A Study on the People Evacuation Safety for the Underground MRT Station

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ABSTRACT

Passengers have to conduct the activity of evacuation as a large disaster takes place in a MRT Underground Station. How to escape effectively and safely for occupants evacuating from platform to ground, and the planning of escape routes are the key issues in the processes of evacuation. In order to ensure the variety of safety factors in the processes of evacuation, it would brook no delay to conduct the survey and research on the planning evacuation in MRT Underground Station. In this paper, it discusses the relationship between evacuation behavior and egress facilities design from the accident of Daegu Korea subway fire in February 18, 2003, and studies Taipei, Kaohsiung and several country city MRT system evacuation design rules, and compares those with NFPA130 evacuation design rule. Finally the conclusions and suggestion of evacuation safety for MRT system would be presented.

Key words: Underground Station; Evacuation; MRT System

1. PREFACE

A fire occurring in Daegu Korea subway on February 18, 2003 caused lots of casualties. From this accident, it can be realized that fire on the underground station may result in a great number of casualties due to the nature of the space and complexes in usages and management for underground stations. The important subject of fire safety design on underground station is the evacuation safety.

The completion of Taiwan Taipei Rapid Transportation System made the nearby area having been highly developed. Millions of people use the Rapid Transportation System for commuting. Kaohsiung Rapid Transportation System has been built in 2001, and will be completed in 2006. Subsequently, the MRT system will be the primary transportation for the commuters in the area of Kaohsiung metropolitan. Under the huge capacities of MRT system, the evacuation of passengers will become a critical issue. To ensuring the evacuation safety of passenger escaping to a safety point within the available egress time, the principles of egress systems in MRT shall be reviewed and understood. The issue for evacuation safety involves the arrangement of station facilities, and egress route design, and fire safety management of underground station, and the standard operating procedures in the event of emergency.

This paper will discuss the relationship between evacuation behavior and egress facilities design from the accident of Daegu Korea subway fire, and will study Taipei, Kaohsiung and several country city MRT system evacuation design rules, and will compare those with NFPA130 evacuation design rule. Finally the conclusions and suggestion of evacuation safety for MRT system would be presented.

2. THE CHARACTERISTICS AMALYSIS OF MRT STATION PASSENGER EVACUATION BEHAVIOR

Due to the nature of underground station space and the patterns of a disaster occurring in a ground station, it is difficult to estimate the safety level of MRT system whilst many passengers use it. Therefore, the implementation of disaster management becomes an imperative subject. This chapter addresses various explanations on MRT system space style and human behavior in fires and tabulates to illustrate the relationship between the patterns of people behavior in fires and MRT station evacuation.

2.1 The space style characteristics of MRT system

From the perspective of disaster management, we must consider following characteristics when many people use MRT system:

1. The vertical distance from the bottom of a station to ground is very long and people feel very tired when walking upward for evacuating. When a fire occurs, the propagation direction of smoke flow and evacuation direction are overlap. It will cause the environment becomes more untenable and difficult for people evacuation.
2. Egress route is limited by numbers, locations and widths of final exits.

3. Limited on the nature of space in an underground station, the information of unfolding conditions is difficult to transmit.
4. Due to the limitations in terms of occupant capacities, locations, nature light from outside, make-up air, and poison gases produced from a fire, the activities of rescue would be affected seriously by the inappropriate operations of mechanical ventilation systems.

2.2 The major characteristic of life threaten by underground station fires and evacuation behavior in MRT system

It is very important to consider the people life in the event of MRT station fires. We can discuss the connection between MRT system and people evacuation from the major characteristic of life threaten by underground station fires and evacuation behavior as follows:

1. When a fire occurs, a large number of people on the platform will evacuate simultaneously; consequently, lots of evacuees congregate in the vertical evacuation routes such as staircase and escalator.
2. Due to the limitations of supply of make-up air, and uncompleted burning producing the appearances of smoke, soot, and poison gases, the concentrations of oxygen are possible below the critical value for maintaining human life.
3. Because underground station evacuation route and the smoke flow route are overlap, the safety of people who enter the vertical route is influenced by smoke.
4. Because of the limits of egress route and the distance from platform to ground is very long, passengers will be threaten by smoke before reaching the safety point – ground.
5. Because of the piston effect and ground wind effect, it makes the complex of air current.
6. Because the air space capacity is small, it will be full of smoke and heat rapidly (train fire or electricity cable fire).
7. Because MRT station is almost a sealed space, when it loses electricity, people who lose sense of direction will become anxious.
8. Except for train fires and fires in public areas, it is very difficult to control unfolding condition and fire location whilst a fire is occurring in other areas.
9. It is very difficult to transmit the information among passengers, staff and fireman.

