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Optimization of Emergency Evacuation Behavior for Sudden High Passenger Flow in Resilient Hubs

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Abstract

With the changes in natural environment, global urban development has entered "resilience" development stage, and resilient cities' development has been clearly made the important component of high-quality urban development in China. The construction of resilient transportation hubs is a prerequisite and foundation for the construction of resilient cities. Emergency management capabilities and evacuation efficiency are important indicators of the development level of resilient transportation hubs. The study combines the concept of resilient transportation hubs with sudden large passenger flows, explores the characteristics and influencing factors of emergency evacuation behavior of sudden large passenger flows in the construction of resilient transportation hubs, identifies the core issues in the evacuation of sudden large passenger flows in resilient transportation hubs, and explores the scientific nature of the physical structure of resilient transportation hubs, the systematic nature of emergency evacuation management mechanisms Propose optimization strategies in terms of professionalism in emergency evacuation management of sudden large passenger flow, as well as passengers' own emergency evacuation and response capabilities, to provide theoretical support for the construction of resilient transportation hubs in major cities.

Keywords

Resilient Transportation Hub, Sudden Large Passenger Flow, Emergency Evacuation Behavior, Optimization Research

1. Introduction

With the frequent occurrence of global warming and natural disasters, the development of "resilient cities" has been the key component of city construction

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in international society. In 2020, the "Several Major Issues of the National Medium and Long-term Economic and Social Development Strategy" first pointed out that it is necessary to formulate urban development plans under the guidance of the idea of ecological civilization and the overall national security concept, to build livable cities, resilient cities, and smart cities, and establish high-quality urban ecosystems and security systems. The "Transportation Network Resilience" evaluation system, which reflects the requirements of building a strong transportation country and is also an important indicator for measuring the development level of resilient cities, was proposed the "National Comprehensive Three-dimensional Transportation Network Indicator Framework" in the same year, and the "Outline of Building a Strong Transportation Country" also points out the importance of building resilient transportation.

With the economic development, the diversification of travel modes and routes requires the better transportation capacity and service level. As a key node in the entire urban transportation network, transportation hubs also need to continuously improve their ability to resist risks while completing transportation tasks. The development of resilient transportation system is inseparable from the construction of resilient transportation hubs, which are an important foundation for serving economic development. With changes in the natural and economic environment, emergency capabilities and efficiency have become the core content of resilient transportation construction.

The ability and efficiency of emergency evacuation and handling of sudden large passenger flows are important indicators of the development level of resilient transportation hubs. Sudden large passenger flow is a surge in passenger flow in a certain period, including sudden passenger flow, passenger flow backlog and greatly exceeding daily or expected passenger flow, which is characterized by unpredictability and uncertainty. As a distribution and transfer center for passenger travel, transportation hubs often detain many passengers due to peak travel hours, extreme weather, large-scale events, emergencies, etc., exceeding the scope of daily passenger transportation. If a sudden large passenger flow cannot be effectively, timely, and safely evacuated in a short period of time, it will cause passenger accumulation, not only seriously reducing traffic efficiency and service level of high-speed railway stations, but also causing congestion and stampede incidents, and even causing casualties and economic losses, leading to safety accidents. Transportation hubs need to have a certain level of resilience to respond to emergencies. How to control operating costs, give full play to the advantages of resilient transportation hubs, alleviate passenger congestion in transportation hubs, guide passenger flow to evacuate safely, and ensure the smooth operation of the transportation system are important issues that need to be solved.

2. Literature Review

2.1. Resilient Transportation Systems

The concept of "resilience" was initially applied in the field of engineering, and the study of the resilience of transportation systems began with Hansen (1992)'s Hansen study of the impact of road closures after earthquakes. Regarding the concept of resilience in transportation systems, Murray-Tuite (2006) believes that resilience reflects the operational ability of transportation systems in abnormal situations and the recovery speed of systems after damage. Berdica (2002) defines the ability of a transportation system to recover to its initial state after external damage as resilience. Liu et al. (2020a) believe that resilience is the ability of road transportation systems to continuously respond, adjust functions, and quickly restore to normal operating conditions during external disturbances. Pan et al. (2021) hold that the resilience of transportation systems as the ability to resist external interference and threats, absorb losses caused by internal disturbances, and ultimately restore to their original state.

