Research Paper

Pedestrian planning in High-Speed Rail station neighbourhoods

The case of Beijing South

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Abstract

From 110km in 2008 to 40,000 kilometres in 2021 and 70,000 projected by 2035 Chinese Highspeed Railway (HSR) has grown exponentially connects major city hubs in the country, making travelling long distances more efficient, less polluting, and more convenient.
This has led to the construction of new infrastructure, the re-development of existing neighbourhoods or the construction of new railway station neighbourhoods. The construction of railway stations is responding to a functional need to provide fast connections between cities in one of the world's largest countries. Railway stations have been designed as large hubs in China, like airports with differentiated arrival and departure levels, an ID check, a security system and ramped access for motorized vehicles. Stations often have a large waiting hall to accommodate a large number of passengers especially during peak periods.

While stations can handle passengers travelling and arriving, as they should, is this their only function? What is the role of a station in the 21st Century? How can a station not only satisfy technical requirements, but also achieve urban, social, and economic objectives? Since the 2010s, the question of integrating stations with the urban fabric has been key in China. Unfortunately, the question of pedestrian movement has still not been resolved in these station neighbourhoods, which has led to critical challenges which need to be addressed. These are pedestrian network connectivity, access to the station by active modes and active streets around the rail station.

To answer these key challenges, we refer to Beijing south station as a case study and compare it with two other stations: Paris Nord and Tokyo Station. We create an 800m buffer, or 10-minute walking buffer, around each station to compare the pedestrian environment between them. Spatial network analysis indicators will be used as benchmarks to compare different characteristics of the pedestrian network between these three stations.

Keywords

Pedestrian, transport planning, railway stations, walkability

1. Introduction

From 110km in 2008 to 40,000 kilometres in 2021 and 70,000 projected by 2035 Chinese High-speed Railway (HSR) has grown exponentially. HSR connects major city hubs in the country, making travelling long distances more efficient, less polluting, and more convenient. The development of HSR has led to the construction of new infrastructure, the re-development of existing neighbourhoods or the construction of new railway station neighbourhoods. The construction of railway stations is responding to a functional need to provide fast connections between cities in one of the world's largest countries. Railway stations in China have been designed as large hubs, similar to airports with differentiated arrival and departure levels, an ID check, a security system and ramped access for motorized vehicles. Stations often have a large waiting hall to accommodate a large number of passengers especially during peak periods.

While stations are able to handle passengers travelling and arriving, as they should, is this their only function? What is the role of a station in the 21st Century? How can a station not only satisfy technical requirements, but also achieve urban, social, and economic objectives? Since the 2010s, the question of integrating stations with the urban fabric has been key in China. Unfortunately, the question of pedestrian movement has still not been resolved in these station neighbourhoods, which has led to critical challenges which need to be addressed.

The first challenge is providing access to the station using active modes, to create a sustainable, low carbon neighbourhood. This means defining key routes from and to the station, to create a hierarchized and wellconnected pedestrian network, so that station districts can fulfil their economic potential.

The second challenge concerns pedestrian connectivity around the station. Stations often act as barriers in cities. Current station design has created fragmented urban space around HSR stations, making it difficult for people from surrounding neighbourhoods to travel across stations. Due to a car-oriented environment, pedestrian space around stations is often disconnected, creating situations where wayfinding is complex.

Finally, the last challenge is functional and economic – current stations are mono-functional, serving only the passengers. However, they are transit a transit node for both passengers and non-travellers, not only the surrounding development around stations should be multi-functional but the station itself should welcome a variety of activities to be fully integrated in the urban context.

After presenting the challenges and benchmarking Beijing south to Tokyo and Paris, in the final section of this paper we will propose potential solutions adapted to the Chinese context. Three potential solutions will be suggested to improve pedestrian integration around railway stations, which can benefit the local economy and positively impact social and environmental aspects.

2. Methodology and definitions

To answer these key challenges, we refer to Beijing south station as a case study and compare it with two other stations: Paris Nord and Tokyo Station. We create an 800m buffer around each station to benchmark the pedestrian environment. To achieve this, we use spatial analytical tools and indicators.

2.1. Spatial network

For the spatial analysis we use the pedestrian network as base for this study. The pedestrian network is coded in QGIS and is based on Open Street Maps (OSM), edited, and completed manually with satellite imagery, Google/Baidu Streetview and field knowledge for Beijing and Paris. Pedestrian streets are usually represented with a centre line, however, to better reflect pedestrian movements, space will be represented using a hybrid methodology, as shown on the diagram below:

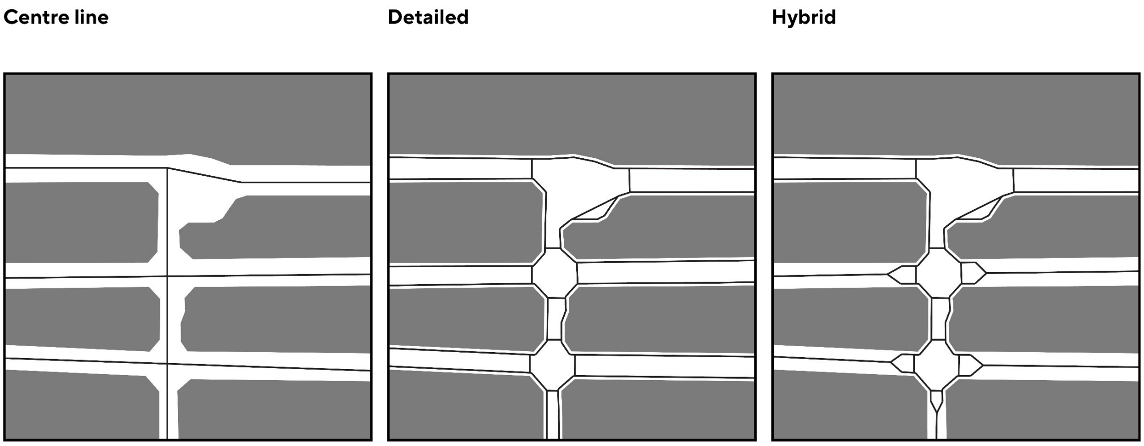


Figure 1 Spatial network coding, source Wedderburn Transport Planning

Centre lines are used when there are no obstructions on the street and people can cross freely, while a line for each frontage is used when space is segregated with fences, or when the road is too large to allow free crossing. The network is coded in 3D, it includes public indoor network, such as malls, underground tunnels, and footbridges.

Connectivity and pedestrian flow potential are the two metrics used to assess the spatial network. Connectivity is defined as the number of spaces immediately connecting a space of origin (pedestrian connections) within a catchment. The more the pedestrian connections in an area the higher the connectivity. Pedestrian movement potential is defined by overlaying the pedestrian routes for all possible pedestrian connections within a catchment. People naturally chose their routes based on the shortest and most direct route (Penn, 2003).

This study will calculate connectivity, flow potential and distance to/from the stations on the pedestrian network in an 800m buffer. The edges of the of the pedestrian network might show a lower connectivity in the study, even though the urban fabric still continues, due to a buffer effect.

2.2. Accessible Diversity Index

The Accessible Diversity Index (ADI) measures the diversity of activity in a certain radius on the pedestrian network. To assess the diversity, we use Points of Interest (POIs) as a dataset to obtain information of the main functions of a building. One building can have multiple POIs if it has many retail units or different types of functions.

Data sources are multiple since case studies are located in different parts of the world. For Beijing South station, Gaode is the preferred data source because it is one of the most complete datasets available that requires little manual editing. For Tokyo and Paris, the data is harnessed from Open Street Maps (OSM) (Zhang and Pfoser, 2019), however many missing points were completed manually based on Google Streetview and Google maps.

We created two levels of POI categories, the first level is based on Moreno's 15-minute city (Moreno,2020) and second level categories are a refinement of it, as shown on the diagram below:

Level 1 Category	**Level 2 Category**
Living	Residential
	Hotel
Working	Office
	Industrial
	Primary sectors
Commerce	Convenience retail
	Services
	Specialist retail
	Food & beverage
Healthcare	Local healthcare
	Specialist healthcare
Education	Pre-school
	School
	University
Leisure	Recreation
	Community
	Cultural
Public transport	Stations
	Bus stops

Figure 2 POI Categories

The Level 1 category regroups the main activities in a city; however, it lacks granularity to reflect land uses that generate pedestrian movement. For the purpose of this study, we use the second level of POI categories to calculate the Accessible Diversity Index. The index calculation is based on the Simpson Diversity Index(Yue *et al.*, 2017).

With this dataset we will calculate the accessibility in a 100m, 200m and 400m walking radius or: 1 minute, 2minutes and 5 minutes. The 100m radius will be used to estimate the diversity of activity on a street, while the 200m radius will be used to measure it on a block scale and finally the 400m on a neighbourhood scale.

