Proceedings of Business and Economic Studies, 2026, Volume 9, Issue 8
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on Enhancing Resilience in Chinese Large Cities Based on the TOD Model

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Abstract: The development of large cities is plagued by urban maladies and random internal and external disturbances, making it necessary to enhance urban resilience. By coordinating transportation and urban planning, the TOD model builds a multi-modal and three-dimensional transport network, improves the connectivity of urban space, boosts mobility, and enhances the resilience of large cities. By integrating regional functions in planning, the TOD model fosters a polycentric and distributed urban form, and improves cities' stability, flexibility, and innovativeness amid disturbances, thereby elevating the resilience of large cities. Through above-ground and underground space development centered on public transport networks, the TOD model reduces land occupation, delivers low-carbon transportation, promotes the balance between jobs and housing, preserves the diversity of natural environments, improves environmental redundancy, and strengthens resilience. The practice of the TOD model requires support from a sound institutional system. Emphasis should be placed on the compatibility and adaptability of planned spaces, and planning contents shall be dynamically adjusted in response to social development and technological progress.

Keywords: TOD; Resilience; Large cities; Urban resilience

Online publication: August 31, 2026

1. Introduction

China's urbanization rate reached 67.89 % in 2025. About two-thirds of China's population resides in cities. National demographic survey data indicate that China had 105 large cities in 2020, including 7 megacities and 14 super cities, and 19 urban agglomerations had taken shape. According to the *Notice of the State Council on Adjusting the Standards for Classifying Urban Sizes (Guo Fa [2014] No. 51)*, cities with an urban permanent resident population between 1 million and 5 million are defined as large cities. Cities with an urban permanent resident population between 5 million and 10 million are super-large cities; cities with an urban permanent resident population exceeding 10 million are megacities. The strategic layout of the "19+2 Urban Agglomerations" was officially put forward by the National Development and Reform Commission in 2016.

Large cities, super-large cities, megacities and urban agglomerations constitute the primary carriers of China's population and economic activities.

The development of large cities is subject to diverse internal and external disturbances. During rapid urbanization, the vast majority of large cities suffer from varying degrees of "urban diseases," such as traffic congestion, shortages of public resources including education and healthcare, severe air pollution, and prominent heat-island effects. As urban population size expands and agglomeration accelerates, mismatches between the demand and supply of urban functional spaces become more pronounced, exacerbating urban maladies. Industrial diversification and the growing complexity of demographic structures in large cities also give rise to multiple potential social risks. In recent years, driven by the greenhouse effect, extreme weather events such as heatwaves, typhoons, and heavy rainstorms have become more frequent, exposing numerous cities to natural hazards including heat stress, floods, and debris flows. In July 2026, several Chinese cities, including Nanning, Shenyang, and Wenzhou, were hit by floods, which disrupted partial urban functions and severely affected residents' livelihoods. Collectively, these manifestations reveal the vulnerability of large Chinese cities, highlighting an urgent need to improve their urban resilience.

Systems theory posits that every agent within a system exhibits adaptive responses to external disturbances, while mutual interactions occur among these agents. As cities represent complex systems, improving urban resilience constitutes a systemic challenge that requires consideration of interconnections across diverse subsystems. The transportation system provides foundational support for the operation of other urban subsystems, influencing and even determining their operational efficiency. Within urban-planning practice, transport planning should be coherently coordinated with the planning of other subsystems.

In his monograph The Next American Metropolis: Ecology, Community, and the American Dream, Peter Calthorpe put forward the spatial-design concept of Transit-Oriented Development (TOD). Centered on public-transit stations (e.g., metro stations and bus transit hubs), this concept advocates high-density mixed-use development within a 5 to 10-minute walking catchment, so as to enhance transport and land-use efficiency and optimize urban forms [1]. The TOD development model comprehensively addresses multiple dimensions, including urban spatial configuration, transport and land-use efficiency, urban livability and sustainability, thereby exerting systemic impacts on urban resilience. This paper attempts to explore the pathways and corresponding guarantee measures for the TOD model to enhance the resilience of large-scale cities in China by examining the relationship between transportation and urban development.