Chen et al. (2022) analyzed the resilience of the urban road public transport system with the example of the resilience of the public transport system in the extremely heavy rainstorm disaster in Zhengzhou in 2021. Lv et al. (2020) constructed a road network resilience evaluation system from the perspective of efficiency. Freckleton et al. (2012) explored indicators for evaluating the resilience of transportation systems from the perspective of factors such as passenger demand and travel time. Kilanitis & Sextos (2019) considered the damage of earthquakes to transportation systems, quantified the degree of disaster damage, and evaluated the resilience of transportation systems. Yuan et al. (2019) established a resilience assessment method based on three dimensions and two scenarios to evaluate the resilience of highway systems. Kasmalkar & Suckale (2021) quantified traffic resilience from the perspective of non-highway vehicle and pedestrian accident rates. Yin (2021) studied the resilience of urban road networks to different types of disturbance factors from both structural and functional perspectives. Ni et al. (2021) analyzed the resilience of urban road traffic systems based on parameters such as traffic flow allocation rate and commuting efficiency as key indicators of resilience.

In recent years, the comprehensive exploration of emergency incidents and resilient transportation construction has become a hot research topic at home and abroad. Wang et al. (2020) proposed suggestions for the development of resilient cities in China based on the construction of resilient cities in Boston. Liu et al. (2020b) proposed suggestions for establishing resilient transportation systems and conducting emergency management in the context of epidemic prevention and control, based on the experience of building resilient transportation systems in other countries and in combination with emergency research. Li et al. (2020) proposed epidemic prevention measures for resilient urban transportation systems in the context of epidemic prevention and control by analyzing the characteristics of sudden public health events.

2.2. Evacuation of Sudden Large Passenger Flow

The research on crowd evacuation patterns in foreign countries started early and has developed relatively mature. Givens (1963) first proposed the concept and theoretical framework of crowd evacuation. Afterwards, scholars conducted in-depth discussions on this issue and studied the issue of crowd evacuation through crowd surveys, emergency simulation, and other methods. Mainly studied macro and micro models (Yang et al., 2014). Lovas constructed a macroscopic model to simulate the macroscopic movement of pedestrians under emergency evacuation conditions (Lovas, 1994). Hughes (2002) derived the control equation for human flow based on a fluid dynamics model. Parisi (2005) explored the impact of pedestrian body factors such as gender, age, and physical condition on pedestrian speed.

In terms of the study of pedestrian traffic characteristics, Fruin (1971) was the earliest to conduct research, summarizing and analyzing the physiological and psychological factors that may affect pedestrian activity, the relationship between pedestrian density and pedestrian movement speed, and introducing the theory of highway traffic "service level" into pedestrian movement research. Afterwards, scholars both domestically and internationally actively conducted research on pedestrian traffic flow. Stahl (1982) conducted a detailed exploration of evacuation models in emergency evacuation situations. Li (2008) constructed a pedestrian traffic flow model based on the behavior patterns of three types of passenger flows: inbound, outbound, and transfer. Lam & Cheung (2000) found through actual observations that the relationship between pedestrian flow speed and flow conforms to basic traffic flow characteristics. Hoogendoorn & Daamen (2005) found that pedestrian traffic flow can exhibit a zipper effect with pedestrians as the main feedback for effective information in congested situations, and Helbing & Johansson (2012) conducted empirical research on pedestrian congestion evacuation dynamics from both qualitative and quantitative perspectives.

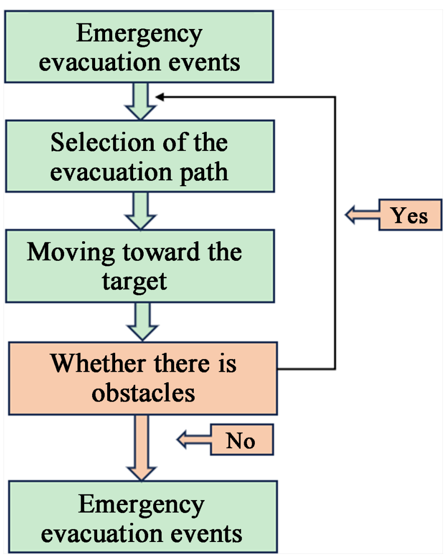
The evacuation problem of sudden large passenger flow has also become a hot research topic for scholars. The research on the evacuation of sudden large passenger flow mainly includes emergency evacuation, organization, and flow line design of passenger flow within passenger transportation hubs. Burghardt et al. (2013) studied the impact of the characteristics of staircase facilities on pedestrian flow. Lan (2018) investigated the actual passenger flow situation of hub stations during holidays and used risk and countermeasure management thinking to organize and optimize large passenger flow. Yang et al (2011) calculated the walking speed of passengers in different areas, while Li et al. (2009) explored the passenger flow density and walking speed of subway stations, and studied the capacity of bottleneck channels. Chen et al. (2008) modeled and calculated the evacuation time of passengers in subway stations, while Guo et al. (2009) analyzed the relationship between passenger attributes, psychology under emergency evacuation conditions, education level, etc. through a questionnaire survey.