3. Challenges

3.1. Case studies presentation

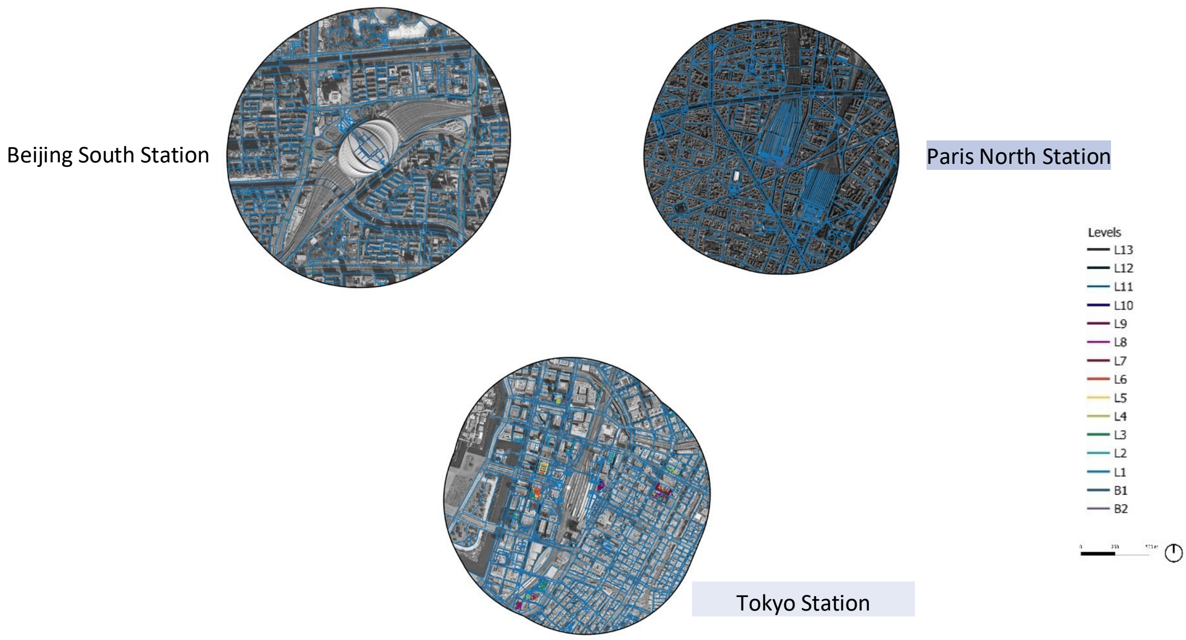


Figure 3 Station neighbourhoud pedestrian network

Beijing South station is one of the first generation HSR stations, it was built in 2008 and its first line connected Beijing to Tianjin in 30 minutes. The station is served by two metro lines (4 and 14). Located between the 2nd and 3rd ring road, in a residential area. The station is encircled by ramps, creating an island between it and the rest of the neighbourhood. This station reflects typical station developments, which is why it is a relevant case study to understand the challenges the pedestrian network faces around HSR stations in China.

Paris Gare du Nord was built in 1846, a time during which Paris was going under a tremendous transformation, city walls were destroyed to let the railway in the city, boulevards were built, etc. The station has undergone multiple extensions and developments and is now one of the busiest stations in France and Europe with almost 300 million passengers a year (including commuters). The station is compact and inserted into a dense, active, and historical urban fabric in the 10th arrondissement of Paris.

Tokyo station opened in 1914, it has been going under multiple extensions and renovations since then. The station is Tokyo's and one of Japan's main railway hubs. The station has an extensive underground pedestrian network connected to the surrounding malls, stations, and streets. It has created a highly connected neighbourhood from the pedestrian network point of view in spite of the large infrastructure surrounding the station.

3.2 A car-oriented environment harming access to Beijing South Station

Car access has priority over other transport modes, which creates large and empty spaces around the station. Car ramps and artificial empty spaces take up most of the space in front the station, reducing pedestrian access to the station (Stransky,2017) and its transport hub. Access and egress to and from the metro station takes more than 10 minutes of walking, making it inefficient to exit the station by foot and for local residents to access public transport.

Beijing's urban morphology around the station is composed of large residential blocks, with many deadends which greatly impacts the pedestrian network. Accessibility of transport hubs is key to unlock their full potential and create dynamic active neighbourhoods. While Beijing South Station has good accessibility on a strategic level by metro (Sun and Wang, 2021), pedestrian accessibility is still lacking which can reduce the neighbourhood's attractivity and vitality.

Moreover, the poor pedestrian network and lack of mass transit stations surrounding the station can create bottle-neck situations. This issue has been encountered on the field; train passengers arrived at the station after metro hours. They reached the taxi-drop-off point, however a few minutes later it was announced that the station was closing. Passengers were not able to exit the station by foot which obliged the station staff to provide a mini shuttle to reach the closest metro station to order a taxi.

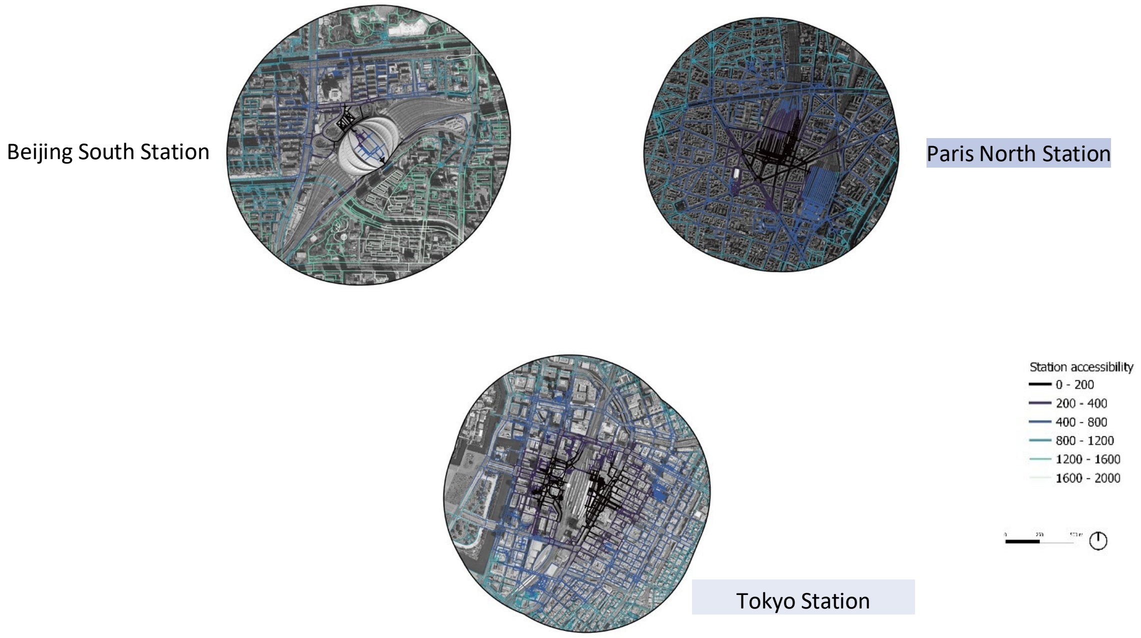


Figure 4 Stations accessibility

In the 800m as the crow-fly buffer around the station only 34% of the station is accessible within a 10minute walking distance, whereas 60% can be reached within 10-minute walking in Paris and 69% for Tokyo. Paris' morphology is characterized by many diagonals, which creates more direct cut-through routes to reach a destination. Tokyo has a finer urban grid than Beijing with smaller blocks, forming a denser pedestrian network around the HSR station. Both stations present better accessibility than Beijing South thanks to a better integration in their respective surroundings.

3.3 A fragmented and disconnected pedestrian network

Stations generally cause severance in urban space, because of the railway lines and in some cases the lack of porosity of the station itself. Connectivity around Beijing South Station has very low values, which is explained by the fragmented pedestrian network around the station and the lack of active frontages. Connectivity in this study is calculated in an 800 meters radius or 10-minute walking radius.

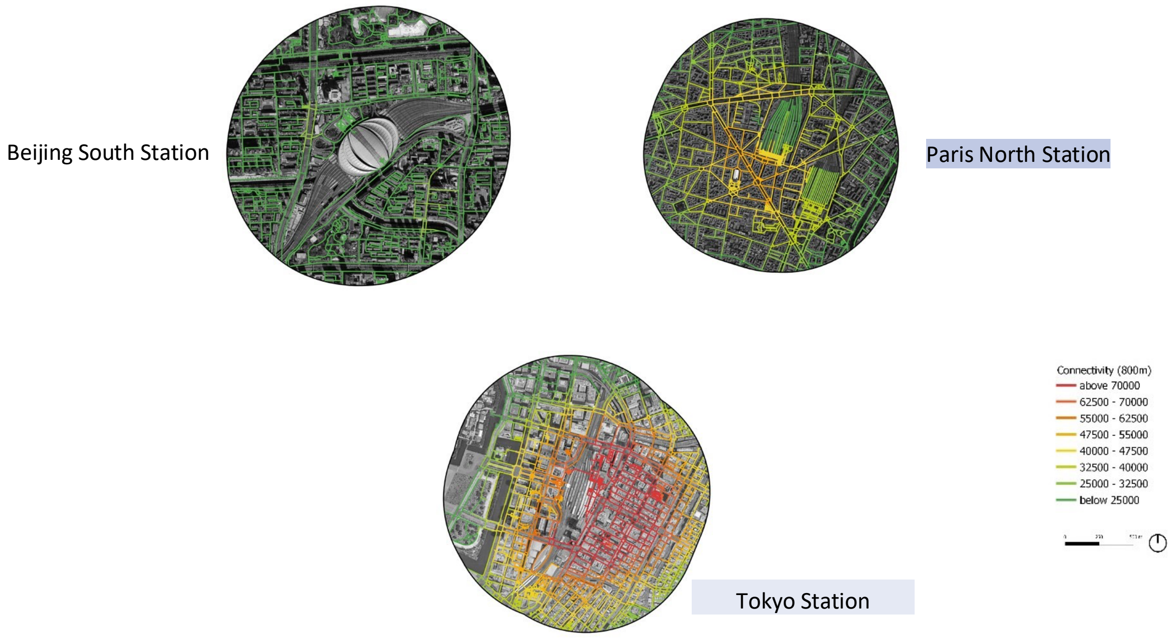


Figure 5 Neighbourhood connectivity

Beijing has an average value of 14,400 for connectivity against 37,500 for Paris and more than 60,000 for Tokyo, which are 3 to 5 more than the average in Beijing. Tokyo's high connectivity is explained by it's complex, dense, and extensive pedestrian network. As mentioned in the previous section, the urban texture is very granular with small blocks around the station, the obstructions generated by large infrastructure have also been mitigated by providing key pedestrian links on the side of the station. Moreover, there is also a very wide underground pedestrian network connecting the station to other neighbourhoods through retail corridors.