2. Literature review

Originating from the Latin word "resilio," the term resilience literally refers to "returning to an original state." Initially adopted in the engineering field, it characterizes the capacity of engineering infrastructures and facilities to recover their initial conditions and functionalities after external disturbances. Holling, a Canadian scholar, first introduced the resilience concept to ecological research. Unlike engineering systems that pursue a fixed steady state, ecological systems lack a unique stable equilibrium. Specifically, ecosystems may either revert to their pre-disturbance status or evolve toward a new equilibrium following perturbations [2]. On the basis of Holling's pioneering studies, resilience theory has been extended from natural ecology to social-ecological systems, laying a solid foundation for contemporary research on urban resilience.

Cities represent dynamically evolving organic systems composed of multiple subsystems, including natural environments, physical infrastructure, organizations and individuals, as well as social institutions and policies. Urban resilience refers to the capacity of cities to cope with and adapt to disturbances. Specifically, it describes the dynamic attributes of urban systems when subjected to shocks or changes: absorbing disruptions, achieving gradual recovery, adapting to shifts, and undergoing transformative development while maintaining structural and functional performance. According to the composition of urban elements, urban resilience can be disaggregated into four dimensions: infrastructural resilience, institutional resilience, economic resilience, and social resilience [3]. Rather than merely restoring pre-disturbance conditions or settling into a new equilibrium state, urban resilience emphasizes continuous adaptation and transformation. This aligns with the stochastic and uncertain nature of internal and external disturbances, as well as the inherent laws governing the dynamic development of urban systems.

The characteristics of resilient cities serve as reference criteria for urban development. Wildavsky identified core attributes of resilient cities, including homeostasis, high flux, flatness, buffering, and redundancy [4]. Ahern argued that resilient cities are characterized by multi-functionality, redundancy and modularization, bio-physical and social diversity, multi-scale networks and connectivity, as well as adaptive planning and design [5]. The Rockefeller Foundation of the United States selected 100 cities worldwide for its 100 Resilient Cities initiative. Its synthesis highlights that resilient cities feature key attributes such as multicentricity, distributed organization, homeostasis, connectedness, and diversity [6]. Key attributes of resilient cities are shown in **Table 1**.

Table 1. Key attributes of resilient cities

Resilience characteristics	Explanation of resilience characteristics
Connectivity	The strength of inter-connectivity among various urban subsystems reflects the density of urban transportation networks and their integration with different functional spaces, and it affects evacuation capacity, efficiency, and other factors after disturbances occur.
Liquidity	The capacity for different elements such as people and materials to achieve spatial transfer among various urban subsystems mainly depends on the efficiency of the urban transportation network and is affected by the level of integration and coordination between transportation and other systems.
Robustness	The capacity of a city to maintain stable and sustainable operation, which is reflected in its ability to keep functioning and rapidly restore normal functions when confronted with internal and external disturbances.
Adaptability	A city's capacity to adapt to the constantly changing internal and external environments enables it to continuously adjust its strategies amid dynamically shifting conditions and reach a new stable state.
Redundancy	In the urban ecological environment, subsystem functions have sufficient margins, enabling them to enhance the capacity to resist disturbances through approaches such as functional complementation and substitution.
Flexibility	The capability of a city to rapidly perceive disruptive factors and swiftly adjust its operation plans and strategies enables it to function normally under disruptive conditions.
Multicentricity	Cities feature multiple development centers, each with relatively well-rounded functions and its own advantageous industries, enabling them to withstand various disturbance factors.
Independence	The capability of various urban subsystems or centers to operate independently after being disturbed, without interfering with other subsystems or centers.
Diversity	Cities consist of multiple subsystems that adopt diverse development strategies to generate distinct forms and functions, such as industrial diversity and ecosystem diversity.

3. The relationship between transportation and urban development and the significance of the TOD model

Transportation serves as a fundamental prerequisite for the operationalization of urban functions and underpins urban expansion and morphological evolution, thereby constituting a core subsystem of urban spatial planning. Urban development generally follows an evolutionary trajectory from a monocentric structure to a polycentric framework, and eventually toward metropolitan and urban agglomeration systems. Urban spatial expansion is primarily driven by agglomeration economies; however, excessive population concentration and unregulated urban sprawl can exacerbate environmental pressure and trigger pervasive issues such as traffic congestion, which ultimately constrain sustainable urban development.