The specific meaning of resilience will vary depending on the field of study and the object of study, and the study defines resilience as the ability of the transportation system to return to its original normal state when it is invaded by external aggression and to develop a better system operation mechanism through difficulties and challenges. This paper combines the concept of resilient transportation hubs with sudden large passenger flows, discusses the characteristics and influencing factors of emergency evacuation behaviors of sudden large passenger flows in the construction of resilient transportation hubs in key station areas of Beijing-Tianjin and Hebei Province, identifies the core problems in the evacuation of sudden large passenger flows in resilient transportation hubs, and proposes evacuation optimization strategies.

3. Characteristics of Emergency Evacuation Behavior in Sudden Large Passenger Flow

The causes of sudden large passenger flows can be varied, but can be broadly attributed to four types: holiday travel peaks, large-scale events, extreme weather and emergencies. For example, during holidays such as the Spring Festival and National Day, concerts and gatherings, heavy rains, heavy snowfalls, hurricanes, or catastrophic events such as fires, floods, and earthquakes, many passengers gather in a short period of time in the transportation hub. Resilient transportation hubs should have certain emergency response and recovery capabilities, and in the event of a sudden large passenger flow, the evacuation process usually follows the principle of "emergency evacuation event, selecting the passenger flow evacuation path, guiding passengers to move towards the evacuation target, reaching the evacuation target", and the evacuation process is shown in Figure 1, which indicates the key role of ensuring the smoothness of the evacuation route.

In resilient transportation hubs, the emergency evacuation behavior of sudden large passenger flow is essentially a collective behavior with a cluster effect. The



Source of information: drawn according to the rules issued by Ministry of Emergency Management of the People's Republic of China, https://www.mem.gov.cn/gk/zfxxgkpt.

Figure 1. The evacuation process of sudden large passenger flows.

characteristics of individual behavior in passenger flow are the fundamental factor of clustering effect, and the integration of all individual behavioral traits of passengers determines the overall effect of emergency evacuation for sudden large passenger flow. From a dynamic perspective, safety and survival needs are essential characteristics of individual behavior in emergency evacuation of sudden large passenger flows, which have a significant impact on the overall evacuation effect. During the evacuation process, individuals may engage in some irrational behaviors, such as conformity, delay, competition, and companionship, which are typical and logical escape behaviors.

The fundamental reason for the emergence of herd behavior is due to deficiencies in passengers' self-awareness and ability to make rational decisions in emergency situations, and thus choose to follow many passenger movements. The fundamental reason is that individuals lack trust in the information they possess and do not accurately grasp the environment. Conformity generally leads to congestion and delays the evacuation process, but not in all environments, conformity behavior can lead to adverse outcomes. During the emergency evacuation process of aviation passengers, herd behavior has a significant delay effect at the middle cabin door of the aircraft, causing clustering and forming "unilateral congestion". However, when both the front and rear emergency exits of the aircraft are available, herd behavior did not cause a significant delay effect, but instead accelerated the overall evacuation efficiency. The same situation exists in transportation hubs such as trains and cars. When there is only a single exit, single stair, and other single facilities, herd behavior reduces evacuation efficiency, while for resilient transportation hubs with multiple evacuation exits, evacuation efficiency is improved.

Delayed behavior mainly refers to the reaction and preparation process of passengers before evacuation in the event of an emergency, including obtaining evacuation information, gathering among travelers, and organizing personal belongings. The consequences of delayed behavior are influenced by factors such as resilience hub layout and individual heterogeneity of evacuation behavior. If the layout of the resilience hub is reasonable, the evacuation signs are clear, the evacuation channels are wide and unobstructed, and the evacuation behavior is individual and rational, then the evacuation speed is faster, the efficiency is higher, and the delay time is relatively small.

The main manifestation of competitive behavior is survival competition, such as in the evacuation scene of a flight accident or a hub fire evacuation scene. Under the influence of danger, complex external environment, and personal fear, individuals hope to quickly get out of the predicament and obtain safety. In this situation, competitive behavior is prone to occur during the evacuation process, which presents a state of disorder and mutual competition. This behavior is very evident in the competition for space, and is also the reason for the phenomenon of "competition delay" and "competition acceleration".