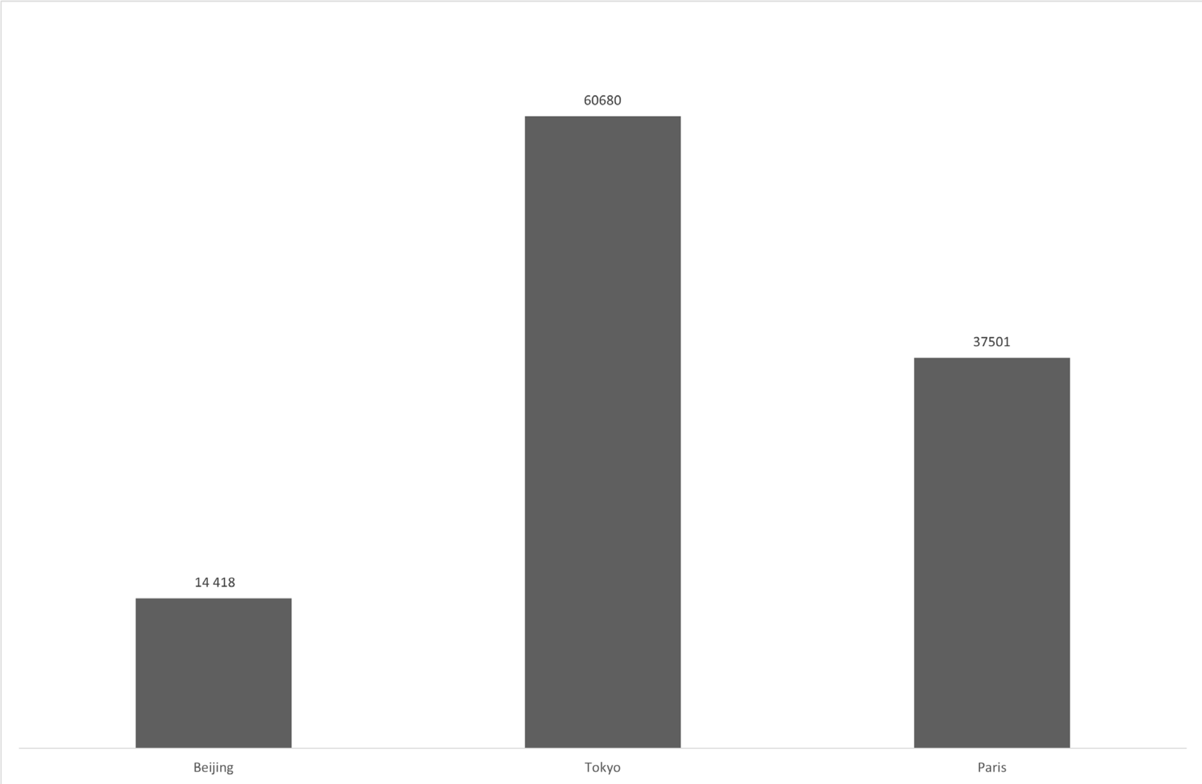


Figure 6 Connectivity average values comparison

While new Transport Oriented Developments in China make extensive use of underground networks (Wang and Wu,2020), there is still a case for existing stations to upgrade their pedestrian network connectivity. Stations can be better integrated within their neighbourhoods to reinforce their centrality in the city.

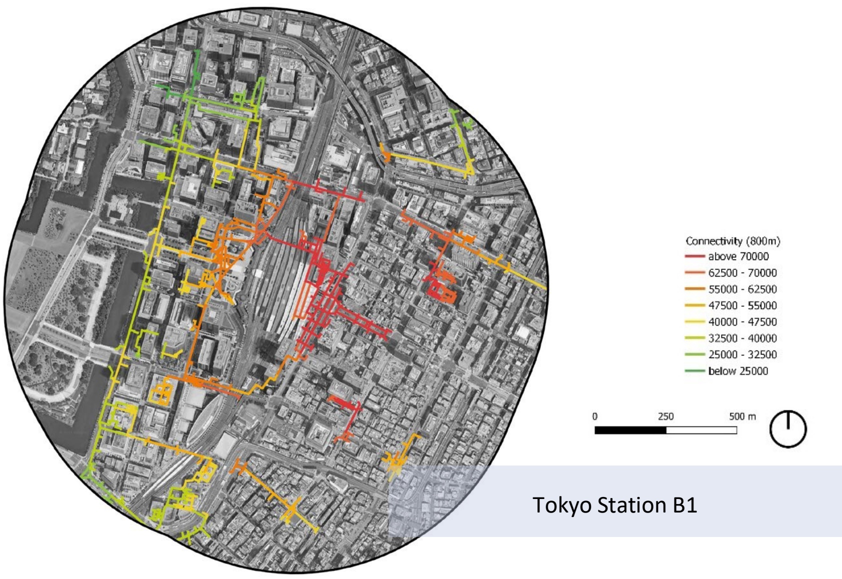


Figure 7 Tokyo station below ground level 1 Connectivity

3.4 Unactive and low flow potential streets

Pedestrian movement potential indicates which routes are the most likely to be used by pedestrians. The redder the link, the higher the pedestrian flow is expected to be.

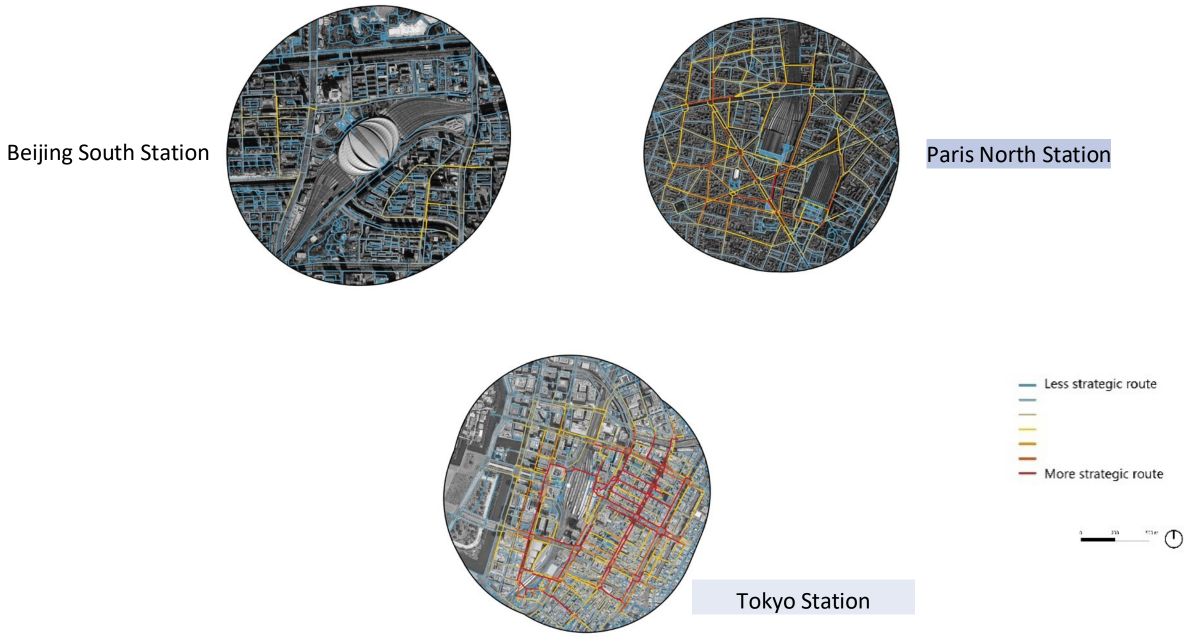


Figure 8 Flow potential comparison

Beijing South Station has a low flow potential around the station, nonetheless key desire lines within the surrounding neighbourhoods can still be identified (as shown in the diagram). These paths are essential to reconnect the areas around in a way that corresponds to pedestrian movement. In addition, these improvements can foster modal shift towards non-motorised vehicles in the station's neighbourhood by creating direct pedestrian routes.

By comparison, Paris has an active neighbourhood around North station and key pedestrian corridors are also located next to the station. Paris North was built prior to cars at the end of 19th Century whereas Beijing South was built in 2008. Therefore, the area is less impacted than Beijing South by the dominance of highways infrastructure.