Under spontaneous development regimes, locations with superior transport accessibility tend to evolve into new urban expansion poles to accommodate growing spatial demands and mitigate spatiotemporal travel barriers. For instance, peripheral stations along major urban transport corridors and their surrounding areas often emerge as urban subcenters due to their convenient accessibility and abundant undeveloped space. To facilitate orderly urban development, municipal governments implement systematic spatial and transport network planning to guide the redistribution of population and economic activities along transport corridors, thereby shaping a disciplined and hierarchical urban spatial expansion pattern.

Densely populated metropolises including Hong Kong and Tokyo have undergone a typical transformative process: urban transport networks initially adapt to pre-existing population layouts, and subsequently reshape population distribution and migration patterns. This evolutionary process ultimately fosters a rail-dominated public transport system and forms a transit-oriented urban spatial morphology.

Like the overall urban system, transportation systems are inherently vulnerable. Such vulnerability has become more multifaceted owing to the diversification and high-speed characteristics of modern urban transport vehicles, the integration and complexity of transport networks, as well as the digitalization and intelligent transformation of transportation systems. A representative case occurred on 31 March 2026, when Wuhan's Apollo Go autonomous-driving system suffered a full-scale breakdown during the evening rush hour. Large numbers of self-driving vehicles stalled mid-journey, giving rise to substantial safety hazards. Notably, motorization and networking of transport have led to substantial compression of time-space dimensions. Once disruptions emerge, their impacts can escalate rapidly, triggering commuting difficulties for workers and students, constraints on urban material supply, and even widespread urban functional failure. To mitigate risks within transportation systems and their associated subsystems, transport planning should take into account socio-development contexts, urban development strategies, and comprehensive urban spatial master plans, so as to enhance system stability and effectiveness. As an integrated planning paradigm, TOD explicitly addresses the interrelationships between transportation and other urban subsystems.

Early formulations of the TOD model emphasized planning principles such as moderate high-density development, mixed-use land patterns, and well-connected public transit systems. With accumulated practical experiences of TOD implementation across cities worldwide, the connotation of this model has been substantially enriched. Beyond spatial planning and design, it has gradually incorporated multiple planning objectives, including integrated transit-land development, jobs-housing balance, and equitable distribution of land value appreciation [7].

Prioritizing public transit and walking as dominant travel modes, TOD helps mitigate greenhouse-gas emissions. Moderate high-density construction and mixed-function design around transit stations and along transit corridors contribute to reduced land consumption, improved jobs-housing balance, and shorter commuting distances. By alleviating the spatial-temporal dilemmas prevalent in large cities, TOD represents one viable solution for reconciling agglomeration economies and congestion costs. Based on the above analysis, the drivers of urban vulnerability and pathways for resilience enhancement are shown in **Figure 1**.