Companion behavior refers to two or more individuals walking together, which allows individuals to maintain a companionship with their peers. Compared to walking alone, it requires more space, and this behavior characteristic is more evident during emergency evacuation. In addition, due to the accompanying behaviors of gathering, mutual assistance, and communication during the evacuation process, walking speed is reduced. Companion evacuation behavior is also accompanied by waiting, searching, gathering, and returning, prolonging the entire evacuation process. Companion behavior has an impact on both evacuation speed and evacuation space.

4. Analysis of Factors Influencing the Emergency Evacuation Efficiency of Resilient Hub with Sudden High Passenger Flow

4.1. Passenger Behavior Factors

The behavioral factors of passengers themselves play a central role in the evacuation of sudden large passenger flows in resilient transportation hubs. In emergency evacuation, the subjective behavior of passengers is influenced and controlled by personal thinking, and the influencing factors are specifically manifested as physiological factors, psychological factors, and other factors.

Physiological factors refer to the differences in passenger's objective physiological conditions, leading to differences in evacuation speed and efficiency. Physiological factors such as age, gender, and physical health status. From the perspective of evacuation response and efficiency, male young adults are the most efficient in emergency evacuation. After encountering sudden emergency situations, young adults have strong perception, quick response, agile behavior, sufficient human functions, and relatively stable psychological state. From the perspective of gender factors, female passengers are relatively prone to psychological panic, evacuation and escape actions are relatively slow, and step size and frequency do not have advantages. The elderly, children, pregnant women, disabled individuals, and others are the "vulnerable groups" who evacuate and escape from dangerous disaster accidents. They do not respond quickly enough and have slow escape speeds, which are the key groups that need to be paid attention to in emergency evacuation.

Psychological factors have the most significant impact on passenger behavior during emergency evacuation. As an internal influencing factor, psychological factors affect passengers' level of understanding of the environment, as well as their time to receive and respond to emergency information. They interfere with behavior, speed, and path selection, not only affecting evacuation efficiency, but also causing irreversible damage to personal and property. Firstly, when individuals are evacuated in environments with limited space, unclear evacuation routes, blurred evacuation signs, and chaotic evacuation, passengers may experience panic, leading to loss of normal rationality and judgment, panic, and increased burden on already crowded evacuation routes; Secondly, when evacuees are unfamiliar with their environment, their cognitive patterns are prone to change during emergency events, leading to a passive mentality and delayed passenger response, resulting in the loss of the initial important evacuation opportunity; Thirdly, passengers' blind obedience and fluke mentality can also affect their normal evacuation speed, potentially leading to collective errors and missing the optimal evacuation time, which will lead to a decrease in overall evacuation efficiency in sudden disaster accidents and an increase in passenger casualties. In addition, impulsive psychology can also have a significant negative impact on evacuation efficiency. For example, in the event of a fire, passengers who cannot escape quickly lack rational judgment and choose to jump from high windows or floor fences regardless of height, which can easily lead to passengers falling or even dying.

In addition, factors such as personal cognitive level, educational level, disaster escape experience, luggage carrying, and familiarity with the physical structure of transportation hubs can all affect evacuation efficiency, such as the number and proportion of passengers carrying luggage, the quantity and type of luggage, and whether passengers have received evacuation and evacuation training. Usually, the familiarity of passengers with terminal buildings is directly proportional to the evacuation effect. In unfamiliar environments, most passengers will focus on signs and fresh things around them, or move with the mainstream of the crowd, which will affect the speed of passenger flow.

4.2. Physical Structural Factors of Resilience Hub

The physical structure of a resilient hub is also a major factor affecting its ability and efficiency in emergency evacuation of sudden large passenger flows. Reasonable structural design, smooth passage, wide space, easily recognizable evacuation guidance signs and clearly marked escape routes will make evacuation in emergency situations relatively easy.

The reasonable layout of the physical structure of the transportation hub and the sufficient space for evacuation and escape routes are important factors that affect the evacuation efficiency of passengers themselves. Although complex buildings can achieve more functions of the station, if the space for passenger evacuation and escape is occupied by other functional buildings, it will pose a hidden danger to the safe evacuation of passengers. Physical structure, transportation facilities, building materials, ventilation and lighting, fire protection facilities, and obstacle distribution have a significant impact on the evacuation effect. The impact of building structure on evacuation effectiveness is most prominent, mainly reflected in three aspects: the complexity of the building, the location of evacuation exits, and the passing capacity of evacuation paths. In addition, different attributes (such as nature, status, distribution, etc.) or different times, weather, and seasons of emergency events that cause sudden large passenger flow can have an impact on the evacuation effect. Such as Beijing Daxing International Airport, which is comparatively newly built and the building structure is comparatively more effectively designed for evacuation than other formerly built ones.