2.3 The connection of evacuation behavior and evacuation facility design.

In the event of an emergency, it is difficult to control the people escape inducement and habit, but the influence factors as follows should be considered:

1. The characteristic and activity of evacuation people.
2. The arrangement of space in an underground station.
3. The influence of fire protection systems and evacuation facilities.
4. Ensuring the safety of egress routes.
5. The response mechanism of fireman, user and MRT staff.

The factors of influencing evacuation behavior are as follow:
1. The practicality of other substitute evacuation routes.
2. To get the evacuation information.
3. The congestion area.
4. The experience of people evacuation.
5. The influence of environment condition.
6. The habit and background of evacuation people.
7. The characteristics of space.
Therefore, the results of evacuation behavior characteristic are illustrated as table 1:

Table 1: The connection of people evacuation behavior character and escape facility design

Evacuation characteristics	Explanation	The connection with the evacuation device design
Home Orientation	When a disaster occurs, people will return to the original route or move toward familiar routes for self-protection.	When people choice original or familiar routes, congested conditions will be shown in the main exits of staircase or escalator. Otherwise, emergency exits on the platform are seldom used for escape; subsequently, the evacuation time will increase.
Following people	We have more safety feeling when act with the people being familiar with environment	If people are familiar with the environment (for example MRT staff or driver) and those personnel giving appropriately instructions can reduce the possibilities of uncontrolled situations and casualties.
Light Orientation	Because of the smoke, the visibilities in egress routes are not clear. People prone to move toward the light direction (except for fire light)	The emergency exits, signs for evacuation direction and emergency staircases are lighted for being an approach to give instructions of evacuation.
Turning left side	When walking in the dark, right-handed people will turn left naturally.	For decreasing congestion in the intersections of escape route, egress route design should take account of the factor of turning left side.
Eluding	When people feel the situation in danger or a disaster approaching them, they will escape toward another direction immediately.	When people feel the situation in danger or a disaster approaching them, they will escape toward another direction immediately; consequently, it may result in the congestion situation in the egress routes.
Using the daily route	Occupants prefer to use familiar routes such as corridors, stairs, and exits in the event of emergency.	The people who use MRT system everyday and MRT personnel will more familiar with environment than normal passenger.

Moving toward the wide place	The wider place involves fewer obstructions; subsequently, the safety level of it is higher than other areas. Occupants have more opportunities for being alive.	The entrance of stair, escalator or emergency stair can lead to wide space.
Ostrich mind	When passengers are threatened by dangerous conditions and they cannot respond appropriately, people will choose toilet as a waiting rescue area.	Passengers can wait rescue in the toilet.
Potentiality	When people are in the dangerous condition, they can produce uncommon power to remove obstruction for escape.	In the instructions of evacuation, words and illustrations shall be expressed in ways of easy understanding.
Choosing the route being recognized easily	We can choose the first looking route as the first choice of evacuation route.	Basically, escalators or stairs set in the middle of platform can attract most passengers' awareness.
Convenient	People will evacuate in the ways of choosing labor- saving and convenient approaches.	When a stair and an escalator are set together, most passengers will choose the escalator to escape.
Moving toward the nearest route	When evacuation people do not know the location of exit, they will move to the nearest exit.	The emergency stair located in the both sides of platform is not best design.
Choosing the straight route	Most passengers will choose the easy and clear evacuation routes; therefore the straight route for evacuees is more important than short road.	Staircases and corridors should be designated in locations that can be easily noticed by passengers.
Another behavior	For example, waiting information, waiting help, calling fire station, suppressing fire, preventing smoke diffuse, warning or help other people, and so on.	Evacuation is not the first action among some percentages of people.

