Enhancing Beijing’s Resilience by Improving Tongzhou’s Access to High-Speed Rail Transportation

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Abstract The relocation of 400,000 Beijing municipal employees to Tongzhou promises to reduce congestion and pollution in the city center. Further, the relocation could facilitate economic cooperation and integration of the Beijing–Tianjin–Hebei megaregion. Together, these initiatives can help make Beijing and Northern China more resilient, though critical issues of the connectivity of Tongzhou to the rest of Beijing and the megaregion need to be addressed. This paper focuses on two questions related to the success of these efforts: (1) How many additional commuters can be expected to use the existing subway stations in Tongzhou as a result of the relocation; and (2) How can Tongzhou be better connected to the megaregion’s high-speed rail network and a major airport. To answer the first question, a GIS-based model was used to analyze subway ridership data to estimate changes in rush hour commuters at Tongzhou’s subway stations under three scenarios. The results estimate substantial increases in commuters unless large proportions of the workers move their residences to Tongzhou. To answer the second question, a Moving Platform Infrastructure Network (MPIN) was conceptualized as an innovative alternative to provide needed access to high-speed rail and a major airport. The resulting MPIN provides fast and environmentally sensitive connections, while potentially reducing congestion at the Beijing South railway station. In addition, the MPIN concept could be used in other parts of the megaregion.

Keywords Subway • High-speed rail • Megaregion • Resilience • Regional planning

1 Introduction

As the capital of China, Beijing (2015 est. pop. 22 million) serves as the political and cultural center of the world’s most populous country [1]. Over the past two decades, and especially since the 2008 Olympics, Beijing has established itself as a contemporary world capital, with an efficient, modern subway system, an agglomeration of distinguished educational institutions and technology firms, and world-class arts, culture, and architecture. Yet, Beijing faces serious ongoing challenges from air pollution, traffic congestion, and rapidly rising housing costs as well as an ongoing flow of migrants from within China who are seeking to share in the capital’s superior services and job opportunities [2].

Beijing also is the anchor for northern China’s Beijing–Tianjin-Hebei economic megaregion (Fig. 1). Commonly referred to as “Jing-Jin-Ji” (JJJ) in China, the region covers an area of 216,000 km² with a population approaching 150 million [3]. Other than Beijing, major cities in the region include the autonomous municipality of Tianjin (est. pop. 15.5 million), and the largest cities in Hebei province, Baoding (est. pop. 11.2 million) and Shijiazhuang (est. pop. 10.7 million) [1]. The goal of the megaregion is to promote more spatially balanced development throughout Northern China. It is envisioned that the region will link the research facilities and creative culture of Beijing with the economic dynamism of the port city of Tianjin and the development...
potential of Hebei province, bringing together jurisdictions that have not worked together in the past [4]. Challenges for the region include building infrastructure linkages to support economic cooperation and integration, which are considered weaker than those found in China’s Yangtze River Delta and Pearl River Delta regions [5].

In the 1990s, the declining quality of Beijing’s natural environment, especially air quality, moved the central government to take action. As a result, some manufacturing plants were relocated from the city center to suburban areas. As the environmental challenges continued, a second wave of relocations were initiated in the early 2000s that included the transfer of the Shougang (Capital Steel) Group from Beijing to the city of Tangshan, a location considered to be more appropriately situated to accommodate emission impacts, affordable workforce housing and social infrastructure needs and offered enhanced potential for economic growth and job generation [3]. Yet, Beijing still faces important environmental and quality of life challenges. Traffic congestion and pollution remain as serious problems, and the flow of migrants from second and third tier cities, and rural areas continues. Beijing’s population is still rising and the city’s developed area continues to absorb farmland [6]. As a result of the ongoing challenges, Beijing’s most recent strategy for addressing congestion and pollution is to relocate the municipal government.

![Fig. 1 Major cities in the “Jing-Jin-Ji” megaregion](image)
center from the city center to the Tongzhou district on the southeast periphery. This initiative will move 400,000 city employees from offices within the second ring road to what is currently a relatively low density area outside the sixth ring road [7].