Tokyo station was built in 1914, since then the surroundings have been going under urban renewal, which includes large infrastructure to accommodate cars. However, desire lines have been respected and paths on the side of the station are integrated into strategic pedestrian corridors, which helps linking neighbourhoods on both side of the station.

Key pedestrian corridors are not prioritised

Using a weighted analysis, we can identify flow potential around the HSR hub. These routes are hierarchized by flow, the redder they are the most likely they are to be taken by pedestrians, which means a higher flow is expected. These paths are the fastest and the most direct to the HSR station.

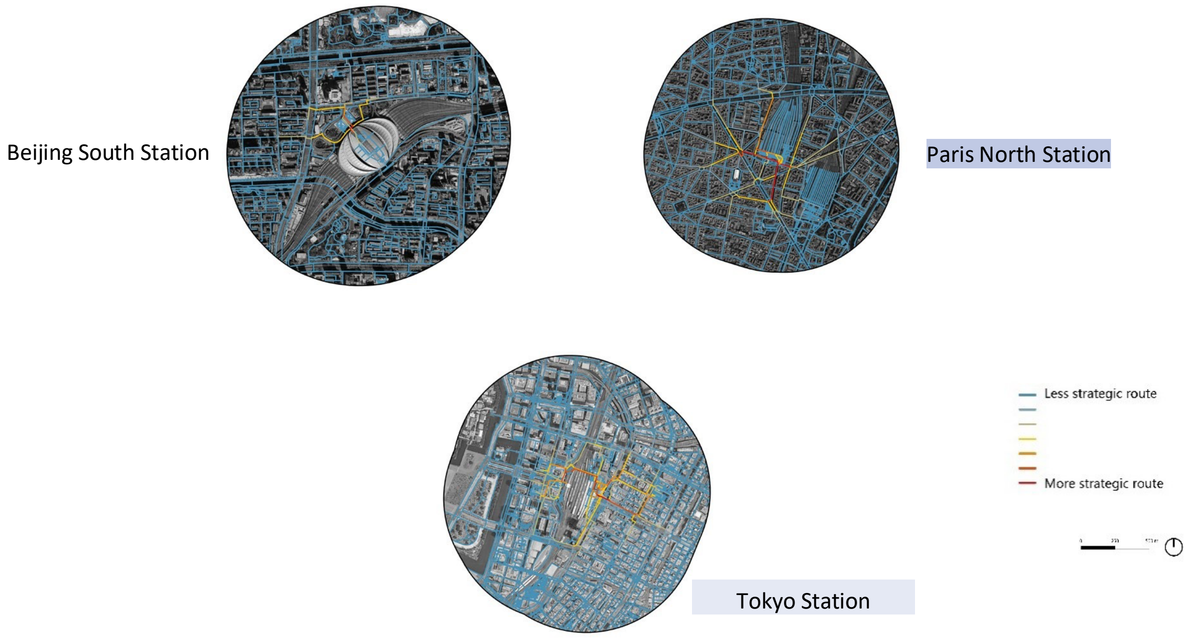


Figure 9 Weighted flow potential comparison

Beijing South Station suffers from a low accessibility due to a car-oriented environment. The ramps to access the station are separating the station from the rest of the neighbourhood and are major obstacles for pedestrians. The main flow potential would be coming from the districts located on the north of the station. However, the street environment, the lack of signage makes it hard for pedestrian to access the station.

Figure 10 Beijing South Station access street (source Baidu Streetview)

Comparatively, even though pedestrian access is complicated around the station, the north square still has a higher flow potential than the south square. Passengers or visitors who want to access the station from the south square in the neighbourhood need to make large detours (Shaaban *et al.,* 2018) because of gated residential compounds facing the station. They need to walk at least 5-10 minutes (400-800m) to reach a residential area or to get out of the station area. This spatial configuration prevents the use of sustainable and low carbon mode to access the station, and its potential of being a local hub is not fully unlocked.

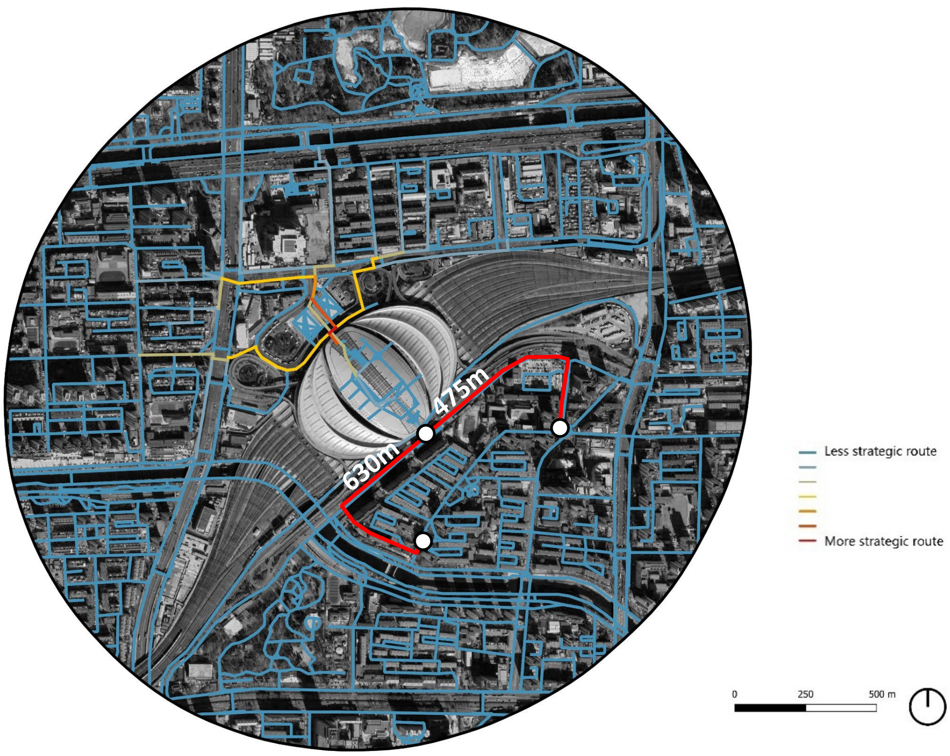


Figure 11 Distance from Beijing South Station to the residential areas

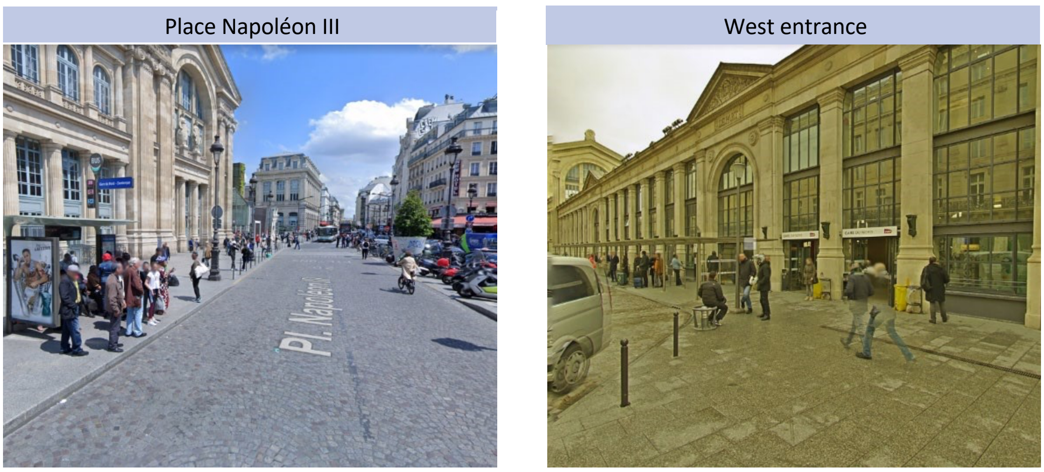


Figure 12 Paris Gare du Nord surroundings (source Google Streetview)

In a configuration where pedestrians have priority over car users, the main pedestrian corridors are adapted to facilitate passenger flow. Paris Gare Nord Napoléon III square is designed as a shared space street with no segregation between motorized vehicles and pedestrians. Speed is reduced to 20km/h on the street to avoid accidents close to the railway station.

According to the weighted flow potential study, an important flow potential would also be expected coming from the west entrance of the station. As the image shows this is also a shared space street with taxi drop-off, prioritizing pedestrians over cars.

Tokyo station configuration is a mix between Beijing South Station and Paris Gare du Nord. The east plaza is facing the city and is located on two main axes, north-south and east-west, while the west plaza is facing Tokyo Imperial Palace. The east front of the station welcomes motorized vehicle access (car, taxi and bus drop-offs). However, it still maintains pedestrian accessibility on key corridors by providing crossings and plazas where necessary. A pedestrian plaza is provided in front of the station which mitigates conflicting issues between cars and pedestrians. The western plaza is more pedestrian friendly, offering a visual dialogue with its surroundings, while respecting key pedestrian movement to access the station.

West plaza

East Plaza

Figure 13 Tokyo Station surroundings, (source Kanpai and Google Streetview)

The spatial configuration of Beijing South Station directly impacts its neighbourhood's vibrancy, the lack of accessibility and dialogue with the surrounding areas is also hurting its economic potential.