3. THE RULE OF MRT STATION PEOPLE EVACUATION DESIGN

The planning of circulation and egress routes of a MRT station should be designated in ways of easy, convenient, reducing congestions, and the shortest travel distance. As a result, those facilities can provide an amenity to passengers for entering train quickly and escaping the station immediately.

3.1 The safety factors of MRT station design.

Based on the passenger safety, the following items should be taken into account when designing the circulation and egress routes of MRT station and service facilities.

1. Passenger moving line

To keep the rule of passenger moving line smooth, the basic factors are directness, simplicity and continuity.

(1) Directness

The distance from ground entrance to the platform must be short. The numbers of changing direction from moving lines must be few.

(2) Simplicity

The moving line must reduce the possibilities of passenger choosing direction, and must reduce the numbers of intersection on the moving lines.

(3) Continuity

The moving line used by passengers entering the station must a continuous and the only route, and do not be interrupted by service area. In addition, the moving line capacity must be efficient, and cannot produce the phenomenon of the traffic bottleneck.

2. Setting escalator and stair

Among MRT station entrance and concourse and platform, the numbers of escalator and stair must set based on occupant loads. Not only do the occupant loads on the platforms and staircases fulfill normal operation but also emergency. For avoiding traffic bottleneck occurring in the concourse, the escape egress capacity from concourse to ground must more than the escape capacity from platform to concourse.

3. Passenger safety

Considerations for passenger safety in MRT station are illustrated as follows:

(1) Platform width: when the length of platform is a fixed value, platform width means the area of the platform affording to contain occupant loads in the normal operation peak hour and emergency condition.

(2) Emergency escape time: when an accident occurs in a station, passenger escape time from platform to concourse, and from concourse to the safety point, cannot exceed the safety time required in the NFPA 130 code.

(3) Escape route load: every escape route load must fit escape requirement (including stair, escalator, fare gates, and entrance).

(4) Escalator design standard: because MRT station installs high-capacity escalators (0.65m/sec), it must contain safety device and increase the clear width between the car and the both sides of the enclosure.

(5) Platform door: platform door can prevent passenger fall to the track area.

(6) Toilet: toilet must be set in the nearby of service office, and it should be avoided to become a crime and arson place.

(7) Space dead angle in the public area: the public area of platform and concourse must have

not any space dead angle.

(8) Fireproof design and fire protection system: related fireproof design and fire protection systems installed in MRT station must fulfill the statutes.

(9) Exit and entry: the size of exit and entry must meet the requirement of normal operation and emergency evacuation.

(10) Facility for disabled person: disabled-person elevator must be offered between concourse and platform in the underground station. The location must be installed in the same direction with exit and entry elevator, in order to reduce the disabled people move distance. The moving lines for normal and disable people should be separate in order to avoid the interruption.

3.2 The principles of design and arrangement of egress route

Due to the phenomena of thousands of passengers being assembled in a station, it is very important to ensure the safety and arrangement of egress routes in the event of an emergency. The primary key points are described as follows:

1. Except for the area of the platform, egress routes should be set sufficiently in the public areas to meet the requirements of evacuation. The occupant loads of exits in concourse areas shall be larger than ones in the platform.
2. Egress route design should be able to ensure that passengers can finish evacuation within available egress time. Therefore, the maximum travel distance and travel distance in one direction should be limited within 60 and 40 meters.
3. The egress routes should be compartmented with fire doors and fire walls.
4. The arrangement of the exits on the platform should make passenger to disperse or assemble easily along with the platform.
5. The public devices in the concourse must be separated with passenger flow routes.
6. If escalator and stair cannot satisfy the requirement of station emergency evacuation in normal time, emergency stairs should be set as additional routes.
7. The public stairs must server every floor of the station, but those cannot connect with mechanical room.
8. If facilities on the egress routes would result in congestions, those should be set far from the egress routes.
9. The setting locations of advertisement signs should be limited and cannot influence the egress signs.
10. Fire doors in the emergency staircase shall be opened toward evacuation direction.
11. As passengers evacuate in the tunnel area, the direction of exhaustion should be opposite to evacuation direction.
12. The level difference between track and platform is quite large. Therefore, ladders should be set on the both sides of platform to provide as a stair for passengers walking upward when passengers escape from tunnel area.