The experience of earlier relocation efforts suggests that careful planning is needed for the municipal center relocation to fully achieve its intended purposes. This paper assesses this major shift of jobs from the perspective of sustainability and resilience. The second section provides essential background information for understanding the resilience context of this research and emphasizes efficient transit infrastructure, including direct access to high-speed rail (HSR) and a major airport, as a critical component for the resilient development of Beijing, Tongzhou and the JJJ region. Section 3 assesses the potential impact of the municipal center relocation on Tongzhou’s subway stations and housing. Section 4 conceptualizes a Moving Platform Infrastructure Network (MPIN) as it might be used to more directly connect Tongzhou and other areas to HSR. Conclusions are offered in Sect. 5.

2 Background

2.1 Resilience

The concept of resilience comes from the field of ecology which considers resilient systems to have the ability to withstand disturbances and still maintain their essential functions; the ability to self-organize in response to disturbances; and the capacity for learning and adaptation in response to disturbances [8]. In recent years, urban planners have increasingly turned to the concept of resilience as a means of fortifying communities against the growing prospect of natural and human disturbances that threaten to disrupt essential urban services [9].

In Beijing, resilience planning is especially timely, as the city and its surrounding region prepare for continued rapid population growth in the face of uncertain social, climatic, seismic, and economic conditions. The 2004 Beijing plan estimated the city’s population would reach 18 million by 2020, but that level was reached before 2010 [10]. The current official estimate is 22 million, with a plan to limit the 2020 population to 23 million residents [11]. The growing population puts added pressure on already stressed local services such as water, sanitation, education and health care, and worsens traffic congestion and air and water pollution [12]. In 2014, the average journey to work for Beijing commuters was 19.2 km, taking 52 min, the longest average commute of any Chinese city [13]. Also, global climate change is expected to produce in Beijing higher temperatures and humidity with little wind, as well as erratic rainfall, resulting in more frequent periods with hazardous air pollution with periodic drought and flash flood conditions [14]. Further, since 2003, there have been ten 4.0 or greater earthquakes near Beijing [15] with an estimated 10% probability of a major earthquake in the Beijing-Tianjin area in the next 50 years [16]. In addition, threats to global financial stability have increased during 2016, requiring innovative approaches to support China’s (and Beijing’s) continued economic expansion [17].

The spatial aspects of resilience become especially important for addressing the increasing disparities in access to goods, services and opportunities across Beijing and Northern China. Spatial resilience deals with the durability of interconnected social-ecological systems at a citywide and regional scale and recognizes that vulnerability to disturbance, reflected in access disparities, varies over space [18]. Ultimately, spatial properties like enhanced connectivity are essential determinants of a region’s resilience capacity [18]. The relocation to Tongzhou is intended to improve regional resource distribution, equality of development, and access to affordable housing. In addition, the resulting reduced congestion in the Beijing city center can contribute to achieving a regional pattern of low-emission mobility. All of this is premised on the ideas that encouragement of non-motorized travel, transit-oriented development, and equality of access are essential for a resilient transit system [19, 20].

2.2 Challenges for Tongzhou

While moving Beijing’s municipal offices to Tongzhou is intended to decongest Beijing’s city center, there will be significant challenges for Tongzhou to accommodate the changes to its social, natural, and built environments. Tongzhou’s transit infrastructure will need to be expanded to accommodate the influx of municipal employees and potential demand for new housing. Between 2008 and 2012, Tongzhou added 252,000 residents but only 28,000 jobs, putting significant strain on the existing bus and subway services that provide access to jobs elsewhere [21]. It has been reported that residents of peripheral districts like Tongzhou are more likely to drive a car to work because the demand for the limited public transit far exceeds capacity, making the use of transit time-consuming, uncomfortable, and something to be avoided whenever possible [13].

2.3 Role of High-Speed Rail

In addition to expanding bus and subway transit services, if the residents and non-resident workers of Tongzhou are to be fully integrated into the JJJ region, efficient access to HSR is essential. Well-designed and fully implemented HSR service has been shown to increase real-estate values,
improve quality of life, reduce air pollution and traffic congestion, and provide a “safety valve” for crowded cities [22]. In China, HSR has improved market access, expanding labor markets, and enhanced spatial agglomerations [22]. In effect, by providing additional location options to firms and workers, HSR has reduced congestion and pollution within megacities and has stimulated the economic growth of nearby second-tier cities [23].