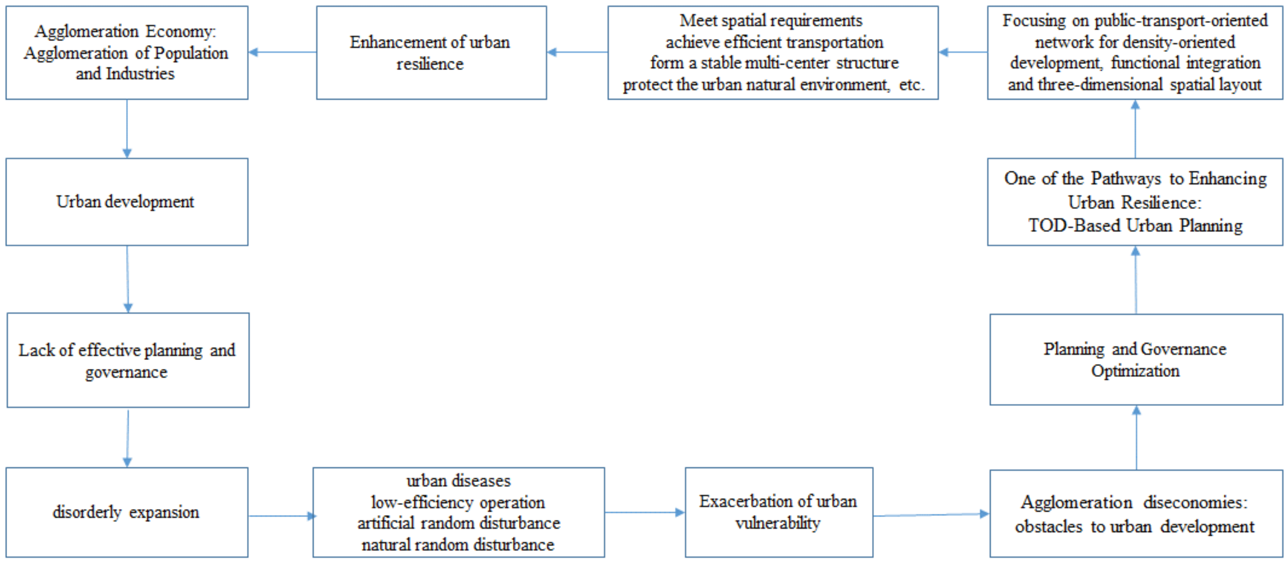

Figure 1. Drivers of urban vulnerability and pathways for resilience enhancement

4. Pathways for TOD model to enhance urban resilience

Cities exhibit varying degrees of vulnerability. Enhancing urban resilience represents an ongoing endeavor [8]. For many countries and regions, the TOD model is more than a spatial paradigm. It also functions as an urban development strategy that can improve urban resilience across multiple dimensions and contribute to sustainable development.

4.1. Functional integration enhances urban connectivity and mobility

Transport networks are regarded as urban lifelines in emergency rescue scenarios, serving as corridors for the spatiotemporal reallocation of various urban elements. Transportation within the TOD framework encompasses multiple public transit modes, including urban metro, light rail, tram, and road-based transport. High-capacity and high-frequency transit networks such as rail transit or bus rapid transit (BRT) generally undertake inter-regional transport functions, while three-dimensional slow-mobility systems and small-capacity public transit cater to intra-area travel demands within planned zones.

Taking transport networks as the structural backbone, TOD planning arranges diverse functional zones for residential, employment, commercial, and other purposes. It maximizes the embedding of transport infrastructure into functional areas to achieve seamless alignment between transport demand and supply. Illustrated by rail-transit station planning under TOD principles, rail lines function as inter-regional transport corridors. Office towers built atop stations provide direct access to transit platforms via elevators and staircases. The immediate station catchment within approximately 500 meters is dominated by commercial facilities and high-density residential developments, connected to transit stations through an elevated slow-mobility network comprising pedestrian sky-bridges, greenways, sidewalks and cycle lanes. The 500–1000-metre peripheral zone consists of low-density residential quarters, schools, hospitals and other facilities, supplemented by feeder bus services and bicycle-parking facilities to facilitate local trips and access to rail stations.

The TOD model features dense and diversified transport networks that enable high-level connectivity across various functional zones and guarantee favorable urban mobility. The pathways to enhance urban resilience are outlined as follows. First, transport demand diversion is realized. Abundant alternative travel modes and routes within the area improve safety and operational flexibility. Second, three-dimensional transport networks reduce intersections and congestion. Even under crisis scenarios, multiple travel options and redundant links can maintain network accessibility, strengthening the robustness of the transport system. Third, diversified feeder transport modes ensure high efficiency of last-mile trips. Meanwhile, since planned districts are constructed around major transit corridors, high inter-regional travel efficiency can be achieved.