3.3 The calculation method of MRT station evacuation time.

The fire safety design and the calculation evacuation time method, in the NFPA 130(Standard for Fixed Guideway Transit Systems) have been detailed illustrated; therefore, those in NFPA 130 can be widely utilized for a principle of evacuation design in every country. The calculation approach used in Taipei MRT system for estimating evacuation time is revised from NFPA 130, and it based on the principle of NFPA130 can satisfy Taipei MRT system scenario.

1. Assumptions of Emergency condition

In order to set design standard, the impossible occurring conditions are not involved in the design requirement. The worse case is assumed that a delayed fire train involving the maximum capacity of passengers enters the station on the peak time.

2. The design criteria of emergency condition.

The worst case scenario and the considerations of evacuation are the design criteria of Taipei MRT system. For the criteria of MRT design, passengers on the platform should be reach emergency exit within 4 minutes; they can reach the safety of a place within 6 minutes. If the station is a multi-floor construction, egress time, 6 minutes, should be added 2 minutes per added floor.

4. EXPERIENCE OF OTHER SYSTEMS

4.1 London Underground System

In 1989, London Underground Limited(LUL)undertook an in-depth review of their Station Planning Guidelines for existing and new lines. A document published by LUL in 1991 provides the philosophy and requirements which have been employed in the design of the Jubilee Line extension. The document embodies many of the features of NFPA 130; however, in recognition if the practical difficulties in designing underground stations to conform with the 6-minute station clearance time in NFPA 130, the document introduces the concept of a “Protected Route” as being the point of safety within the station envelope, rather than grade or the exterior if the station. The protected route is required to provide an unimpeded path to the street. Generally, it is felt that the use of fire doors would impede evacuation speed and increase the risk of confusion to passengers. By virtue of the strict control in the need to use noncombustible materials in the station, combined with the compartmentation required of service rooms and other non-public areas from the circulation routes, the Document requires forced ventilation, i.e., pressurization, of the station to maintain a tenable atmosphere in the protected routes. This is accomplished by the use of tunnel ventilation supplemented where necessary by a station smoke extraction system. Figure 1 is the protected route.

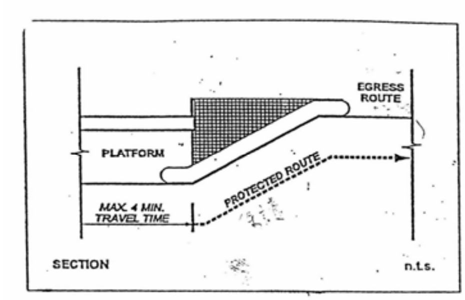

Figure 1 The protected route

4.2 Toronto Transit Commission, Canada

In 1992, the Ontario Ministry of Municipal Affairs and Housing formed a committee in response to a request from the Toronto Transit Commission, to develop regulations for the design of Rapid Transit Stations for inclusion in the Ontario Building Code. Again, the principles of NFPA 130 were followed, but with significant variations. Egress requirements for Rapid Transit stations in the Ontario Building Code(OBC)are based on the following premise:「A station is essentially a facility providing a pedestrian link between trains and the street or other modes of transport」.

1. The worst case scenario is assumed to be an emergency condition on board a train arriving at the station platform which would require the evacuation of passengers in the train and other people already in the station.
2. The evacuation requirements are based on a specified time for a person to travel from the most remote point on the platform to enter a protected route.
3. The protected route requires ventilation to maintain a tenable atmosphere for the people evacuation from the platform.