In Northern China, HSR has played an especially important role. Currently, there are five high-speed rail lines connecting Beijing to the northeast (Jing-Shen line), southeast (Jing-Hu line), southwest (Jing-Guang line), northwest (Jing-Zhang line), and south (Jing-Gang line). As part of the Jing-Hu line, the Beijing-Tianjin HSR is considered to have significantly increased integration and commercial interaction between northern China’s two largest municipalities, improved overall inter-city transport within the JJJ megaregion, and contributed to better regional cooperation [22].

2.4 Role of Airports

In addition to HSR, efficient access to other domestic and international cities via commercial airlines is essential for JJJ’s success. Currently, there are two airports in Beijing, the Beijing Capital International Airport (Capital Airport) in the northeast, and Nanyuan Airport, a smaller airport in the southern part of the city with limited expansion capacity and few commercial flights. In 2015, the Capital Airport was the second busiest airport in the world with nearly 90 million total passengers [24]. Of concern is that in 2015 nearly one-third of Chinese flights were late with air traffic control measures accounting for 30.7% of air delays [25]; this issue is compounded by the rapid increase in passengers (68%) and flights (46%) since Capital Airport’s last expansion in 2007. Anticipating that congestion could become a serious problem for the Capital Airport, a plan was approved in 2013 for the construction of another Beijing international airport in Daxing [26].

The Beijing Daxing international airport (Daxing airport) is currently under construction 46 km south of the Beijing city center, in the southern part of the Daxing district, near the boundary with Hebei province. It is expected to be complete in 2019. In addition to relieving congestion at the Capital Airport, the Daxing airport is intended to serve the expanding urbanization south of Beijing, as well as provide expanded international service for Tianjin and Hebei province [26]. Plans call for a high-speed rail stop at the airport for the Jing-Gang line which connects Beijing with Bazhou in Hebei province and then continues on to Hong Kong [26]. Also, planned is a Daxing airport subway link to the Beijing South station, which has a high-speed rail service to Tianjin and Shanghai [27].

3 Impacts on Tongzhou

3.1 Importance of Transportation Infrastructure

Located approximately 22 km east of central Beijing, the Tongzhou district covers an area of 906 km², or 6% of Beijing’s total area. In the 2010 census, the population of Tongzhou was 1.184 million residents, almost twice its 674,000 population in 2000. The Beijing municipality has set a population cap of 2 million residents for the district [28].

Currently, Tongzhou’s central business district has direct transportation connections with central Beijing via several modes of transportation. These include two subway lines (Batong Line and Line 6), a conventional railway (with service to Beijing Station), and several major highways (G1 and S15). There are no direct connections to the Beijing Capital International Airport or Beijing’s two HSR stations, Beijing South and Beijing West, as access to both requires transfers to other subway lines. As such, the relocation of Beijing municipal government offices may add significant congestion to both Tongzhou’s limited transit options and the transportation infrastructure accessing Beijing’s HSR stations.

3.2 Scenario Model

The added passenger volume on the two subway lines connecting the city center to Tongzhou may lead to much higher levels of congestion during the rush hour commutes. Estimates of the magnitude of these changes are needed to support planning efforts. To estimate the subway eastbound ridership on the two subway lines leading to Tongzhou, a GIS-based model was developed using CommunityViz, an ArcGIS extension [29]. The model analyzes smart card data for commuters using the Beijing subway stations on or inside the second ring road to estimate the number of subway commuters under a range of scenarios.

