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Calculation Method for Public Transit Accessibility Level Oriented Towards the Entire Travel Process: A Case Study of Chengdu

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Abstract: Public transit accessibility plays a positive and vital role in evaluating the service level of urban public transit systems and identifying areas for improvement. This paper presents an overview of the technical analysis framework for the public transport accessibility level (PTAL) and its application practices in China and abroad. The paper deconstructs the entire travel process of public transit and identifies a series of key segments, including walking, waiting, riding, and transferring. By integrating the public transit route planning API of online maps and locally storing public transit network operation data, as well as simulating the travel process in stages, this paper explores a public transit route planning method based on the principle of fast and convenient travel. The method achieves fine simulation of travel times between grid cells and facilitates rapid PTAL calculation. Using Chengdu as a case study, this paper introduces a high-resolution PTAL map of the central urban area using interpolation algorithms. The results reveal a high coupling degree between the spatial distribution pattern of PTAL and the urban rail transit network. Compared to directly using the public transit route planning service of Baidu Map, the proposed method offers significant advantages in accuracy and large-scale application. It can be employed to evaluate the level of service of public transit or the coordination between land use and public transit development.
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Keywords: public transit; accessibility; entire travel process; public transit route planning; Chengdu

0 Introduction

The coordinated development of transportation and land use is one of the important objectives of urban planning. As a bridge between transportation and land use, accessibility analysis is widely applied in the fields of urban planning and transportation planning [1]. With the gradual improvement of the motorization level, urban road traffic congestion and carbon emissions have become new challenges for urban governance, and it is a key link in promoting sustainable urban development to promote the construction of the public transit system. It plays a positive role in measuring the supply and service level of the urban public transit system, and identifying and improving areas to be optimized to study public transit accessibility.

The public transportation accessibility level (PTAL) was first introduced in Hammersmith & Fulham, London, UK, in 1992 [2], and was extended to the entire city of London in 2001, serving as the standard method for assessing public transportation accessibility in the Greater London area [3–4]. This method has formed a comprehensive technical system, which can guide urban transportation development, land use, and the layout of public service facilities from macro, meso, and micro scales. In the meantime, it is widely used as a policy tool in major urban planning and management decisions [2–3].

As Chengdu steps into the ranks of megacities, the rapid population growth has raised higher demands on resource matching, further highlighting the importance of public transit in the urban transportation system. The Chengdu Action Plan for Building a Park City Demonstration Area that Practices the New Development Concept (2021–2025) proposes to improve the interconnected urban transportation network, promote the integrated development and efficient connection of the “rail transit + bus + non-motorized” system, lead and drive regional coordinated development through transportation, and promote the rational allocation of public resources and the balance between work and residence [5]. Therefore, building a convenient, efficient, and safe urban public transit system has become a major livelihood project for Chengdu to attract residents to adopt green travel.

To scientifically evaluate PTAL, drawing on Chinese and international experience, this paper systematically reviewed the complete path of public transit travel, and combined the application programming interface (API) for public transit path planning of the online map to construct a PTAL calculation method and application system for path planning services, providing reference and support for the evaluation of controlled detailed planning and the optimization of the public transit network in Chengdu.

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1 Accessibility level of public transit

1.1 Technical system of reachability analysis

An important method used by Transport for London (TfL) to evaluate the effectiveness of transportation infrastructure construction and services is accessibility analysis. Its technical system (see Tab. 1) includes PTAL analysis, isochronous analysis, access to opportunities and services (ATOS) analysis, and location-based catchment analysis. This system has been widely applied to transportation facility layout planning around the world since its introduction more than 20 years ago [6–7]. PTAL refers to people's opportunities to access and use public transit services, reflecting the service capacity of urban or regional public transit systems. It often utilizes data such as urban rail transit, buses, and road networks to calculate the travel cost (travel time, travel distance, etc.) of obtaining public transit services from a certain location.

Tab. 1 Technical analysis framework for the accessibility of London's transportation planning

Content	Meaning of spatial unit value
PTAL analysis	The area accessible by public transit within a given time
Isochronous analysis	The public transit travel time required to reach other grids from the starting point
ATOS analysis	The relative position of the average travel time of public transit to the last three public service facilities in the average travel time of public transit in the entire region
Location-based catchment analysis	The number of people and facilities that can be served by public transit within a given time