4.2. Polycentric morphology improves urban stability, flexibility, and innovativeness

The TOD model emphasizes the functional integration of planned areas. Stations designed under TOD planning principles cater not only to transportation demands but also to diverse daily-life needs. Underground station spaces and areas alongside pedestrian walkways can accommodate various service amenities such as restaurants, convenience stores, vending machines, and bank outlets. Station superstructures host commercial-office complexes, exhibition centers, health-care service hubs, shopping malls, and leisure-entertainment facilities. Surrounding precincts are equipped with residential quarters, hospitals, schools, parks, and other living-service functional zones. Mixed-use development generates abundant and diverse job opportunities, increasing the potential for local employment and thereby reducing long-distance commuting. Interconnected TOD station districts along major transit corridors can further improve the jobs-housing balance within these corridors.

As a planning-and-development strategy, TOD fosters a distributed, polycentric urban form and consequently enhances urban resilience. Its resilience-building mechanisms are summarized as follows. First, monocentric urban structures suffer from high single-point-failure risks within core districts and thus exhibit low resilience [8]. By contrast, the polycentric structure shaped by TOD endows each urban center with capacities for independent operation and self-sustaining circulation. When disturbances strike, malfunctions in one center will not impair the functions of others, which strengthens overall urban operational stability. Second, TOD improves the redundancy of urban space and functions through three-dimensional development and integrated spatial utilization. For instance, underground spaces can support underground logistics and material stockpiles during disasters; amid public-health emergencies, they can be repurposed as underground hospitals or quarantine sites to enable modular management and strict isolation [9]. Third, individual TOD districts maintain distinctive features, which facilitate the development of diversified industries. Existing studies have demonstrated that industrial diversification contributes to urban resilience [10,11]. Furthermore, polycentric layouts deliver diverse workplaces and residential environments. Such settings attract talent inflows and encourage labor mobility across urban sub-centers, promoting interdisciplinary knowledge exchange and innovation.

4.3. Three-dimensional development improves environmental redundancy and diversity

During the phase of rapid urbanization, the continuous agglomeration of population and resources creates pressing spatial demands for cities, which frequently expand outwards at a rapid pace. Due to the desynchronization between planning and actual development, urban spaces often take the form of unregulated sprawl, figuratively known as “pancake-style urban expansion.” This results in chaotic spatial patterns, incomplete regional functions, jobs-housing separation, and longer travel distances.

The TOD model advocates three-dimensional development to appropriately improve land-use efficiency, and spatial expansion facilitates the integration of regional functions. Land-use density under TOD is not homogeneous; instead, floor-area ratios gradually decline outward from transport network hubs. Taking TOD development around rail transit stations as an example, well-established development paradigms have taken shape in major global metropolitan areas such as Hong Kong and Tokyo. Superstructures atop rail stations and their immediate surroundings feature high-density commercial buildings and high-rise residential blocks with the highest floor-area ratios. Low-rise residences and other functional zones are developed further away from stations, while villa districts and green spaces may appear in the outermost zones. Through three-dimensional spatial development and increased floor-area ratios, TOD builds well-equipped urban communities centered on transit stations. Meanwhile, it enhances the redundancy of urban resources and the environment and improves urban livability. First, three-dimensional exploitation of underground and above-ground spaces within station precincts substantially expands available urban space. It satisfies urban development demands while achieving intensive utilization of land resources. Second, allocating transport services and other infrastructure to underground spaces frees up more ground-level areas, which helps preserve urban green spaces and wetlands and safeguards ecological diversity.

In summary, TOD-oriented practices including public-transport prioritization, mixed-use comprehensive development and environmental improvement promote localization of employment and daily activities. These outcomes are conducive to low-carbon mobility and green lifestyles, and advance the sustainable development of large cities. Mechanisms through which TOD enhances urban resilience are shown in **Figure 2**.