Using this scenario modeling approach, the number of commuters was estimated using four assumptions. First, because the available ridership data only provides the total number of commuters exiting a station, an assumption was needed about the portion of commuters who are municipal employees. An assumption, PropCityEmp, was devised to represent the proportion of municipal employees among the commuters who currently disembark from the central city subway stations. Second, some of the municipal employees can be expected to relocate their homes to Tongzhou after the move of their workplace. Another assumption, PropCommute was devised to represent the proportion of municipal employees who will commute from their current residence to Tongzhou after the municipal office relocation. Third, since there are two subway

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lines connecting Tongzhou, an assumption, \( \text{PropBaton} \), was devised to represent the proportion of municipal employee commuters who will use the Sihui East station on the Batong line to get to their jobs in Tongzhou, with the remainder expected to use the Jintai station on Line 6. Potentially, all the proportions associated with these three assumptions could vary from 0% to 100%. In addition, a fourth assumption was necessary to estimate additional housing demand in Tongzhou. A “Job-Home Ratio” assumption was devised to represent the number of municipal employees per household. For example, a ratio of 1.5 is assumed for this analysis, meaning that for every three municipal employees relocating to Tongzhou, two housing additional housing units will be needed.

Using the information from the four assumptions, three possible scenarios were devised with respect to the proportion of the relocated municipal employees who will live in Tongzhou. The first scenario establishes that all municipal employees will continue to live in their current homes and will commute to Tongzhou (\( \text{PropCommute} = 100\% \)). The second scenario establishes that 50% of the municipal employees will move to new homes in Tongzhou (\( \text{PropCommute} = 50\% \)). The third scenario establishes that all of the municipal employees will move to new homes in Tongzhou (\( \text{PropCommute} = 0\% \)). In each of the three scenarios, it is established that the proportions of city center to Tongzhou commuters will split 60% on the Batong line and 40% on Line 6, as is the approximate current commuter split between these lines (\( \text{PropBatong} = 60\% \)).

A final separate assumption was necessary to establish the proportion of subway commuters currently exiting the city center subway stations who are municipal employees and whose jobs will be relocated to the new municipal offices in Tongzhou. The assumed proportion could not be too low, or the decongestion benefits of the relocation would be insignificant. It was assumed that 50% of the subway commuters currently exiting the city center subway stations are municipal employees who will be moved to the new municipal offices in Tongzhou (\( \text{PropCityEmp} = 50\% \)).

The CommunityViz software, a planning support system extension of ArcGIS, was used because it allows easy adjustment of the values of the four assumptions. As new information becomes available to support assumption different values, the scenarios can be quickly re-evaluated simply by moving the assumption slider bars to the new values.

### 3.3 Scenario Model Results

Table 1 shows the estimated subway ridership and housing demand in Tongzhou under the different scenarios. The model estimates there are 220,786 morning rush hour commuters traveling to the Beijing city center. Assuming half of them are municipal office employees and they all continue to live in their current residences, about 110,000 additional commuters are expected to take the two subway lines to Tongzhou (Scenario 1). Under this scenario, commuters using the Sihui East station on the Batong Line will increase fivefold, from 15,862 to 82,098. At 82,092 commuters, the Batong Line will have more morning rush hour commuters than are currently using Line 1 in the Beijing city center (e.g. eastbound from Xidan) (Fig. 2). A similar impact is estimated for Line 6 when comparing the number of commuters using the Jintai station with commuters using the Dongsi station. Depending on the capacity of the Tongzhou stations, such large increases in commuter volume may result in significant congestion delays, and associated direct and indirect costs.

Under Scenario 2, it is assumed that half of the municipal employees will move their homes to Tongzhou, resulting in an estimated 48,980 morning commuters on the Batong Line. This ridership is just below the average ridership for the city center on Line 1 and Line 6 (about 52,000). The estimated additional demand for housing in Tongzhou is 36,798 U, about 7.5% of the estimated 490,000 current residential units [30].

Under Scenario 3, there is no expected increase in subway ridership, assuming all the relocated municipal employees will be able to walk, bike or take local buses to work, while the demand for housing in Tongzhou will increase by 73,595 U, a nearly 15% increase.

The results of the scenario modeling show that the relocation of the Beijing municipal government offices is likely to substantially increase the subway ridership (for both the Batong Line and Line 6) and/or demand for housing in Tongzhou, depending on how many of the relocated workers move their residences so they do not need to take the subway to get to work. The next part of this paper conceptualizes the design and use of an MPIN for enhancing Tongzhou’s (and the relocated municipal workers’) access to HSR. This conceptualization also takes into consideration another major development in Beijing that will impact the use and efficacy of the JJJ regions transit infrastructure, the new Daxing airport.