1.2 PTAL calculation method

The existing studies on the PTAL calculation method can be broadly categorized into three types: 1) The cost analysis method based on GIS software [8–10]. This method involves buffer zone analysis and network analysis, utilizing the Euclidean distance or network distance as the travel cost to quantify accessibility. However, the accuracy of travel cost calculation highly relies on the precision of vector data, and real-time updating is challenging. 2) The accessibility index analysis method based on the public transit service network [3,11–12]. Represented by the PTAL calculation method in London, this approach integrates various information of public transit service points, including the departure frequency, transfer conditions, and the fare level, and assigns the reliability weight to different public transport travel modes to obtain the overall accessibility index. It heavily relies on the empirical coefficient, necessitating the construction of different sets of weight coefficients for applications in different regions. 3) The high-precision accessibility analysis method based on travel process simulation. This method encompasses high-precision accessibility analysis of public transit based on high-performance graph databases [13–14], that of public transit based on APIs [15–16], and that of public transit using staged simulation of travel processes (hereinafter referred to as "staged simulation method of travel process") [17–19]. Real-time updating of the high-performance graph database poses significant challenges. We can yield precise and real-time results by obtaining travel paths directly through APIs, but the limited number of daily API calls makes large-scale accessibility calculation difficult to achieve. The staged simulation method of travel process simplifies the complex and variable travel process into a combination of multiple fixed patterns by extracting different behavioral characteristics in public transit travel, thereby simplifying the calculation process and achieving efficient batch output.

To promote the widespread application of the PTAL calculation method, this paper drew on the phased simulation approach of travel processes, and built a localized public transit route planning service by breaking down the entire process of public transit travel and combining it with online map APIs, achieving a rapid and accurate estimation of public transit travel time between any starting and ending points in the central urban area of Chengdu. Furthermore, it explored the PTAL calculation method based on travel time.

1.3 Application practices in China and abroad

After nearly 30 years of development, the PTAL has been widely applied in comprehensive transportation and land use planning research in major cities both in China and abroad. In some regions, it has gradually been established as a standard method and policy tool through pilot assessment and analysis, assisting in the implementation of urban master planning and the optimal allocation of urban resources. Its application directions are mostly concentrated in the fields of transportation facility layout optimization and public transit network optimization, public activity center system planning, work-residence monitoring, and land development intensity adjustment (see Ta. 2). Chinese cities, led by Shanghai [20], have applied PTAL to the land development intensity zoning model since 2003, and it is now deeply reflected in the Shanghai Master Plan (2017–2035). Cities such as Beijing [21], Shenzhen [16], Wuhan [22–23], and Hangzhou [2] are also actively exploring and practicing it.

Tab. 2 Domestic and international PTAL application practices

Region	Application overview
London	It supports the development planning of urban space and the planning of the London Public Activity Center system over the years, guides the formulation of standards for the construction of parking spaces for residential, commercial, and office land development, evaluates the rationality and fairness, and supports construction of auxiliary transportation facilities in the transportation system.
Singapore	It explores the relationship between work and residence, and identifies employment concentration areas and residential communities with poor accessibility.
Melbourne	It analyzes the population coverage in different PTAL regions, studies the proportion of various public transportation modes in different PTAL regions, and identifies areas with poor accessibility.
Beijing	It evaluates the PTAL of the capital functional core area and supports the public transit coverage and transfer environment indicators in the Detailed Control Plan for the Capital Functional Core Area (Block Level) (2018–2035).
Shanghai	It supports the implementation of evaluation and optimization of the work-residence supply and control of the urban land development intensity, and construction of a public activity center system in the Shanghai Master Plan (2017–2035), and guides the optimization and improvement of public transit functions in the five new cities.
Shenzhen	It develops the PTAL evaluation tool based on the TransPaaS platform, and evaluates the rationality of work-residence land use combined with population distribution data.
Wuhan	It develops a multi-level transportation accessibility analysis system to provide quantitative analysis guidance for public transit development, including evaluating the spatial connectivity capability, the time efficiency of public transit spatial connectivity, and urban rail transit network schemes.

2 PTAL for the entire travel process

2.1 Technical route of the phased simulation method for the travel process

The technical route of the staged simulation method for travel process is shown in Fig. 1. Firstly, the entire process of public transit travel is decomposed in detail, identifying key links such as the walking trajectory, waiting for a ride, the riding process, and waiting for transfer. Secondly, the public transit route planning API of the online map is utilized to make detailed corrections to the walking network and public transit network, and real-time operational information is supplemented to form a public transit basic data foundation. Subsequently, a rule system for public transit route planning is constructed to achieve accurate judgment of public transit travel time between any grids. Finally, based on the travel time matrix, the PTAL of the study area is calculated using the reachable range within a given time as the measurement standard.

