Safety Risk Analysis and Countermeasures Study on Regular Mass Passenger Flow of China’s Urban Subway

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Abstract

In view of the normalization and complicate trends and current situations of China’s mass urban passengers, this article determines the definition of “mass passenger flow” and its judgment standards, analyzes causes for mass passenger flow and safety problems it brings about, and concludes with suggestions on prevention and response measures on mass passenger flow phenomenon.

1. Definition of Mass Passenger Flow and Current Situations

The so-called mass passenger flow refers to the case that during a certain operation period, the number of passengers waiting and staying at a rail transit station reaches the maximum passenger capacity, or the actual passenger capacity of trains exceeds the original design, and the passenger number continues to increase. According to the predictability, mass passenger flow can be divided into predictable mass passenger flow and sudden mass passenger flow. And according to its causes and characteristics, predictable mass passenger flow can be divided into workday mass passenger flow, holiday mass passenger flow, event mass passenger flow, and bad weather mass passenger flow.

Currently, mass passenger flow phenomena at different degrees appear in Beijing, Shanghai, Guangzhou, Shenzhen and other big cities with large-scale rail transit network, and those phenomena tend to be regular and complicated. As for Shanghai, workday passenger flow of over 9.5 million passengers and over 10 million weekday passengers will become the new normal state. And the average daily passenger traffic intensity per kilometer of Guangzhou has reached 24,600 passengers/kilometer-day as the top in China, exceeding 19,700 passengers/kilometer-day of Beijing and 14,400 passengers/kilometer-day of Shanghai [1]. The rail transit capacity of Beijing and Shanghai has accounted for about 50% of the transport capacity of the whole city, close to transport capacity limit.

Aiming at mass passenger flow, subway operation units carry out flow-limiting and dispersion measures at platforms, halls and doorways. Beijing currently has 63 stations with regular flow-limiting measures, Shanghai has 34, and all transfer stations in Guangzhou carry out regular flow-limiting measures; all these have brought great challenges to the public safety of subway.
2. Judgment Standards on Mass Passenger Flow

Currently, judgment standards on mass passenger flow of different cities are more or less alike. Take Beijing as an example. Its judgment standards are as follows:

1. Centralized passenger flow reaches 70% capacity of doorway;
2. Walking speed in passageways is below 0.75 meter/second and subsequent passenger flow continues enter passageways;
3. More than 5 people in line waiting at ticket gates, and passenger flow continues to increase;
4. After 2 subway trains in the same direction, 1/4 passengers remain on the island platform, 1/3 remain on the side platform;
5. Segments with over 100% section load factor for trains departing;
6. Segments with over 100% section load factor for trains departing of transfer lines.

3. Causes for Mass Passenger Flow

3.1. The deviation of predicted passenger flow results in transport capacity shortage

The predicted passenger flow is the most important basis for the design, construction and operation of subway lines. Currently, according to investigation and survey, the large error of this value is an important reason resulting in mass subway passenger flow. Take Beijing Subway Line 4 opened in 2009 for example. Its predicted average daily passenger volume in initial stage is 781,200 passengers; the predicted value for short-term passenger volume is 903,600, and long-term 1,090,800. As of this year, however, the actual daily passenger of this year reaches 1,132,000, exceeding the long-term forecast. Due to insufficient prediction, Shanghai Subway Line 6 and 8 adopted the C-train, causing transport capacity shortage and crowded passenger flow right after its opening. And Line 16 opened at the end of 2013 didn’t learn a lesson from these two lines but adopted trains with 3 carriages. After its opening, almost all stations along the line need flow-limiting measures.

3.2. Planning changes bring passenger flow explosion around subway

At present, subway is an important driving force in the process of urban construction, playing a crucial role in population dispersion of city center and industrial transfer. In most cases, the development of a city goes together with its subway lines. Driven by economic interests, changes in urban planning become possible. In general, it takes at least 5 to 6 years from the planning to the completion of a subway line. Subway passenger flow is forecasted based on the overall urban planning and regulatory plan at the moment of planning. But after the subway construction plan is approved, driven by economic interests and the needs for urban development, large-scale residential districts, large business districts and other crowded areas which didn’t exist in original overall planning will be constructed around subway stations, causing passenger flow explosion after the subway opens and increasing the subway operation risks.

3.3. Severe “tidal phenomenon” leads to concentrated passenger flows

Rail traffic network is featured with relatively concentrated morning and evening peak passenger flows. According to statistics, the daily morning and evening peaks (7:00-9:00, 17:00-19:00) account for approximately 30%-40% of total passenger flow, and this phenomenon is especially severe for suburban lines. As result, subway passenger flows are highly concentrated in short time and evacuation is extremely difficult.