3.5 A mono-functional neighbourhood

Stations can be vibrant mixed-use neighbourhoods (Yue *et al.,*2017), that attract talent, offices, commerce, services and residents. Land-use diversity of use can be measured with the accessible diversity index (ADI). ADI is calculated on the pedestrian network, which reflects better accessibility to surrounding functions.

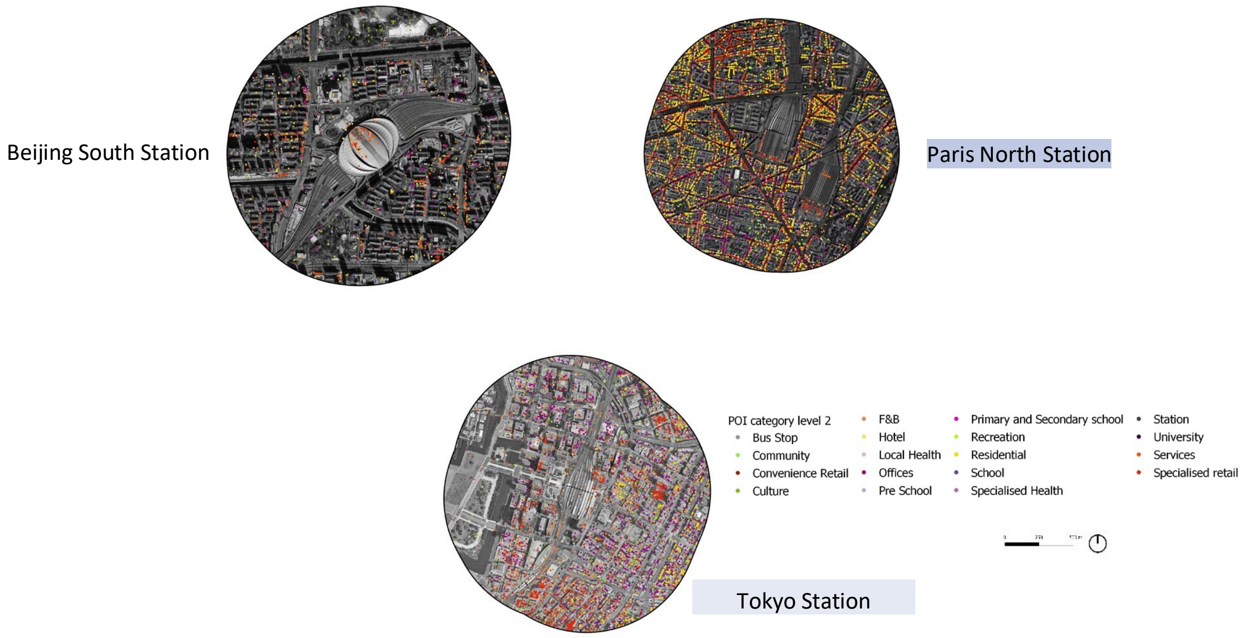


Figure 14 POI Spatial distribution

A neighbourhood lacking activity

Figure 14 shows the spatial distribution of POIs, using the Level 2 classification. Beijing POIs are located close to the residential compound, the area around the station being almost empty. The station itself has some retail units but they are only used by passengers inside the station. Beijing urban fabric is composed of residential buildings with large footprints and wide space in between, creating a looser morphology. Tokyo and Paris have a more compact urban fabric, which means a higher built-up density, allowing a higher density in activity as it shown in the POIs spatial distribution.

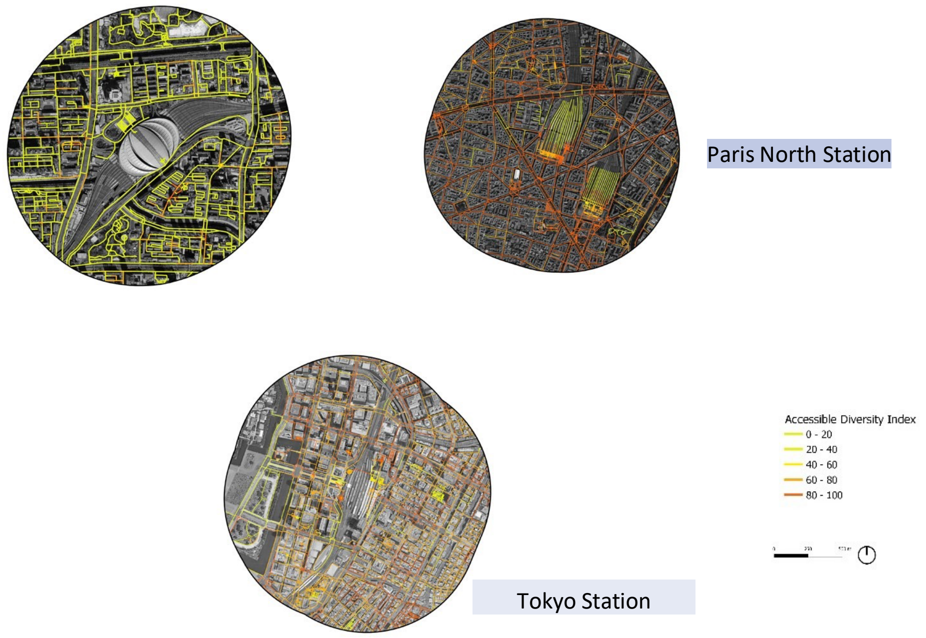
While density is an important factor to create active neighbourhoods, mixed-use is essential to ensure economic dynamism, promoting sustainable modes and create vibrant areas (Moreno *et al.,*2017). Railway stations have the potential to become very active districts, where different type of populations can meet. They can become important economic, social, and innovative nodes in a city. To reveal the full potential of an HSR station, it is key to first create a walkable area, so accessibility is improved (Srour and Wedderburn,2021), and urban fragmentation is reduced. Secondly, mixed-use around the station benefits the passengers, visitors, and the local population. Activity diversity around the three stations has been calculated in a 100m, 200m and 400m walking distance. The Accessible diversity index (ADI) ranges from 0 to 100, 100 being the most diverse.

Inactive streets around the station

The average diversity in a 100m walking radius is of 12 for Beijing, it reaches almost 40 in a 200m radius and 66 in a 400m radius. 100m radius accessible diversity can be defined as the diversity of activity on a street. According to the results, it suggests that there are almost no activated streets around Beijing south station. Some streets present a higher index of accessible diversity, but the car-oriented environment makes it unattractive for pedestrians.

Beijing South Station

Paris North Station



Tokyo Station

Figure 15 ADI in a 100m walking radius

Kaiyangli 3rd street

South station Xingfu road

Figure 16 Beijing South Station streets activity (source Baidu streetview)

The average of accessible diversity around Paris North Station is of 73, meaning that each street in the area welcomes a wide range of activity. Boulevard de Denain is located in front of the station, the street has a wide offer of restaurants, bar, convenience store, services, hotels, etc. Moreover, the street has large footways to accommodate pedestrian flow coming from/to the station and special pavement treatment to alert vehicles to lower their speed.

Boulevard de Denain Paris

Yojuin Street Tokyo

Figure 17 Streets around the stations, (source Google Streetview)

Tokyo has also an average of an accessible diversity of 73, which means many of the streets around the station are activated with different types of activities.

Blocks and Neighborhoods that are diverse but inaccessible from the station

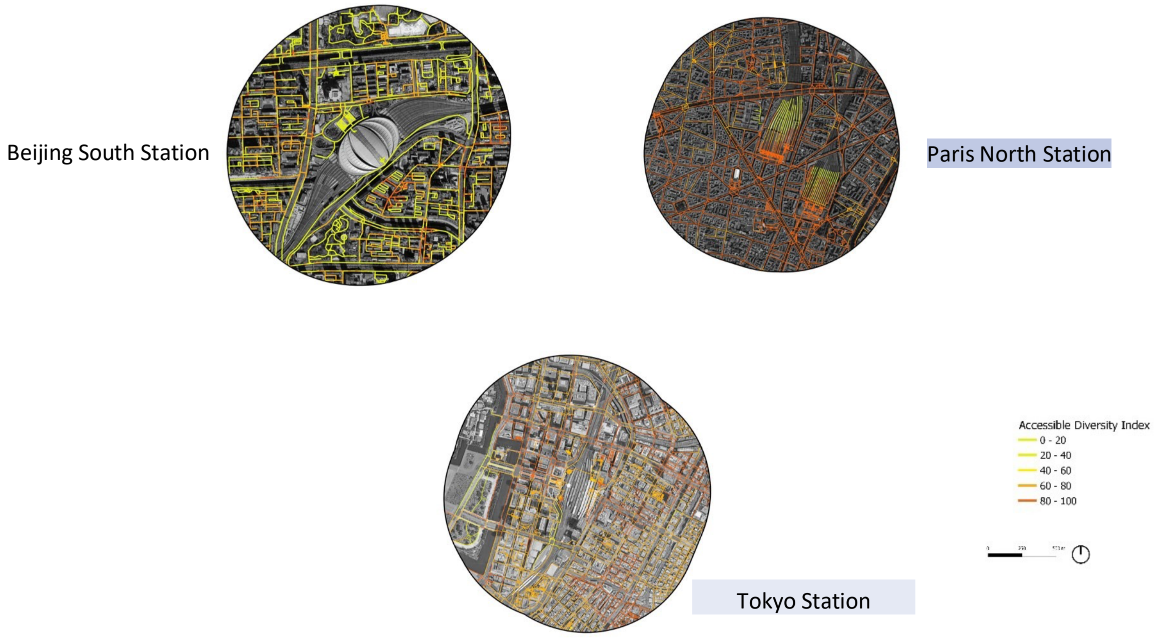


Figure 18 ADI in a 200m walking radius

While Beijng South diversity improves in a 200m and 400m radius to a score of 40 and 66 respectively, its accessibility is restricted to residential gated compounds on the south part of the station and the western side. The north side of the station has a better accessibility to the different land-uses than the south side.