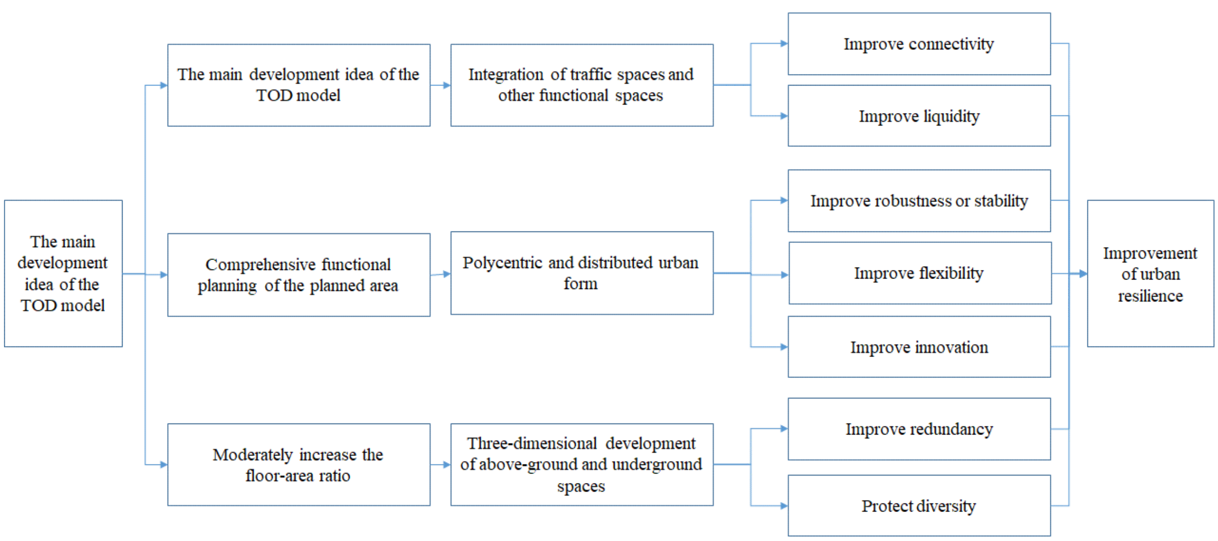

Figure 2. Mechanisms through which TOD enhances urban resilience

5. Common problems and key strategies for TOD implementation

The practical implementation of TOD faces considerable challenges, which are primarily reflected in the temporal disconnection between TOD planning and urban socio-economic development [12]. Two typical scenarios can be identified. In the first scenario, rapid population-industry agglomeration triggers land encroachment, causing TOD planning to lag behind urban development and fail to materialize. In the second scenario, mismatches between functional spatial arrangements and real-world demands, together with insufficient policy guidance, reduce the attractiveness of planned zones. Slow inflows of population and industries further erode locational advantages, which in turn dampen regional appeal and give rise to a vicious cycle. To better leverage the TOD model for improving urban resilience, several key issues deserve careful consideration.

5.1. Cities need to establish a sound institutional system for TOD

Urban spatial planning is government-led. Where planning involves multi-sector collaboration, cross-governmental agencies are required to conduct coordinated governance and establish effective cooperative mechanisms [13]. Given that TOD implementation entails joint efforts from transport authorities, land-administration agencies, urban-planning departments, and other stakeholders, a high-level cross-sector governmental organization such as a "TOD Resilience Steering Committee" should be established. This ensures consistency and continuity of TOD planning principles and resilient-city philosophies across different administrative departments.

Beyond the establishment of governing bodies and operational mechanisms, the relevant institutional framework also covers planning continuity, financial support, resilient-community governance, and resilience-oriented development evaluation. The improvement of urban resilience should be initiated at the planning stage and embedded within short-, medium- and long-term urban development strategies and planning documents. Large Chinese cities including Beijing, Shanghai and Wuhan have incorporated resilience-building objectives into their urban development and regeneration plans. Communities usually serve as the frontline in responding to various crises. Government guidance and cultivation are essential to foster disaster prevention and mitigation awareness among residents of TOD communities, as well as collaborative mechanisms among diverse organizations inside and outside communities. Sound policy instruments such as tax incentives, credit support, and rent concessions are required to facilitate the sound development of TOD practices. To reinforce the effectiveness of governmental interventions and institutional arrangements, key performance indicators for resilient cities can be incorporated into the official performance-assessment system.

5.2. TOD planning requires dynamic updating in response to economic and social development

Cities are exposed to stochastic and uncertain disturbances throughout their continuous development. Enhancing urban resilience should be embedded within short-, medium- and long-term TOD planning, and urban plans ought to be dynamically adjusted in response to shifting developmental contexts.