3.4. Extreme passenger peak during important events triggers mass passenger flow

During various large-scale sports and cultural events, subway stations around venues play a major role in passenger transport. Especially after the end of the event, relevant stations will receive a wave of extreme passenger peak in a short time. Besides, the subway operation interval is longer than morning and evening peak hours, so it is more likely to trigger mass passenger flow.
3.5. Transfer passenger intersection leads to mass passenger flow

Mass passenger flow phenomenon is particularly serious in each rail transfer station where transfer passenger flows from different directions can easily form intersection in a station, causing passenger congestion. For example, Shanghai Subway currently has 41 transfer stations (1 four-line transfer station, 11 three-line transfer stations, 29 two-line transfer stations), transporting approximately 4 million transfer passengers daily, accounting for 46.7% of total daily passenger flow. Among these stations, 29 are transfer stations within inner ring, and transfer passenger flows in the central city area are in high pressure. Most of the early transfer designs adopted “zero transfer” and “single transfer point for multiple lines”. With small space and a short distance, collision and intersection can easily appear in passageways, stairs, etc., increasing stampede risk.

3.6. Potential emergencies may cause mass passenger flow

It mainly refers to operating rail line failure, natural disasters, fires, jumping on rails for suicide, man-caused damage, terrorist attacks and other emergencies which force the train to stop and cause operation delay. As result, stranded passengers in stations and on platforms cause mass passenger congestion unpredictable.

3.7. The evacuation standard is too low

Currently, subway evacuation system is primarily designed based on the “Code for design metro” [2]. The number of people for evacuation in this specification has a large deviation with relevant building evacuation standards and with the actual situation, resulting in insufficient capacity of station entrances, escalators, staircases and transfer channels. In addition, the requirement on the station hall area in this specification is too stringent which limits underground station concourse area to 5000m2. This will result in limited passenger storage space and traffic capacity, especially for the transfer stations. During peak hours, passenger flow with high density and fast moving speed has large inertia and is difficult to be stopped. Once passengers push each other and fall, dangerous accidents are likely to occur instantly.

3.8. Security check blocks evacuation exits

Security checkpoints of rail transit station are set in front of ticket gates. Each station usually has two security checkpoints with security check equipment and isolation railings on evacuation routes, hindering the speedy passage of personnel. According to field research, security channels tend to cause passenger congestion at peak hours.


With the normalization and increasing complexity of mass passenger flow, rail traffic safety situation is facing many new problems and challenges, mainly including the following aspects:

- Firstly, risk response and disposal measures on mass passenger flow are inadequate.
  1. Some stations with regular mass passenger flows lack normalized system guarantee on response and disposal measures targeting at specific time frames. The common practice is to assess daily passenger flow and then initiate emergency plan. In particular, some transfer stations operated by cross-sector companies have preventive measures with limited cooperativity, and have no normalized working system and work practice, thus facing the problem of “relying on emergency response to dispose normal risks”.
  2. Stations are short of real-time and accurate early warning and monitoring tools. Currently, most of the mass passenger flow risk assessments rely on personnel’s field observations and experience, with strong subjectivity and narrow coverage. Without accurate, real-time early warning and monitoring at specific risk points, this kind of assessment lacks scientific quantitative criteria.
  3. Passenger flow guidance systems and containment facilities are inadequate. Some stations face the following problems: passenger guidance signs are not visible; entrances and other important parts lack remote warning prompts; mass-passenger-flow risk points implementing normalized diversion and flow limiting have not yet installed isolation facilities, or installation positions of a part of isolation facilities are inappropriate and block emergency evacuation routes, etc.

- Secondly, the mass passenger flow damages the original subway evacuation system and increases stampede risk.
  At present, most rail stations are underground stations with closed structure. With platforms and tunnels in deep underground (the deepest point in Chongqing reaches 60 meters), subway stations have limited space, tortuous channels,
complex structure, narrow spacing between the carriage and the tunnel, low visibility in tunnel, and tunnel floor inconvenient for walking due to tracks and signaling equipment; all these factors will increase evacuation difficulty. Mass super-mass passenger flows frequently occur in some stations at morning and evening rush hours. Due to a serious shortage of emergency exits and evacuation routes and their insufficient clear width, these passenger flows reach or exceed designed long-term peak passenger flow, bringing great pressure to fire evacuation system of the subway.

In addition, security check facilities, various self-service equipment and other commercial facilities increased by the station later, as well as fixed flow limiting handrails, have changed the original evacuation system to some extent. During peak hours, some stations with mass passenger flows tend to form congestion points at stairs, escalators and other narrow places, and form passenger flow intersection at stairs, passageways and platforms, thus having increasingly prominent mass passenger stampede risks. In case of fire and other emergencies, evacuation will be difficult.

- Thirdly, the mass passenger flow increase dynamic security risks within the station which are difficult to be disposed.