4.3 General Analysis of Protected Routes/Areas

Compartmentation is required based on the concept that all public circulation areas are considered to serve as both the normal and emergency exit routes from the platform, and that a portion of those routes will be designed to comply with the requirements for a protected route. As such, all non-public areas are fire-separated from the circulation routes. Where a concourse is provided at an intermediate level between the platform and street level, the OBC considers the concourse to be a compartment boundary (fire separation) and only permits stairs, escalators and elevators to penetrate through the concourse (floor assembly).Elevator and other openings are required to be enclosed by fire separations to maintain the compartmentation between the concourse and platform level.

5. An Analysis of Daegu Subway Fire Evacuation Question

This paper discusses MRT system evacuation design and fire safety in Daegu subway.

5.1 Fare gate is a stumbling block for evacuation.

From the experience of Daegu subway fire, there were many dead and injured in the fare gate which showed the fare gate will block evacuation. We find that the fare gate is not high and is not difficult for passenger to evacuate; when a fire occurred, the gate is in open condition. Furthermore, the height of fare gate is about 1 meter, and passenger can jump through the fare gate easily. But it shows the fare gate is a stumbling block for evacuation obviously in this fire. Based on the analysis of people evacuation characteristics, at fire time, it can be concluded that passengers changed their evacuation directions when the space is filled with smoke and is dark. Further, fare gate is a familiar place for passenger, when a fire occurred, there are many people will evacuate to this place and it will have a bottleneck effect naturally. Passenger who cannot go through the fare gate smoothly will reduce the evacuation speed.

5.2 The importance of emergency light in the underground station.

After Daegu fire, we interviewed some survivors. According to their descriptions, the subway station was dark throughout the station and full of smoke. They felt panic. Fortunately, their cellular phones have light function, and they depend on the small light to find the direction of exit in the underground station. From this case, we can analyze if underground station have the emergency light function, those facilities will help many people to escape. Moreover, we find the emergency direction light in Korea subway is big style. It is not lighten in normal time; however, the emergency direct light will function as one fire or another accident occurs. But it does not have emergency direction indicating light set on the ground. In Taipei MRT system, every station has the emergency direction indicating light which is set on the ground. Instructed by those facilities, people will find the exit direction quickly in the smoke environment.

5.3 When MRT system has fire, getting down to the track to evacuate is a feasible method.

In the experience of Daegu subway fire, it can be noticed that many people, in the whole process of evacuation, escaped toward tunnel leading to another station, and saved their life. This activity is different from the required procedure in Taipei MRT system emergency evacuation process because it is inconvenient to evacuate in the tunnel. The track is not flat, and the tunnel is dark as well. Korea subway has sky cable to supply electricity, but it is different in Taipei MRT system which has the third track electricity system. In the beginning process of evacuation, we must consider the question of off-electric to avoid the second disaster. From Daegu subway fire, we can discuss that it is possible in Taipei MRT system to occur the tunnel evacuation in the future, but we must consider some safety step, for example, tunnel light, distance label, and so on. In this paper, we must discuss the differences between Korea and Taipei MRT system. In Daegu subway fire, so, there are many people dead in the No.1080 train because the car door cannot be opened. If Korea MRT trains have the evacuation ladder set in the first car and the last car, passengers can use them to escape when the car door cannot be opened. We can believe will reduce death and injured. However, doors on Taipei MRT train car just can be opened manually from outside of the car in emergency condition, but those on Korea MRT train can be opened manually and simultaneously from inside of the car. Therefore, passengers on Taipei MRT trains have to utilize the emergency doors set in the first car or the last car for escape. The emergency response mechanism of Kaohsiung MRT system is that passengers evacuate by means of the maintain-use sidewalk in the tunnel and doors on train must be opened. If the train driver cannot open car doors immediately in the first time, it will lead to more dangerous conditions.

5.4 The discussions of evacuation start time in the underground station.

The process of calculating evacuation time in NFPA 130 is not considered the evacuation start time. This approach assumed that occupants will start to evacuate immediately in the break of an emergency. However, most passengers are unfamiliar environment and usually wait more information or instructions; subsequent, the pre-movement time increases. Therefore, the calculation approach in NFPA130 is discreditable. From the Daegu subway fire, many pictures illustrate that the passenger still have no response and just sit in the seat although smoke has flowed into the train car. This condition is hardly understood. This is weak of evacuation consciousness. When we calculate the evacuation time, we do not take account into the pre-movement time; apparently it needs further study.