The guarantee ability of emergency facilities is the basic guarantee for safe evacuation. In case of sudden large passenger flow, the evacuation facilities and equipment in the resilience hub can play a normal evacuation function to alleviate the danger caused by accidents, which can earn a certain amount of time for passenger evacuation. Such as alarm devices, evacuation indicator lights, fire emergency lights, etc., can all play a role in rapid evacuation in a fire. In many cases, delaying the occurrence of hazardous accidents can often greatly reduce the losses caused.

4.3. The Experience and Level of Emergency Management

The experience and level of emergency management by emergency evacuation managers directly affect the efficiency of emergency evacuation. Managers with rich experience in emergency evacuation management and high quality in emergency management can handle emergency events calmly, and play a decisive role in guiding, handling, organizing, and coordinating sudden large passenger flows, as well as formulating emergency evacuation strategies. On the contrary, incorrect instructions may be issued, which both fails to organize evacuation and causes serious consequences.

The formulation of emergency evacuation management strategies in the event of a sudden large passenger flow also affects and even determines the speed and efficiency of emergency evacuation. The emergency evacuation strategy includes the emergency evacuation strategy conveyed to the passenger flow through various media, the linkage strategy of guidance, evacuation and emergency function of emergency facilities, as well as the psychological and emotional guidance strategy of passengers, and the connection strategy of evacuation traffic.

5. Major Issues in Emergency Evacuation of Sudden Large Passenger Flow in Resilient Hubs

5.1. The Physical Structure Design of the Resilience Hub Is Not Perfect Enough

The current design of evacuation corridors for resilient transportation hubs is insufficient. In the case of sudden large passenger flow, the emergency evacuation efficiency is directly affected by the surrounding evacuation channels and evacuation flow lines. The scientific and reasonable design of evacuation channels and evacuation flow lines is an important guarantee to ensure that passengers can quickly identify evacuation routes and evacuate efficiently. However, at present, the physical structure of most resilient hubs is imperfect, and the design of evacuation streamlines is reasonable, but the total width of evacuation does not meet the evacuation requirements of the maximum number of agglomeration people. If there is a lack of effective guidance and management during the evacuation process, it may cause congestion and stampede.

In addition, the emergency guidance signs are not set up reasonably. Emergency guidance signs are signs that help passengers determine their location, quickly judge and choose the fastest evacuation route. Especially in the obvious location of the station, there should be clear and unambiguous wayfinding signs. However, although many resilient hubs have installed relevant emergency guidance signs, their location is not obvious enough, especially in railway transportation hubs, there are no special evacuation indication signs in the hall, and traffic direction guidance signs are usually set on the ground, which is not eye-catching enough to make passengers quickly notice them. Some other smaller navigation sign icon shapes are also not clear enough, resulting in the difficulty of icon identification, and this unreasonable guide icon design can also increase the passenger flow evacuation time, and even mislead the passenger flow evacuation direction, increase panic, affect the evacuation speed and efficiency.

5.2. The Emergency Evacuation Management Mechanism Is Not Systematic Enough

The emergency organization and management system of most resilience hubs is not systematic. In terms of emergency evacuation management and related system design, there is currently no systematic, standardized, and professional standard system for resilient transportation hubs. Many of the relevant emergency evacuation management measures and institutional structures are modeled after the fire and evacuation standards of civil buildings, and most of them have not formed a corresponding management system with strong pertinence and heterogeneity for different hub systems such as aviation hubs, railway hubs, and highway hubs. In actual operation, the allocation standards of internal security organization personnel have rarely been scientifically certified and analyzed, and the design of relevant emergency management positions is not scientific enough.

In addition, the content of emergency evacuation drills is not systematic. Judging from the actual inquiries and the review of emergency evacuation records, most of the drills of resilience hubs are mostly single and local drills, and lack of systematic and multi-departmental coordination and linkage of comprehensive drills. At the same time, the setting of the drill environment is relatively simple, which is quite different from the situation of emergency evacuation of real sudden large passenger flow, and there is a lack of sufficient number of passengers to participate in the drill process, and the insufficient number of passengers is not conducive to improving the emergency response awareness and ability of the staff, and it is also difficult to quantitatively analyze the evacuation and escape efficiency of passengers under different quantities, resulting in the drill being more of a formality, and it is difficult to reasonably estimate and quantify many influencing variables in the real situation.

