway stations, and subsequently examines various personnel evacuation and rescue strategies for different fire locations within stations, which holds significant importance for fire safety research on large subway station fires and provides valuable references for subway station design and management.

Full Text

2. Characteristics of Subway Fires and Early Warning Systems

2.1 Characteristics of Subway Fires

Due to the relatively enclosed nature of underground spaces, subway station fires present several critical hazards. First, subway systems experience high traffic volume with concentrated passenger loads and limited interior space, resulting in poor fire resistance. When a fire breaks out, it can easily cause mass casualties. Second, certain decorative materials in subway stations produce toxic gases when burned, and the oxygen-deficient underground environment leads to incomplete combustion, generating dense smoke that spreads rapidly. Third, temperatures rise quickly to high peaks because of the confined environment.

Fourth, smoke accumulates and fails to dissipate effectively; damaged ventilation equipment limits smoke exhaust capacity, and the "intake" effect at underground entrances can draw escaping smoke back inside, creating asphyxiation risks. Fifth, evacuation is exceptionally difficult because upward evacuation routes require more physical exertion than downward movement, and the direction of smoke and hot airflow coincides with the bottom-to-top evacuation path, demanding higher evacuation speeds. Sixth, rescue operations face significant challenges as underground space limitations and fire conditions prevent real-time situational awareness, while large firefighting equipment cannot be deployed, increasing the difficulty of both rescue and fire suppression efforts.

2.2 Fire Warning System

The subway fire prevention and alarm system (FAS) comprises three integrated components: an automatic fire alarm system, a gas suppression system, and a tunnel fiber optic temperature monitoring system. The automatic fire alarm system handles fire detection, alarm activation, and firefighting linkage control for all station areas except gas-protected zones, as well as monitoring fire hydrant buttons and emergency telephone jacks in tunnel sections. The gas suppression system manages fire detection, alarm, and suppression control for critical equipment areas including communication equipment rooms, signal equipment rooms, environmental control electrical rooms, and high/low voltage distribution rooms. The tunnel fiber optic temperature monitoring system oversees fire detection within tunnel segments. The FAS integrates with the Equipment Monitoring and Control System (EMCS) to complete fire detection and alarm functions, transmitting fire mode signals to the environmental equipment monitoring system, which then executes coordinated control of environmental control, ventilation, and smoke exhaust equipment under fire conditions.

2.3 Equipment Monitoring and Control System

The subway Equipment Monitoring and Control System (EMCS) provides centralized monitoring of station environmental control, escalators, water supply and drainage, platform screen doors, lighting, and civil defense doors, with distributed deployment at each station and the Operations Control Center (OCC). Monitoring workstations track and record operational status and alarms for all station systems, receive fire alarm signals from the station FAS, control the transition of ventilation and air conditioning systems to disaster mode operation, and provide feedback on execution status. For fire alarms, monitoring workstations feature three-level alarm escalation, automatic alarm screen pop-up, alarm acknowledgment, and processing functions. The Manual Control Panel (MCP) serves as a backup monitoring device for the station EMCS, capable of receiving alarm information from the station FAS, generating audible and visual alarms, and initiating fire or blockage modes for the station and tunnels under emergency conditions. The overall EMCS architecture is illustrated in Figure 1 [Figure 1: see original paper].

2.4 Fire Safety Early Warning Protocol

The early warning protocol classifies fire risks into three levels based on hazard assessment, urgency, development trend, and potential damage: Level I (red), Level II (orange), and Level III (yellow), with Level I representing the highest risk. During the warning phase, comprehensive control rooms transmit video and equipment information to the EMCS platform, which then relays signals to the 119 emergency command center. The 119 command center monitors the activation status of fixed firefighting facilities including emergency broadcast systems, smoke exhaust systems, and emergency lighting; identifies the number and distribution of injured passengers by zone; and implements corresponding measures through real-time information exchange with the comprehensive control room via the platform. The subway station fire emergency response mechanism is shown in Figure 2 [Figure 2: see original paper].