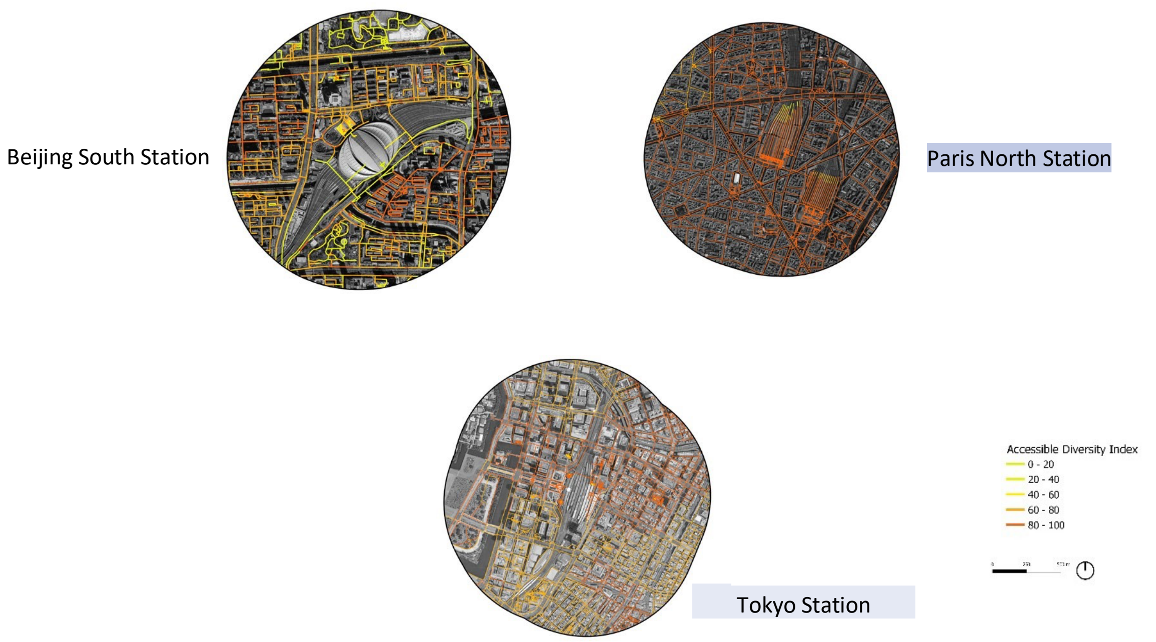


Figure 19 ADI in a 400m walking radius

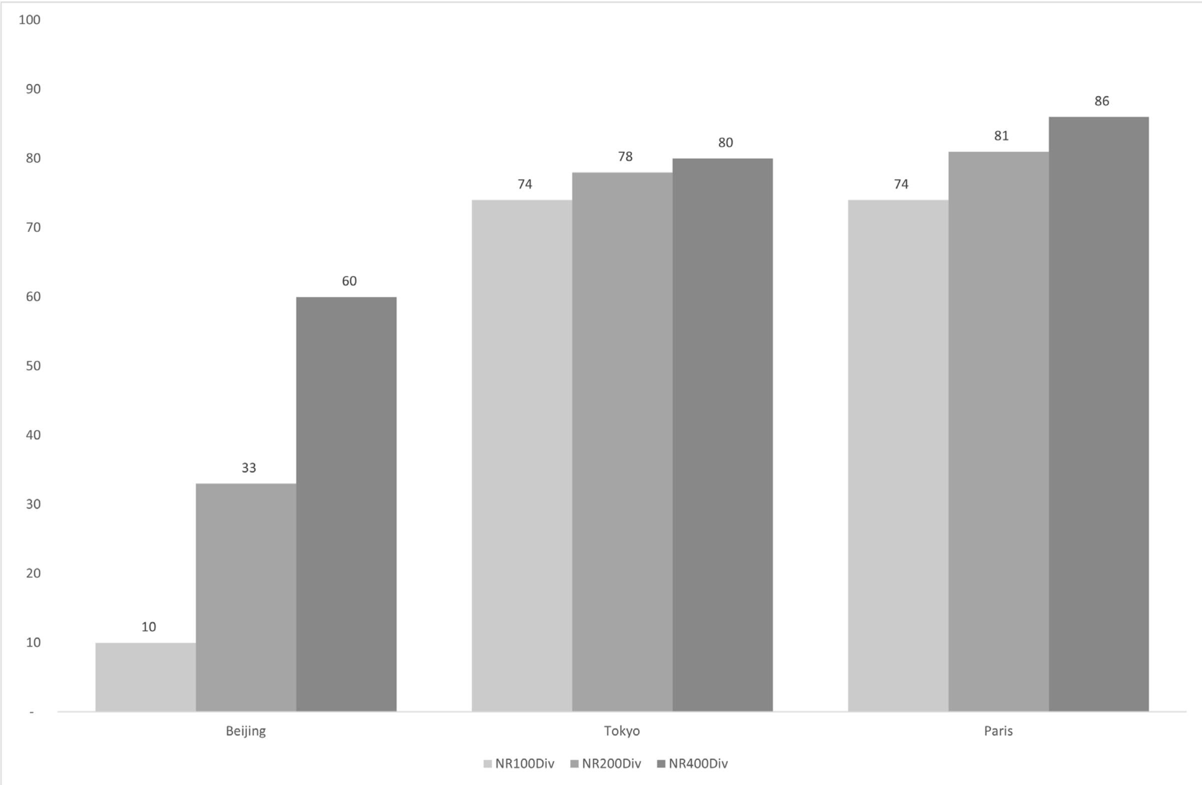


Figure 20 ADI comparison

The ADI score reaches 80 and 85 in a 200m and 400m walking radius in Paris, which means the barrier effect of the station is not that important, and most neighbourhoods have good accessibility to active streets. Tokyo has a score of 76 and 80 in each walking radius, diversity is also very high on average, however it is more clustered than Paris and has a pattern similar to Beijing. The north-east and north-west areas around the station are characterised by a high diversity. They are directly linked to the station and connected through it. Unlike Paris and Beijing, the station in this case acts as a connector between both districts with public pedestrian paths on its side.

4. Potential Solutions : the use of evidence-based tools to improve the pedestrian realm

Paris and Tokyo station both have elements of station design and spatial characteristics that could be beneficial and re-adapted to Beijing South Station's case. There are three potential solutions that can be tested on the spatial network:

1) The city links
2) Opening gated compounds around the station
3) Activate the large public space around the station