5.5 The discussion of operation management in underground station.

On the design phases of Taipei MRT system, it was assumed that the conditions on a train occurring fires can be noticed by means of passengers, a driver, or surveillance camera (CCTV). Passengers and drivers finding the fire can inform CSS (central supervising station) immediately. CSS will inform off-fire train to being not enter station or through the station. This style of management replies on the effectiveness and familiarity of operating mechanism when personnel face the emergency conditions. From Daegu subway fire case, we know that the evacuation time will be affected if MRT system operation management system cannot work properly. Nowadays many countries use the ITS (Intellectual Traffic system) to reduce labor, but the uncertainty is increased. When MRT system has fire, we must enforce evacuation guideline. In consider of rescue, we think about MRT system must need more fire device.

6. CONCLUSION AND SUGGESTION

From above discussion and analysis, we make some conclusion and suggestion as follows:

6.1 Conclusion

1. Evacuation conducted in the tunnel is possible when underground station has fire.
2. The calculating evacuation time of NFPA 130 does not take account of the pre-movement time.
3. Since Daegu MRT station platform has not set emergency evacuation stair, these will have bad influence for the whole evacuation.
4. According to the survivors, they find the exit by using cellular phone light function, which shows the important of emergency light in MRT station fire.
5. From Daegu subway fire case, there are many people dead near the fare gate, which shows fare gate is a stumbling block of evacuation.
6. ITS (Intellectual Traffic system) is used to reduce manpower, but the safety factors of operation management should be considered when the system is utilized.

6.2 Suggest

1. We suggest that the temporary refuge areas should be set in MRT system. For disabled people, it is very difficult for them to escape using ladders when they face high and difficult walking stair or escalator. In addition, their activity will decrease the travel speed of normal people walking on the stairs and cause the congestions on the staircases. Figure 2 shows temporary refuge areas can be arranged at the protected staircases. This place should install two-way communication system, make-up air facilities, and a sign indicating instructions.

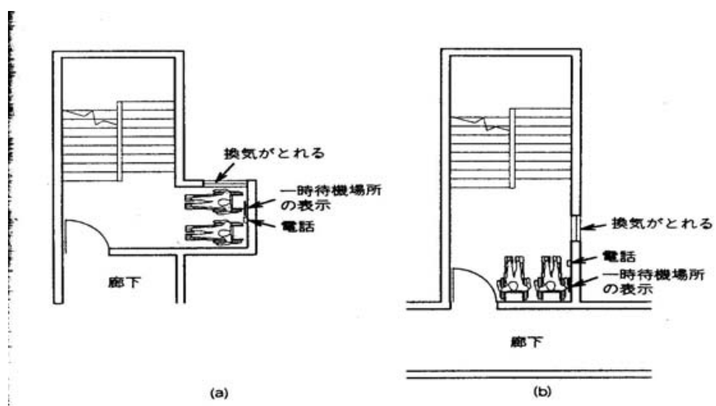

Figure 2: MRT system temporary refuge area

2. Emergency light plays a very important role in the event of fires. The evacuation direction lights in MRT system have been embedded in the ground; therefore, passengers can follow those facilities to find the locations of exits even in the dark or environment filled smoke.
3. Except for fixed emergency lighting devices in MRT system, it suggests that additional flashlights can be installed on the sidewalls or columns; subsequently, occupants can use those flashlights in the event of an emergency.
4. To decrease the evacuation start time, the numbers of the detector and CCTV in a train car can be increased. In addition, the driver in the train car can check the location of original

fire by means of CCTV, and can quickly adopt emergency response.

5. For cases of MRT station or train fires, passengers may adopt the activities of evacuation in the tunnel. To ensure the evacuation safety, the related facilities, such as ladders located in driver room, divices used to open car door, lights and distance signs, should be installed completely.
6. Because fare gate is an obstruction resulting in congestion, it suggests that a two-way opened gate is the better choice in underground station design. Except for the two-way opened gate, the gate should be designated to open fully in the event of a fire; therefore, passengers can negotiate gates quickly.

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