### 4 High-Speed Railway Accessibility for Tongzhou Residents and Workers

#### 4.1 Need for Alternative HSR Access

The subway ridership analysis illustrates that relocating a workplace without making provisions for relocating residences may create excessive demand on existing transit. This could be mitigated if a substantial number of the relocated employees move their residence to Tongzhou.
However, this may create other problems due to the lack of direct accessibility of Tongzhou to HSR stations and airports. The new Tongzhou residents and worker’s additional demand for HSR travel may add to the already significant subway and surface motor vehicle congestion near the Beijing South and Beijing West HSR stations, adding time delays, reduced productivity, and increased air and water pollution.

If a new HSR station more accessible to Tongzhou were added, this congestion may be mitigated. One possible solution would be an additional HSR station near Tongzhou. However, another problem may arise from adding the new HSR station. It takes a considerable amount of time and energy for high-speed trains to accelerate to operating speed. This time and energy is lost when trains must slow down to drop off and pick up passengers and then re-accelerate. This is why HSR stations are more widely spaced compared to slower conventional passenger rail service. Consequently, passengers on average are required to travel greater distances to reach HSR rail stations, compared with traveling to conventional rail stations which can efficiently be located closer together. Therefore, HSR stations draw passengers from an expanded area resulting in higher transit and motor vehicle volumes near HSR stations. This can exacerbate station-area congestion and air pollution, especially in already congested urban areas such as Beijing [31]. Yet, both existing HSR station congestion reduction, and travel time and energy reduction benefits could be achieved if the high-speed trains could avoid stopping to pick up and drop off passengers. The MPIN offers just such a means for transferring passengers on and off the HSR [32].

### 4.2 Potential of MPIN to Address Tongzhou’s HSR Access Needs

The MPIN concept is intended to allow passengers to embark and disembark from trains while the trains are moving, thereby making a high-speed rail network more efficient. The MPIN uses a tram system to collect passengers from local stations. The tram accelerates to match the speed and link to the HSR train, at which point passengers

### Table 1 Morning rush hour ridership on subway from Beijing to Tongzhou under different scenarios

| Scenario | Assumptions | Ridership to central Beijing | Ridership from Beijing to Tongzhou | Additional housing unit demand in Tongzhou |
|----------|-------------|-------------------------------|------------------------------------|------------------------------------------|
|          | Existing conditions (based on smart card data) | 220,786 | 15,862 | 9710 | 0 |
| 1        | PropCityEmp = 50% PropCommute = 100% PropBaton = 60% | 110,393 | 82,098 | 44,157 | 0 |
| 2        | PropCityEmp = 50% PropCommute = 50% PropBaton = 60% Job-Home Ratio = 1.5 | 110,393 | 48,980 | 31,789 | 36,798 |
| 3        | PropCityEmp = 50% PropCommute = 0% PropBaton = 60% Job-Home Ratio = 1.5 | 110,393 | 15,862 | 9710 | 73,595 |

Scenario # Batong ridership = existing ridership to central Beijing × PropCityEmp × PropCommute × PropBaton + existing Batong ridership (e.g. Scenario 1 Batong ridership = (220,786 × .5 × 1 × .6) + 15,862 = 82,098)

Scenario # Line 6 ridership = existing ridership to central Beijing × PropCityEmp × PropCommute × (1 – PropBaton) + existing Line 6 ridership (e.g. Scenario 1 Line 6 ridership = (220,786 × .5 × 1 × .4) + 9710 = 44,157)

Scenario # additional housing demand in Tongzhou = existing ridership to central Beijing × PropCityEmp × (1 – PropCommute)/Job-Home Ratio (e.g. Scenario 2 additional housing demand in Tongzhou = 220,786 × .5 × (1 – .5)/1.5 = 36,798)
Potential impacts on environmentally sensitive natural and historic areas; Total travel distance and time for all passengers, given other constraints.