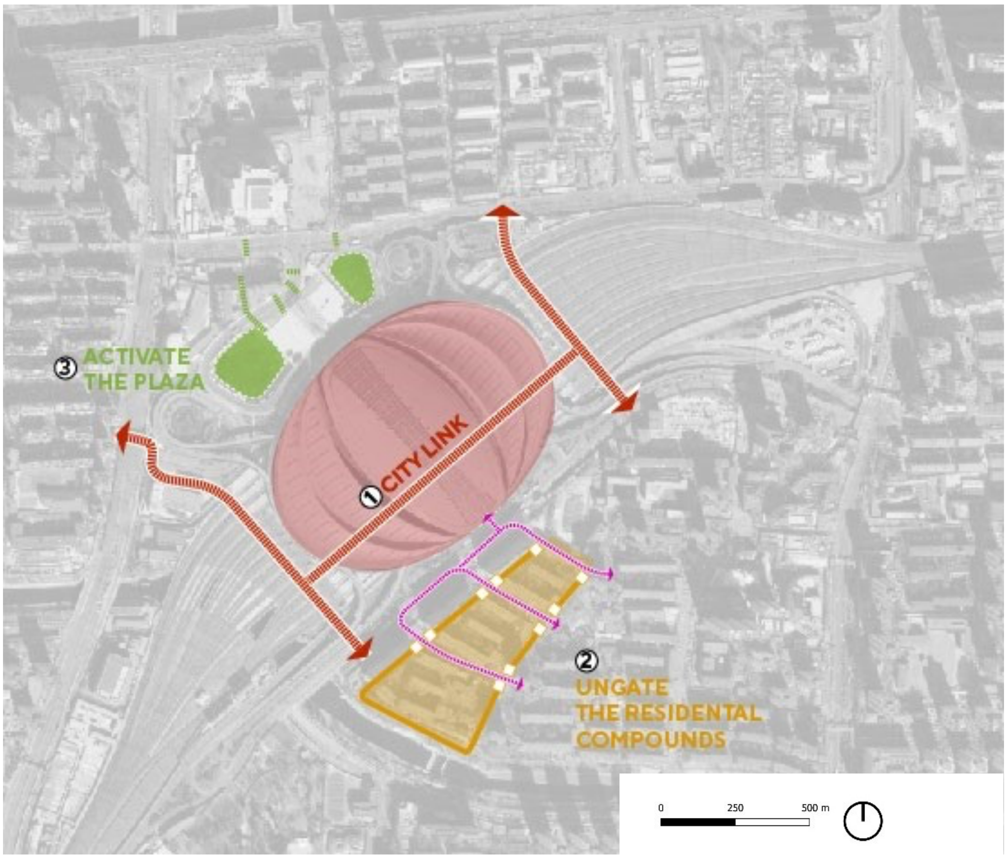


Figure 21 Options planning

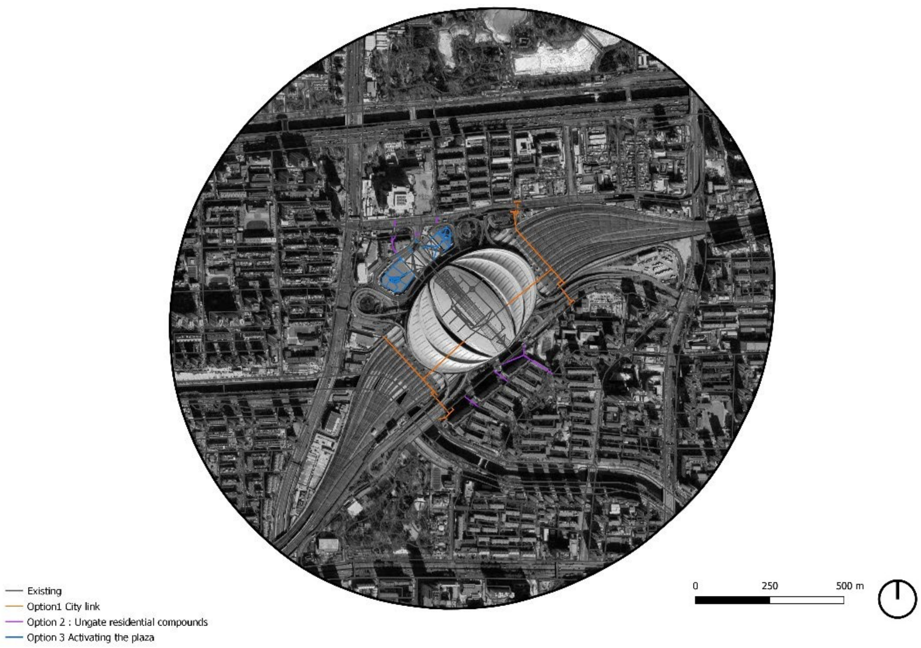


Figure 22 Options on the Spatial network

These three options will be tested separately and together to estimate the impact it has on the network.

The city link: connecting stations spatially and functionally

Tokyo station's model is similar to Beijing, the centre of the station is gated while there are public links on the side of the station. To improve neighbourhood accessibility, Beijing South Station could potentially provide city links on its side on B1 level. These links could be at first independent from the station with a reservation to connect with it in the future. In this option we tested the best-case scenario, which is activated B1 links (with retail along it) and connected to the station.

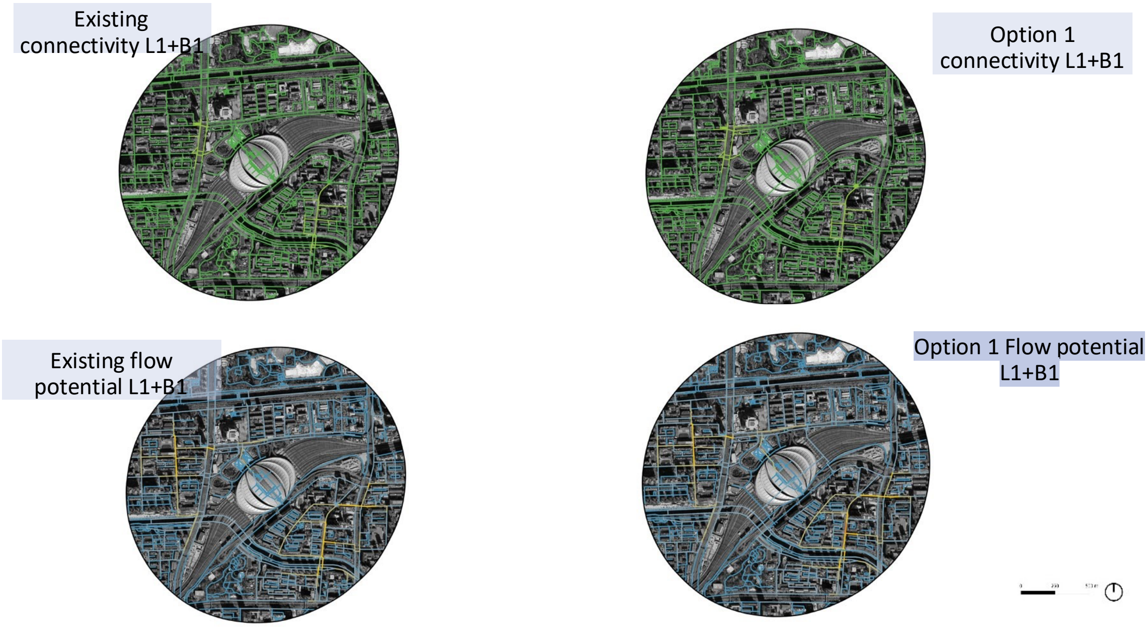


Figure 23 Option 1 and existing comparison of metrics

Opening the gated compounds around the station

Compounds adjacent to the station are gated, which isolates the southern part of it. Residential communities could be partially ungated to allow pedestrian movement to and from the station, improving its accessibility.

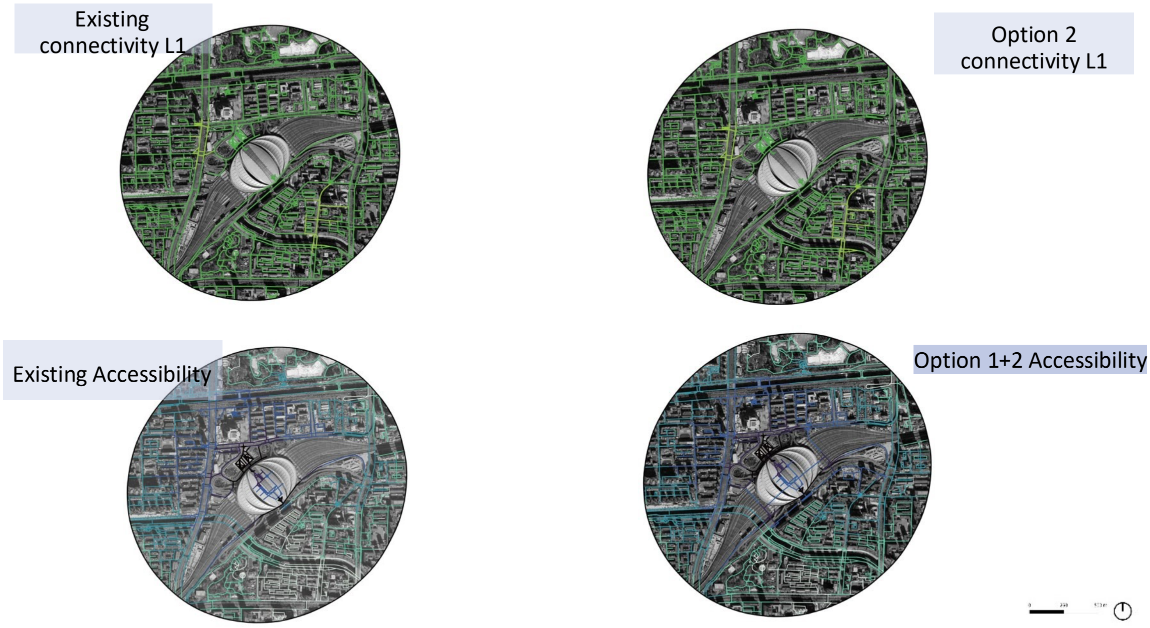


Figure 24 Option 2 and existing comparison of metrics

Activate the plaza around the station

The entrance of the station has large plazas and empty spaces that could be re-used and activated with retail developments and green spaces. This could improve the area's attractivity and space quality by providing more activities around it. To improve accessibility to it, crossings could be added along desire lines.