3. Evacuation and Rescue Modes

When a subway station fire occurs, casualties result from toxic gases such as CO, high temperatures, oxygen deprivation, and structural collapse. The objective of safe evacuation is to remove personnel from the fire area before these hazards cause harm. The available evacuation time depends on fire intensity, smoke concentration, human tolerance thresholds, building fire resistance, and smoke control facilities. According to relevant research, evacuation must be completed within six minutes in subway accidents, as survival becomes virtually impossible beyond this timeframe. Therefore, in large subway stations, properly configured emergency response facilities and unobstructed evacuation routes are critically important. Based on different fire locations, scenarios can be categorized as: fires within the station itself, fires on trains at the station, and fires on trains in tunnel sections.

3.1 Safe Evacuation for Fires Within the Station

Fires within stations are classified as either concourse fires or platform fires, both requiring immediate emergency response and passenger notification for safe evacuation. Evacuation program development must integrate several key considerations. First, implement a staff responsibility system that links fire warning and passenger evacuation implementation to specific personnel responsibilities to ensure accountability and efficiency. Second, the duty station master should serve as the incident commander at the fire scene, issuing emergency evacuation plans and reporting to the control center. Third, advertising lightbox power supplies must be shut down while fire ventilation systems are activated. In fire conditions, the station' s normal ventilation and air conditioning mode transitions to emergency ventilation mode. Subway station fire scenarios are similar to other underground building situations, allowing for corresponding fire prevention measures and emergency evacuation plans for platforms and concourses. However, because subway stations are highly concentrated areas with limited exits, evacuation procedures must also incorporate proper smoke control facilities, necessary firefighting equipment, reasonable evacuation routes, and effective emergency plans. Additionally, selecting appropriate evacuation and rescue modes is essential. When a fire occurs on an operating train, every effort should be made to move the train to the next station to utilize the station platform for passenger evacuation and the station’ s tunnel smoke exhaust control system. If the train stops mid-section, ventilation timing and intensity must be strictly controlled, with the tunnel ventilation system’ s airflow direction maintained opposite to the primary passenger evacuation direction.

3.2 Safe Evacuation for Train Fires at the Station

When a train fire occurs at a station, the fire emergency evacuation plan should be executed immediately to prevent passengers and trains on other routes from entering the fire area while evacuating passengers through stairways and station exits. The specific evacuation procedures are essentially identical to those for fires within the station.

3.3 Safe Evacuation for Train Fires in Tunnel Sections

When a fire occurs in a tunnel section during train operation, the train should proceed to the next station whenever possible to evacuate passengers using the station platform. If the train cannot reach the next station and stops within the tunnel, immediate passenger evacuation is required. When the train head is on fire, passengers must quickly move from the rear cars to the rear station. When the train middle section is on fire, passengers must evacuate from both ends to the front and rear stations respectively. When the train tail is on fire, passengers must quickly exit from the front cars and evacuate to the front station. During this process, the tunnel ventilation system activates rapidly to exhaust smoke, provide necessary fresh air, and create favorable wind velocities to facilitate safe passenger evacuation.

Conclusions

Through analysis of large subway station fire characteristics, exposition of subway fire warning systems, discussion of preventive measures, and examination of subway fire evacuation issues, this study draws the following conclusions. First, due to the complex nature of fire scenarios in large subway stations, equipping advanced and comprehensive fire warning equipment and establishing fire safety early warning plans are particularly critical. Second, smoke and toxic gases from subway fires, limited evacuation routes, obstacles, and lack of reasonable and clearly marked evacuation pathways constitute the primary causes of significant casualties in major subway fires. Third, in addition to installing smoke control facilities, necessary firefighting equipment, reasonable evacuation routes, and effective emergency plans, selecting appropriate evacuation and rescue modes is essential for ensuring passenger safety.

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Note: Figure translations are in progress. See original paper for figures.