The Tongzhou MPIN was conceptualized to include two linked but separate rail components (Fig. 3). The first rail component would establish a feeder tram line along the Beijing-Tianjin HSR line with a north tram station at Daxing and south tram station at Langfang, a distance of approximately 40 km. Southbound passengers would board the feeder tram at the Daxing station. Coordinated with the southbound HSR train coming out the Beijing South station, the feeder tram would accelerate to the same speed and link to the HSR train for 3 min to allow passengers to transfer. Then, the tram would delink, decelerate, and stop at Langfang station. It is estimated that the feeder tram requires approximately 20 km. for acceleration and 8 km. for deceleration. At a traveling speed of 250 km/h, the 3-min boarding period requires a distance of 12.5 km. Northbound passengers on the Beijing-Tianjin HSR line with Tongzhou, Daxing, the Daxing airport or Langfang as their destination could disembark onto a northbound feeder tram to Daxing. The feeder tram rail component would add an additional set of rails on each side of the Beijing to Tianjing HSR line for the 40 km. distance from Daxing to Langfang.

The second rail component of the Tongzhou MPIN would be a light-rail loop connecting Tongzhou, Daxing, the Daxing airport and Langfang. At an average speed of 120 km. per hour, the travel time on the light-rail between Tongzhou and Daxing or between Tongzhou and Langfang would be approximately 20 min. The travel time between Daxing and the Daxing airport would be approximately 15 min.

The alignment of the light-rail line would follow a newly established rail corridor designed to be sensitive to local features of the natural environment, such as along the Yongding River near the Daxing airport and the Grand Canal near Tongzhou, where the light-rail corridor would be part of a riverfront conservation green corridor development. This design would follow a biophilic approach, based on the concept of Biophilia for designing buildings and facilities that enhance nature, as popularized by Harvard myrmecologist and sociobiologist E.O. Wilson [37]. Biophilic cities can have a positive influence on psychological, physical, and social well-being [38]. Residents in biophilic cities are directly and actively engaged in

### 4.3 Conceptualizing a MPIN for Tongzhou

A conceptualization approach was used to as a first step in assessing the impact of an MPIN linking Tongzhou and the new Daxing airport with the Beijing-Tianjin HSR line. Conceptualization is the process of development and clarification of complex concepts [35] and serves as a necessary preliminary step before conducting a more detailed analysis. This approach is considered to be appropriate for the initial assessment of emerging innovations, such as the MPIN, where real-world applications have yet to be implemented. The approach was chosen after reviewing the available literature and recognizing that sufficient data for a conventional impact assessment did not exist and could not be collected [36].

As part of the conceptualization, an illustrative MPIN route was selected and mapped. This has been done based on the assumptions that:

- A significant number of Beijing municipal government employees working in Tongzhou, as well as others in Tongzhou, will want to board the HSR southbound toward Tianjin;
- A significant number of passengers arriving at the Daxing airport will want to board the HSR southbound toward Tianjin;
- A significant number of passengers on the HSR northbound toward Beijing will want to disembark to go to the Daxing airport; and
- A significant number of passengers on the HSR northbound toward Beijing will want to disembark to go to Tongzhou.

In addition, it is assumed that the following factors would be considered in siting the MPIN corridor:

- Distance along the Beijing-Tianjin HSR line required for MPIN acceleration, docking, and deceleration;
- Potential impacts on environmentally sensitive natural and historic areas;
- Potential impacts on current and future local economic development (jobs, housing) and property values;
- Potential impacts on current and future social connections;
- Potential for needed environmental amenities related to greenways, scenic walking and bike paths, storm water retention, etc.; and

The Tongzhou MPIN was conceptualized to include two linked but separate rail components (Fig. 3). The first rail component would establish a feeder tram line along the Beijing-Tianjin HSR line with a north tram station at Daxing and south tram station at Langfang, a distance of approximately 40 km. Southbound passengers would board the feeder tram at the Daxing station. Coordinated with the southbound HSR train coming out the Beijing South station, the feeder tram would accelerate to the same speed and link to the HSR train for 3 min to allow passengers to transfer. Then, the tram would delink, decelerate, and stop at Langfang station. It is estimated that the feeder tram requires approximately 20 km. for acceleration and 8 km. for deceleration. At a traveling speed of 250 km/h, the 3-min boarding period requires a distance of 12.5 km. Northbound passengers on the Beijing-Tianjin HSR line with Tongzhou, Daxing, the Daxing airport or Langfang as their destination could disembark onto a northbound feeder tram to Daxing. The feeder tram rail component would add an additional set of rails on each side of the Beijing to Tianjing HSR line for the 40 km. distance from Daxing to Langfang.