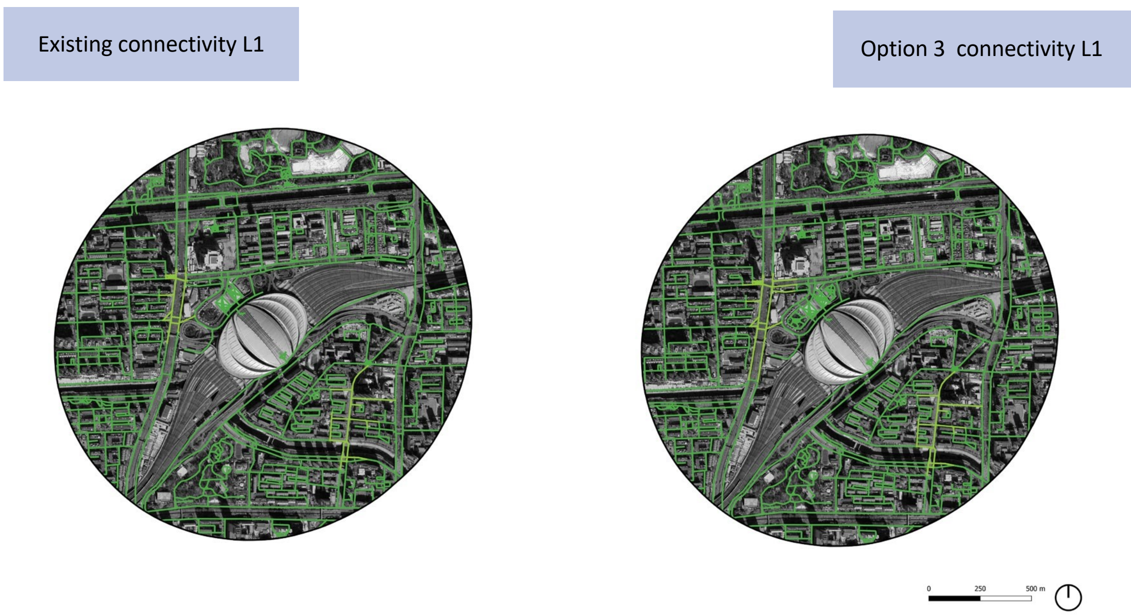


Figure 25 Option 3 and existing comparison of metrics

The new developments could serve the local population around the station and also the passengers.

All options combined

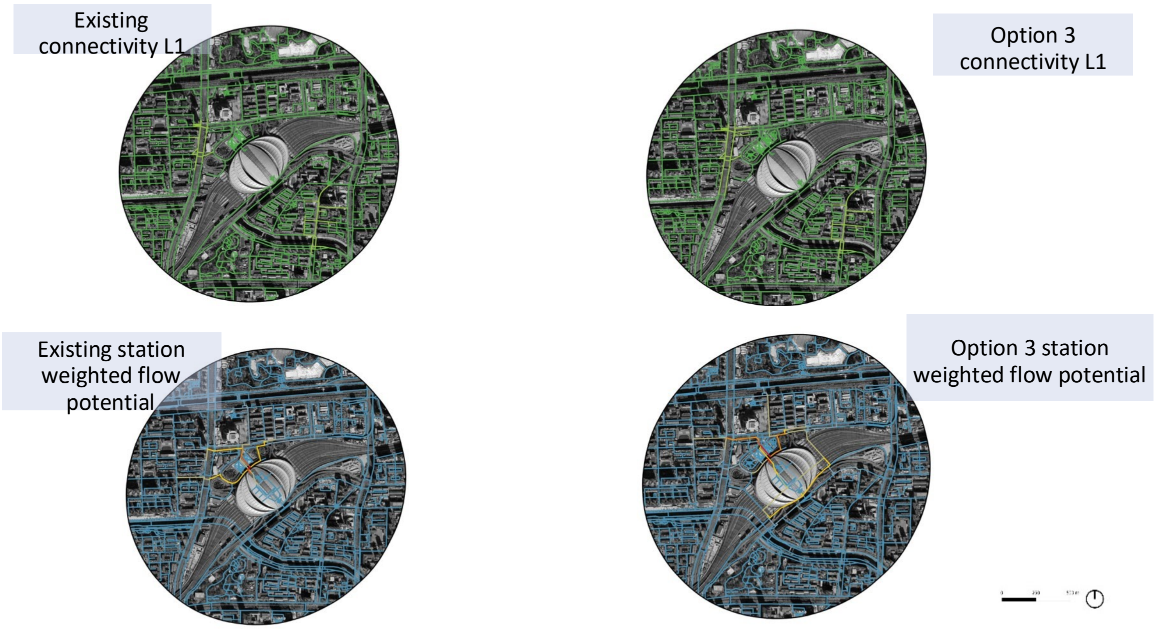


Figure 26 Existing and all options combined comparison of metrics

Tested all together the options have a greater impact on the network's connectivity, there is an uplift of 15% between the existing connectivity average value and the combined options value.

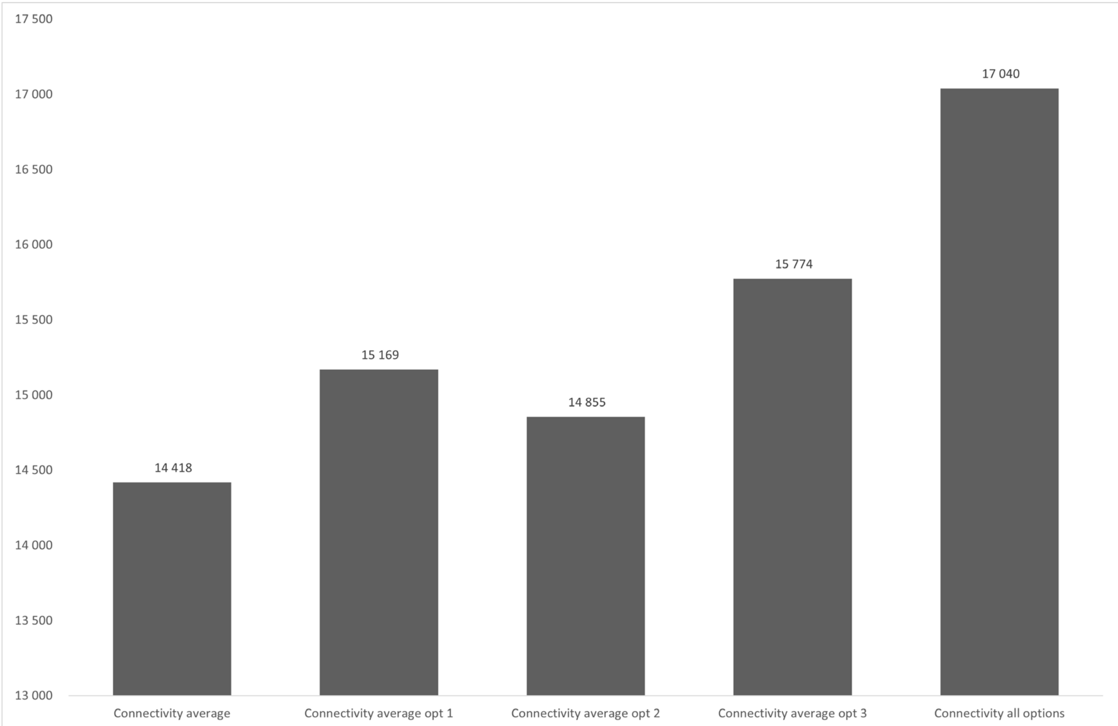


Figure 27 Connectivity comparison between existing and options

5. Discussion and conclusion

First generation HSR developments in China prioritises motorised vehicles over active modes (TU, ZHANG AND LUO, 2022), and the station has public transport access that is restricted to serve the station only but not the surrounding neighbourhood. While promoting train travel is essential to continue the decarbonisation of metropolitan areas and promote modal shift, how can HSR neighbourhoods be sustainable if they do not benefit from the transit connections to the city and are built around the needs of car travel?

This results in congestion around the station, which can generate air and noise pollution and affect the local population's health. The lack of activity around the station also does not help promoting active modes for passengers and the local population, the relation between land-use diversity and active neighbourhoods is already a well-documented phenomenon as mentioned in the previous section.

Moreover, land-use availability has become scarce in Chinese cities, where construction is now limited in most of them. Land around first-generation stations can be seen as resources that can be redeveloped to improve economic vitality, promote active travel modes, and allow social interaction. This has become even more important since the COVID-19, where compounds around HSR stations were deserted during lockdowns.

In this study we used evidence-based metrics to measure the pedestrian network around the station. Most of the metrics measuring the pedestrian network around Beijing South Station performed poorly (connectivity, flow potential and accessible diversity index) compared to Tokyo station and Paris North station, both also located in city centres. These metrics are good tools to compare the pedestrian network's conditions between cities. These tools could be implemented into the planning system to do assessment work and could be used in regeneration schemes around HSR stations.

5.1 Limitations

While the tools can be helpful to do analysis, there are limitations that we faced during this study. The first limitation is data availability, especially regarding POI data. The POI data formatting varies from provider to provider, there is not a unified classification and data quality also varies by region and data provider. For this study most of the data was entered manually, which might produce some discrepancy with reality.

The second issue is lack of high-quality and up-to-date mapping around and inside the station. This can impact the quality and accuracy of the pedestrian network as well as the outputs.

To reduce the margin of error to a bare minimum, extensive mapping and monitoring of pedestrian movement and activity could be done around HSR stations. With real-time data it would be possible to have a more accurate assessment, better identify the issues and propose more adapted solutions.

5.2 Prospects

Station development in China has involved several phases, and concepts have evolved from a car-centric to a human-centric approach, which promotes walkability, low carbon areas and active neighbourhoods. New stations developments such as Beijing sub-centre station and Shenzhen Xili Stations are following these concepts. However, there is still a case for existing HSR stations to be regenerated to unlock their full potential.

The regeneration of HSR stations can be an opportunity for cities with scarce land resources to boost the local economy and accelerate modal shift. There is a question to make these areas not only places of passage but also places of dwelling and living, where residents and passengers can meet. To accompany this change of paradigm, the tools used must be adapted to support the new planning system and offer measurable metrics to quantify the effect of the policy change.

6. References

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