5.3. The Level of Emergency Evacuation Strategy Is Not Professional Enough

The handling of emergency evacuation of sudden large passenger flow reflects the resilience of the resilience hub and the level of emergency handling. After an emergency occurs, from the initiation of emergency response procedures, the reporting of relevant information, the transmission of core information, to the formulation and implementation of emergency strategies, all reflect the professional level of emergency management and emergency response of emergency commanders, managers, and operation staff in the resilience hub. Most of the staff of human hub lack the theoretical knowledge base and practical experience of emergency management, which is manifested in the problems of relatively weak emergency response ability and relatively low degree of emergency specialization in emergency evacuation, and the professional handling ability of emergency evacuation needs to be continuously improved.

The professional level of emergency evacuation and response is not professional enough, which also reflects the lack of comprehensive emergency plans for resilient hubs. Only by formulating all kinds of emergency plans in an all-round and professional way can we minimize the impact on public safety and minimize casualties and property losses in the event of an emergency evacuation event with a large passenger flow.

5.4. The Emergency Evacuation Plan Is Not Operational

The emergency evacuation plan of the resilient hub is to quickly and efficiently establish a command system, formulate evacuation strategies in a targeted manner, and organize the evacuation of large passenger flows in a timely and effective manner, to minimize possible casualties and property losses as much as possible and minimize the impact on the transportation order of the hub. At present, the emergency plan of most transportation hubs in Beijing-Tianjin and Hebei Province is still relatively general, although the emergency management leading group is clarified, the responsibilities of the emergency command center and other relevant organizations are designated, and the emergency management system has been established, but the specific departments and units such as hub passenger transport, safety, technology, and police stations are still relatively vague in the actual emergency evacuation. At the same time, there is no accurate and efficient information sharing platform, resulting in the process of emergency evacuation and disposal, only to form a comprehensive symmetry of information, coordinated and unified processes, clear rights and responsibilities, and effective and consistent linkage of the disposal mechanism. When an emergency really occurs, the personnel of the relevant units and departments are not clear about their own responsibilities, they are not familiar with the process of incident disposal, and the specific contact information of each unit and department is not clear, and the emergency evacuation plan is not operable when dealing with emergencies, and the linkage mechanism is not flexible enough.

In addition, in the handling of emergency plans for transportation hubs, professional publicity and education for passengers is still insufficient. Many transportation hubs are not enough for ordinary passengers' emergency publicity and education, and many passengers in airplanes, railways and public transportation systems do not know how to use emergency evacuation and escape equipment correctly, and do not know how to carry out emergency self-rescue, and the publicity and education of emergency management of transportation hubs for passengers is still relatively weak.

6. Optimization Mode of Emergency Evacuation of Sudden Large Passenger Flow

6.1. Improve the Scientific Nature of the Physical Structure of the Resilience Hubs

The physical structure of the resilient hub with scientific design and reasonable structure has a direct impact on the improvement and perfection of various functions in the later hub. From the design level, considering the evacuation of passengers in the event of a sudden large passenger flow, the number of passengers, passenger herd behavior, and gathering behavior are included in the system design variables, and the form, number, width, and height of safety passages are set: 1) The setting of the entrances and exits of the resilient hub should meet the requirements of fire protection, environmental protection, collision prevention, flood prevention, and collapse prevention. The general layout should meet the requirements of resilient city planning, and reasonably plan the setting of the hub connection transportation system, while paying attention to potential safety hazards, such as power lines, water pipeline lines, market communication lines, sewer pipes, etc. 2) The graphic design and functional zoning and layout of the resilient hub should be reasonable, and the hub should have good ventilation, lighting, hygiene, disaster prevention and other conditions. All passages are barrier-free, with guide belts, barrier-free elevators or stair lifts. 3) The design of the evacuation exit meets the flow requirements and emergency evacuation needs when there is a sudden large passenger flow. Increase the number of exits, and the exit location should not be too far away from the area where the passenger flow is concentrated. In addition, leave enough space at the exit to reduce the possibility of congestion at the exit. The design of evacuation routes such as passages and exits should fully consider the evacuation capacity, first meet the evacuation space, and then consider the functional design of other aspects.