TOD planning requires phased implementation to avoid urban spatial idleness and waste or functional shortages stemming from temporal mismatches in infrastructure construction, industrial growth and population agglomeration. In the initial phase, priority should be given to government-led development of basic urban functions. Financial resources are preferentially allocated to build public transit networks, administrative premises, and public-service facilities covering education, healthcare, culture and sports, so that well-established infrastructure can attract the inflow of residents and enterprises. Throughout the whole development process, land parcels surrounding transit stations are leased in phases as development zones and prospective zones. Development proceeds stage-by-stage according to demographic conditions and passenger-flow volumes, with revenues generated from early-stage development reinvested into subsequent construction. Dynamic assessment of regional functions and resilience performance should be conducted to revise planning schedules and strategies, thereby achieving the goal of urban resilience improvement.

TOD strategies need to be adapted to evolving social trends. Population aging, for instance, represents a major challenge for future societal development. Urban spatial planning, design and resilience enhancement must account for the needs of the elderly. TOD spatial configurations should incorporate age-friendly housing supporting independent and comfortable living, barrier-free transport networks, community hospitals, and health-care centers. Urban resilience can consequently be strengthened by adapting to demographic structural changes.

TOD development calls for the adoption of emerging technologies and the construction of smart cities to strengthen urban resilience. Digital technologies enable real-time monitoring of passenger flow volumes and travel directions, improve the matching between transport supply and demand, and enhance the effectiveness of decision-making. Digital technologies also support forecasting and early-warning functions. For instance, digital-twin urban models simulate future urban conditions using available dynamic data, facilitating the early identification, warning, and resolution of potential problems. Such models can further analyze the impacts of alternative strategies on urban development. All these mechanisms contribute to the improvement of urban resilience.

Cities should attach importance to the flexibility embedded within the TOD model. Three-dimensional development under TOD enables functional differentiation between above-ground and underground spaces, allowing spatial functions to be reconfigured in response to diverse disturbances. Such functional transitions should be incorporated at the planning and design stage. Developing spaces featuring upgradability, easy reconstruction, compatibility, transformability, and modularity enables rapid conversion between regular-use and disaster-response functions alongside multi-functional switching, thereby enhancing urban resilience. Conversely, some scholars argue that infrastructure with rigid, fixed functions may undermine urban resilience; flood-control facilities, for example, may trap cities in an either-or predicament [14]. Beyond resilience strategies targeting physical infrastructure, diversification of organizational arrangements and response plans is also critical for enhancing urban resilience.

6. Conclusion

Large cities occupy a pivotal position in China's urban development. Enhancing resilience constitutes a critical challenge confronting large cities. As the foundational underpinning for the operation of various urban subsystems, transportation systems are central to urban functioning. At its core, the TOD model promotes transport-led urban development. By incorporating multi-faceted planning considerations—such as the interplay between transport and land use, transport efficiency, urban performance, and urban sustainable development—TOD generates comprehensive impacts on urban resilience.

The TOD model aims to plan and construct diversified and three-dimensional urban transport networks and emphasizes the integration of transport networks with other urban systems. Such practices can strengthen urban spatial connectivity and improve urban mobility, enabling cities to respond to disturbances and carry out evacuation in a timely manner. TOD highlights functional integration and operational autonomy within planned areas. It fosters a polycentric urban form and distributed operational patterns, which helps avoid the risk of single-point system failure. This improves urban stability and flexibility under disturbances and facilitates internal collaborative innovation to unlock new development opportunities. TOD calls for intensive land use and three-dimensional development of above-ground and underground spaces. On the one hand, this reduces land occupation on the surface and protects urban natural environments. On the other hand, differences between above-ground and underground spaces can be leveraged to implement spatial segregation, underground logistics, and other measures for coping with various disturbances.

The resilience enhancement of cities through TOD practices relies on a sound institutional support system. Furthermore, it requires the dynamic iteration and optimization of TOD planning philosophies in response to evolving societal development and technological advancements.

Funding

Hubei Social Science Foundation Project "Research on the relationship between rail transit and intensive and sustainable development of large cities" (Project number: 2020052)

Disclosure statement

The author declares no conflict of interest.

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