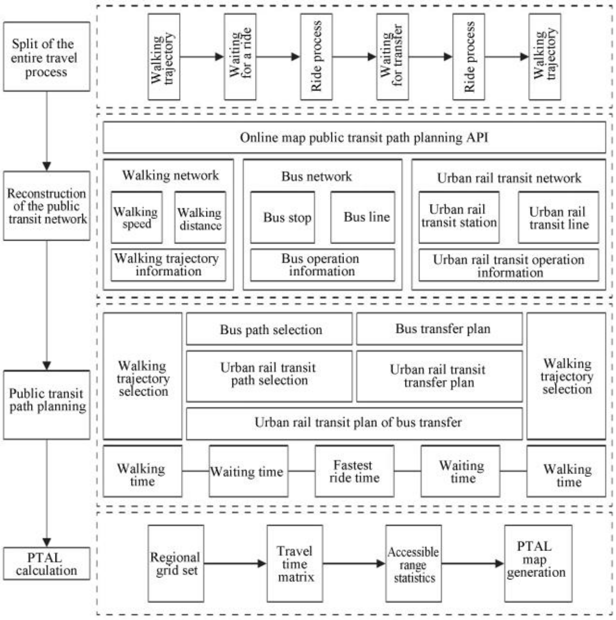


Fig. 1 Technical route for the stage-based simulation method of travel process

2.2 Division of the entire process of public transit travel

This paper took the entire process of public transit travel as the research object, dividing travel time into different stages by dissecting the key links of the travel process. Based on the travel characteristics of typical groups, taking walking as an example for connecting trips, we simplified the entire process of public transit travel as shown in Fig. 2. In order of sequence, a traveler generally departs from his starting point, walks to a nearby public transit station, waits for a certain period of time to enter the public transit system, and then chooses different combinations of public transit modes to travel, aiming to reach his destination as quickly as possible. After exiting the public transit station, he continues to walk for the connecting trip to reach his destination. The entire process of public transit travel is clear and divisible, so the total travel time can be converted into the sum of travel time in different stages, where the calculation of travel time in each stage follows the corresponding travel rules.

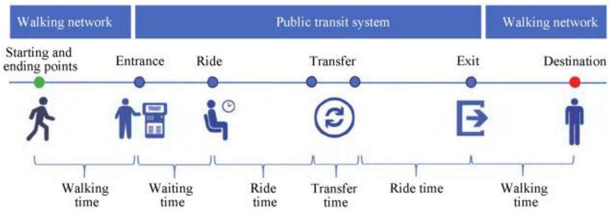


Fig. 2 Illustration of the entire public transit travel process (using walking connection as an example)

1) The walking connection process from the starting point to the public transit entrance and from the exit to the destination

The formula for calculating the walking connection time is

$$Twalk = Dwalk/v \ ,$$

where *Twalk* represents the walking connection time, in s; *Dwalk* denotes the walking connection distance from the starting point or destination to the public transit station, in m; and v is the walking speed, in $m\cdot s^{-1}$. The walking speed of adults on a flat slope is generally 1.0–1.4 $m\cdot s^{-1}$. In this paper, the per capita walking speed in Chengdu is selected as 1.17 $m\cdot s^{-1}$.

2) The waiting process for boarding after passing through the entrance

This paper utilized the Baidu Map public transit route planning API to obtain the departure frequencies of all urban rail transit lines and bus routes, and then calculated and stored the waiting time for each route during peak hours (7:00 to 9:00 and 17:00 to 19:00), off-peak hours (9:00 to 17:00), and low-peak hours (22:00 to 7:00). The calculation formula is as follows:

$$Twait = 0.5Tw(l, t) \ ,$$

where *Twait* represents the waiting time for boarding/s; $Tw(l, t)$ represents the departure interval time of public transit line l during time period t, in s.

3) The process of boarding and transferring after entering the public transit system

This paper utilized the Baidu Map public transit route planning API to obtain the travel time between every pair of stations for urban rail transit lines and bus routes, as well as the average transfer time at transfer stations. The route conversion rules, as well as the travel and transfer times, are stored locally for easy one-click access. The calculation formula is as follows:

$$Tpublic = Tr(p1, p2) + Tt(px) \ ,$$

where *Tpublic* represents the time for taking and transferring public transit, s; $Tr(p1, p2)$ denotes the travel time from the starting station $p1$ to the destination station $p2$, s; $Tt(px)$ is the transfer time at station px, s.

The travel time of the above three travel stages is added up to obtain the total travel time *Ttravel* by public transit. Based on the principle of quick travel, this paper compared the total travel time of all travel paths, and selected the travel path with the shortest time for the same starting and ending points as the target path.