In addition to the design process, attention should also be paid to further improve the physical structure of the existing hub. For example, further evacuation signs are added to the evacuation flow line. Unclear, not easy to identify evacuation signs are also an important influencing factor affecting the emergency evacuation of passenger flow, can be added based on the existing hub physical building streamlined signs, in terms of text, graphic signs, to use eye-catching colors, symbols are simplified, humanized, textual description sentences to be concise, so that passengers can clearly understand the direction and route indicated. The width of the evacuation passage can also be further improved based on the existing physical building, and the width of the evacuation staircase leading from the hall to the platform can be widened and improved to meet the effective width requirements and ensure the emergency evacuation efficiency in the case of sudden large passenger flow.

6.2. Strengthen the Systematization of the Emergency Evacuation Management Mechanism

Formulate a systematic emergency plan, and the emergency management personnel of the hub should make corresponding emergency arrangements for various events that cause sudden large passenger flows, such as abnormal weather, terrorist attacks, mass riots, fires, and public health incidents. If the safety of passengers' lives and property is threatened due to flight or train delays, fires or flooding in the hub due to extreme weather, the emergency manager of the hub shall immediately report to the relevant departments and dispatch additional police forces to be on duty in the area, and at the same time cooperate with the public security, traffic police, transportation and other departments to carry out emergency evacuation.

The emergency evacuation management mechanism of the resilient hub should strengthen the management of passengers, including effective guidance and emotional comfort for passengers in evacuation. In the emergency evacuation of sudden large passenger flow in the hub, there is an obvious phenomenon of "fast is slow", that is, the more anxious the passengers are during the emergency evacuation, the more likely it is to be congested, which will reduce the overall evacuation efficiency. Therefore, the emergency management mechanism should focus on how to reasonably organize the on-site order, how to identify the law of large passenger flow, how to increase guidance in the evacuation channels that are prone to congestion, how to remind passengers to choose other routes to pass quickly, how to reduce the negative reactions to safe evacuation caused by delayed behavior, herd behavior, panic behavior, etc., prevent the occurrence of secondary accidents caused by emergencies, and reduce the group inefficient evacuation caused by agglomeration behavior. On the other hand, the psychological factors of passengers are one of the important factors affecting the sudden large passenger flow in the emergency evacuation, during the emergency evacuation, the passengers are nervous, and some even lose control, completely overwhelmed. Reliable prediction of all kinds of events that may cause sudden large passenger flows, rational analysis of possible harm, overall consideration of the number of passengers, herd psychology, agglomeration psychology and possible panic psychology in the event of an emergency, take special measures to appease emotions in a timely manner, through broadcasting, LED screens, etc., inform passengers of rapid evacuation, no major accidents, hub can ensure pedestrian safety and other information, relieve passenger tension.

Also, ensure that emergency facilities are always available, including evacuation facilities, firefighting facilities, and backup power. Ensure that the fire and evacuation channels are unblocked, the opening devices of evacuation doors and safety exits should be intact and effective, the opening direction should meet the setting requirements, and the lighting of the safety passage should be intact; The fire-fighting facilities are in good condition and in normal condition, and the communication, warning, alarm devices and broadcasting facilities should be unblocked and put into use; Pay attention to the inspection and management of the generator room, regularly carry out maintenance inspections, if there is an emergency, in the case of the main power failure, the generator should be started immediately to ensure the power supply of fire protection facilities.

6.3. Strengthen the Professionalism of Emergency Evacuation Management

Improve the level of emergency evacuation management of sudden large passenger flows in resilient hubs, and strengthen the scientific and professional management of passage exits in hub center areas. The evacuation width of the hub center area should be much larger than the width of the evacuation exit and evacuation staircase to ensure that the staff is in place at any time. Avoid exit congestion caused by passengers going first. Realize the one-key remote control opening of the exit in the central area in case of emergency, and strengthen the training of staff to enhance emergency awareness, so that they can arrive at the first time when there is a sudden large passenger flow to ensure the smooth flow of the exit.

Strengthen systematic fire drills in resilient hubs, and improve the emergency management level and emergency evacuation organization capacity in humanized hubs when there is a sudden large passenger flow. Carry out several comprehensive drills with multi-department linkage and many passengers to ensure that when a sudden large passenger flow event occurs, the person in charge of the relevant post can immediately and efficiently conduct on-site command and guidance, to reduce the possibility of passenger stampede accidents. Managers of human nature hubs should regularly hold fire safety emergency evacuation drills. The daily emergency training subjects should be in line with the characteristics of the hub itself, and targeted training should be carried out to strengthen the emergency evacuation management level of managers and the ability to deal with dangerous accidents. Passengers should be informed in advance of the drill, and measures should be taken to prevent accidents during the drill. At the same time, the emergency evacuation and rescue plan for sudden large passenger flow should be included in the content of safety technology training and safety publicity and education, and managers and all hub staff should be required to master emergency rescue knowledge, enhance emergency rescue awareness, and improve emergency rescue capabilities. When recruiting and hiring new workers and temporary workers, the human nature hub and its subordinate departments must also undergo emergency management professional level training, and can only take up their posts after passing the examination.