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learning about, enjoying, and caring for the nature around them and have developed important emotional connections with this nature [37]. The light-rail loop ecological corridors would be designed to increase opportunities for passengers to explore and appreciate the natural environment. The light-rail corridor also would provide green walking and biking trails for nearby residents, understanding that the aesthetics may be diminished by the frequent passing of the light-rail trains. The light-rail alignment along the Yongding River also would be designed to negate existing sources of stormwater runoff pollution and bolster the area’s freshwater resources.

5 Conclusions

The sustainability and resilience of a region are dependent on the patterns and dynamics of its natural, built, and social environments. In the complex context of the global marketplace, these patterns and dynamics increasingly depend on the creation and maintenance of conditions that promote economic cooperation and integration through the efficient movement of people, goods and services. With the establishment of the Beijing-Tianjin-Hebei (JJJ) economic megaregion, China has recognized the need for and potential benefits of extending the development of Beijing and Tianjin to a much larger part of Northern China. This approach recognizes that Beijing and Tianjin are reaching the physical limits of their sustainability and that a resilience strategy requires the responsive adaptability that the megaregion potentially offers. Yet to accomplish this, the efficient movement of people, goods, and services across the region is critical.

At the same time, Beijing has been required to take steps to aggressively counter problems of congestion in its city center. The relocation of 400,000 municipal employees to Tongzhou promises to reduce congestion and pollution in the center of Beijing. However, a scenario model based on
the analysis of subway ridership data suggests that the relocation could overwhelm Tongzhou’s existing subway infrastructure unless it is substantially expanded or a large proportion of the relocated workers move their residences to Tongzhou.

This study also recognizes how the relocation of workers to Tongzhou could contribute to the needed cooperation and integration for the success of the JJJ megaregion, though this largely depends on Tongzhou’s improving access to HSR and a major airport. To this end, this research conceptualized an environmentally friendly MPIN that would provide just such access. The resulting MPIN would provide substantial potential for providing fast and efficient connections to both the Jing-Jin HSR line and the new Daxing international airport, while reducing congestion at and near the Beijing South railway station.

In addition, there is potential for the future use of the MPIN concept in other parts of the JJJ region that could contribute to the region’s success as well as enhance its sustainability and resilience goals (Fig. 4). For example, a second MPIN could be used to connect Fangshan and Daxing with the Beijing-Guangzhou HSR line and the Daxing airport. This also would provide additional connections for Tongzhou to other Beijing districts in the west and southwest portions of the municipality, such as Mentougou and Fangshan, and to Zhuozhou in Hebei province. In addition, a third MPIN in the Shunyi district to the northeast of Beijing could be used to connect the Beijing Capital International Airport with the Beijing-Shenyang HSR line to northeast China.

Finally, it is important to acknowledge that this study has been premised on the importance of creating sustainable and resilient cities. The characteristics of sustainable cities include compact form, planned growth areas, and walkable and bikeable neighborhoods which contain a mix of residential, commercial, and recreational land uses integrated with highly connected public transit networks. Resilient sustainable cities have these same characteristics, and in addition have the capability to absorb natural and human disturbances while maintaining essential services. It has been important to consider how Beijing can best emerge both more sustainable and more resilient as the city attempts to resolve the two significant issues addressed in this paper. The rapid development that can be expected in

Fig. 4 Other potential MPINs in the Jing-Jin-Ji megaregion
Tongzhou presents an opportunity for planners to require compact, walkable, mixed-use development with strong public transit connections that can sustain a high quality of life for 3 million people. Likewise, the emergence of the JJJ region offers opportunities for both building resilience capacity and sustainability for both Beijing and Northern China, though neither will be automatic. Clearly, fast and efficient access and connectivity are essential. Ultimately, this study suggests that an MPIN has potential as a sustainable innovation for allowing the JJJ megaregion to cope with rapid urbanization, and the need to relocate workers and expanding high-speed rail access.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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