  In the context of mass passenger flow, some new safety issues and hazards within rail traffic area become increasingly apparent, such as smoking in the station, taking the subway with flammable and combustible materials and dangerous goods, extreme events, etc. And in the case of mass passenger flow, panic crowds may cause disorder in an emergency situation. They can hardly be controlled or guided, thus resulting in high stampede risks. Besides, subway staff and police officers can hardly arrive at the scene rapidly, which also increases disposal difficulty. For example, on April 20, 2015, at Huangbeiling Station of Shenzhen Subway Line 5, a female passenger fainted on the platform and made passengers to be panic. Some passengers fled and stampeded, causing confusion onsite and more than ten people were injured [3].

- Fourthly, mass passenger flow results in overloaded operation of some subway facilities and equipment.

  Rail traffic area is equipped with lots of electrical facilities and equipment. Under the pressure of mass passenger flow, some of the facilities and equipment in overloaded operation for a long time are likely to malfunction and cause a fire.

5. Countermeasure Suggestions

Based on the above analysis, the following measures are suggested in order to further optimize the rail transit planning, construction and operations management, and improve the ability to respond to and prevent mass passenger flow risk:

(1) Optimize rail transit planning and construction.

  First, reserve adequate safety space. Given the sustained and rapid growth trend of rail transit passenger flows, the author suggests to reserve adequate safety space on the new line planning, appropriately raise standards on station design and transport capacity planning, and establish the passenger forecast evaluation mechanism for train-purchase planning stage (about two years before the completion of the station), thus alleviating the risk of mass passenger flow caused by mismatching between transport capacity and traffic volume.

  Second, balance traffic load of subway network. Accelerate the planning and construction of the second loop line in suburbs, and appropriately increase transfer stations in suburbs, thus solving the prominent contradiction of suburb commuters concentrating in the central city for transfer, and relieving pressure and risk brought by mass passenger flow in subway network of central city. The city center should not establish transfer stations involving more than 3 lines any more. Reduce the “intensive transfer on single line” and “concentrated transfer at single station”, appropriately extend the transfer distance and broaden the transfer channel, thus fully improving passenger storage capacity and traffic capacity, and effectively reducing congestion and intersection risks of transfer passengers.

  Third, improve urban public transport organization level. Study on and optimize passenger flow connection between rail transit stations and peripheral bus stations, transportation hubs, large-scale exhibition centers, as well as sports, cultural and commercial centers. Avoid the condition of passenger flows concentrating in a single entrance and improve the microcirculation of passenger flows around the station by dispersing bus stations, extending the audience (customer) departure passageways and other measures.,

(2) Unify and raise standards.

  First, unify relevant standards. For the different requirements on hall area and evacuation design in Code for design metro and Code for Fire Protection Design of Buildings [4], carry out relevant research, and improve safe evacuation design of subway in accordance with the principle of strict requirements.

  Second, increase emergency exits. During design phase, we shall not simply consider the convenience of escalators, but shall ensure the number and width of evacuation stairs and entrances in the station. In regard to evacuation mode design, focus on people-oriented principle and prevention, and take into account the evacuation of young and old, sick and other vulnerable groups; as for the existing stations, consider increasing the station stairs, escalators, entrances and exits according to the actual situation.
(3) Optimize operation management of rail transit.

First, improve passenger flow risk assessment and monitoring and early warning mechanisms. Regularly analyze and assess the normal section of the peak passenger flow and the effectiveness of regular flow-limiting measures of entire subway network, single line and station; and timely adjust regular flow-limiting scope and operation modes. Establish “Big Data Study and Judge Platform of Mass Passenger Flow of Rail Transit” to implement the comprehensive analysis of the real-time data of station gates, cellular signaling data and scanning data, WIFI monitoring and scanning data, and video surveillance data of passenger flows in hidden danger spots, scientifically determining the risk level of specific hidden danger positions and sending out early warning in time.

Second, establish normal response and precautionary measures. Clearly divide stations with regular mass passenger flows into normal flow limit Grade 3 and Grade 2 stations. Appoint duty personnel point by point according to normal regulatory requirements, set passenger flow guidance signs and isolation facilities appropriately, fully prepared for onsite mass passenger flow guidance according to regular mass passenger flow periods. Accelerate the unification of transfer station management systems to achieve the integrated management of transfer stations by a single operating company. Improve the operation dispatching ability of the whole subway network and reduce the phenomenon of bidirectional trains of multiple lines arriving at a station simultaneously.

Third, improve passenger flow guidance and containment facilities. Optimize rail passenger guidance system; increase guidance signs, large LED screens and loudspeakers at entrances, transfer channels and other mass flow risk points; and timely broadcast passenger flows of subway network, flow-limiting and diversion measures and other guidance information. In accordance with the principle of “limiting passenger flows inside the city (rather than outside the city) and long-distance trips (rather than short-distance trips)”, choose sites with large passenger storage space and better evacuation conditions to scientifically set up flow-limiting pints; set isolation facilities, unidirectional transmission of escalators and other measures, so as to guide passengers to take long-distance bypass and one-way passage, reduce traffic pressure on traffic bottlenecks of the station, as well as risks of passenger congestion, intersection and collision.

References