6.4. Improve Passengers' Own Emergency Evacuation Capabilities and Emergency Response Capabilities

The emergency evacuation ability and emergency response capability of individual passengers are one of the core factors affecting the speed and efficiency of emergency evacuation of sudden large passenger flow in resilient hubs. While improving the professional level of emergency management of human hubs, it is also necessary to strengthen the emergency safety awareness education of passengers. Safety publicity and education can be strengthened through posters, brochures, broadcasts, promotional videos, etc., in a conspicuous position in the hub, so that passengers can master the basic knowledge of safe evacuation, and can make correct judgments and favorable evacuation behaviors in emergency situations.

From the perspective of individual passengers, they should have emergency safety awareness during the trip, and observe, understand and be familiar with the physical situation of the hub and emergency facilities during the trip. In most cases, passengers are not familiar with the environment, layout, and evacuation layout of the station, which is extremely unfavorable for individuals to respond to emergencies. Be familiar with the surrounding environment and prevent the negative impact of herd behavior, delay behavior, and agglomeration behavior on evacuation and escape caused by individual reasons. Consciously observe, understand the evacuation channel and fire warning signs, clarify the relative distance between the location and the safe passage and the evacuation route, and take the initiative to make emergency psychological preparations. In addition, it is especially important for individuals to maintain a rational mindset. Sudden large passenger flow events have a greater impact on the psychology of passengers, especially the sudden large passenger flow caused by dangerous events, which will have a greater impact on the psychology of passengers. When evacuating, it is necessary to respond rationally to emergencies, calmly choose the evacuation route, and do not choose the wrong route in a panic. In the sudden emergency evacuation, many major personal injury accidents are largely caused by excessive tension of passengers, or even fainting, resulting in their inability to leave the scene, and also causing the surrounding crowd to easily step on the unconscious, further causing a large-scale psychological panic. Individual passengers should avoid excessive nervousness, treat emergencies rationally, strengthen their ability to overcome nervousness through psychological suggestion, improve their own willpower in dangerous situations, and cooperate rationally with guidance to evacuate quickly.

At the same time, passengers should try to avoid carrying large luggage when traveling individually. Carrying large luggage is an important factor to reduce the efficiency of passenger evacuation, if you have to carry large luggage, you should check it in advance, and only carry a small number of necessary items during the waiting period at the station, so that in the event of a sudden emergency evacuation of large passenger flow, passengers can evacuate and escape quickly. Large suitcases, large backpacks, and other items that take up a lot of space can easily make it difficult for passengers to move, and in case of an emergency, passengers can trip and even cause a group stampede. During travel, especially when you want to stay in the transportation hub for a long time, you should improve your emergency awareness and safety awareness, and check in your large luggage in advance.

7. Conclusion

With the development of resilient city and resilient transportation system construction in China, systematic and scientific emergency management capabilities will become the focus of resilient transportation system construction. How to achieve professional and efficient emergency evacuation of the resilient hub with sudden large passenger flow will be the key concern in the planning, designing and the actual operating process of Beijing-Tianjin-Hebei resilient hubs. From the perspective of emergency evacuation and the resilient hub, the study analyzed the behavioral characteristics of emergency evacuation and the influencing factors of emergency evacuation efficiency in the Beijing-Tianjin-Hebei resilient hub, identifies the problems existing in the emergency evacuation of the current resilient hub with sudden large passenger flow, and puts forward improvement measures and suggestions.

As the systematic practice of emergency evacuation of sudden large passenger flow of resilient hubs is still in the early stage of large-scale application in China, the construction and management of the linkage management mechanism of emergency evacuation of resilient hubs still lack practical cognition, and the systematic linkage and practical effects of the linkage between relevant departments, resilience hubs, station areas and transportation vehicles in the evacuation of sudden large passenger flow still lack a lot of experience and reality testing. In the future, it is necessary to continue to track and analyze the specific operation effects of the above practices among the resilience hubs, and establish a basic database to provide a quantitative basis for the emergency evacuation of sudden large passenger flows in the resilience hub system in the Beijing-Tianjin-Hebei region, and to provide a theoretical and empirical basis for the construction of the resilient transportation system in the Beijing-Tianjin-Hebei region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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