2.3 PTAL map generation process

To quantitatively describe PTAL, this paper rasterized the study area and selected an appropriate grid size to express the differences in PTAL among different regions. Based on the logic of dividing the entire process of public transit travel, the travel time between any two grids was taken as the core indicator to calculate the accessible range from the center point of any grid, and then the PTAL map of the study area was derived.

Taking 45-minute public transit accessibility as an example, the generation process of the grid-based PTAL map from the whole-trip perspective is shown in Fig. 3. Starting from any grid within the study area, we calculate the shortest public transit travel time to the other grids within the area, and form a travel time matrix with this grid as the starting point. We count the number of other grids that can be reached within 45 minutes from this grid, assign this value to the grid, and use it as a quantitative indicator of its accessibility level. We repeat the above operation to count the number of grids that can be reached within 45 minutes from all grids in the study area. Finally, to more clearly describe the differences in PTAL across different areas, we convert the number of grids into the grid area, calculate the proportion of the area that can be reached within 45 minutes from any grid to the total area of the entire region, and use it as the PTAL value of the grid, thus forming the PTAL map.

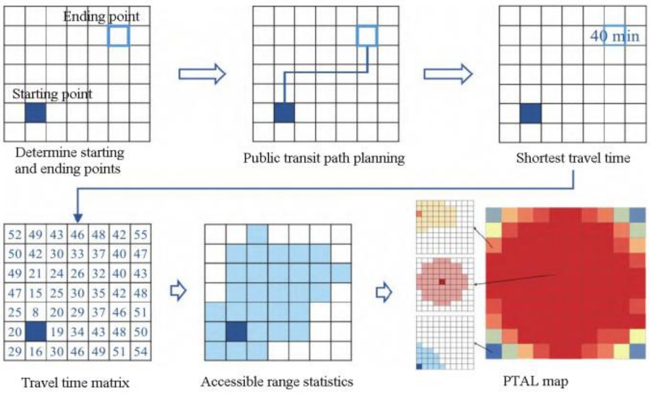


Fig. 3 Generation workflow of PTAL maps from the perspective of the entire travel process

3 Chengdu's case

3.1 Scope of study

As of October 2024, Chengdu has opened and operated a total of 13 urban rail transit lines in four phases (excluding the tram line Rong 2), covering the central urban area (12 administrative districts and 2 economic functional zones) and the eastern new area, with an operating mileage of 640.42 km and an average daily passenger volume of 5.600 8 million. The bus transportation system comprises a multi-tiered system, with over 2 000 bus and trolley bus lines, express bus lines, shuttle bus lines, and community bus lines, covering 23 administrative districts in Chengdu.

The scope of this study covers the central urban area of Chengdu, with a total area of 4 062 km^2, including 13 urban rail transit lines and 1 706 bus lines (see Fig. 4).

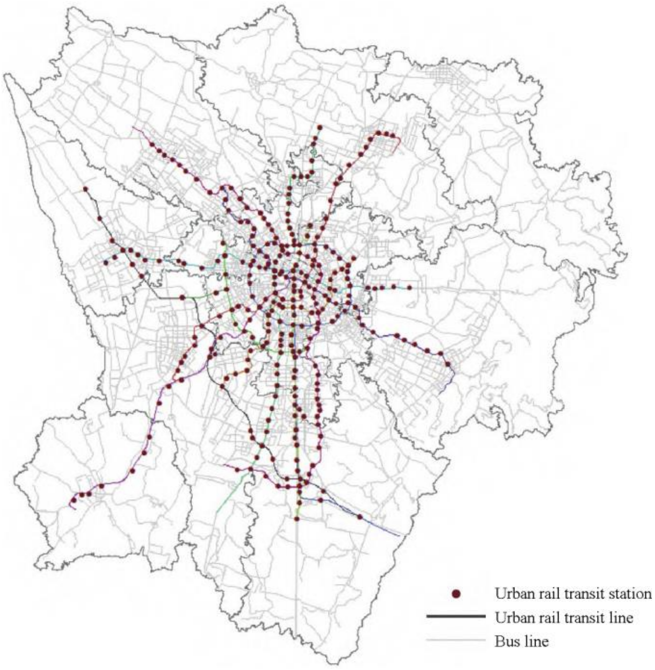


Fig. 4 Public transit system in Chengdu's central urban area

Based on the average walking speed of 1.17 m·s^{-1} in Chengdu, the distance traveled by walking for 3 minutes is 210.6 m. In this paper, a 200-m standard grid was used to sample the study area, with a total of 100 169 grids (due to the sampling sawtooth effect, some grids on the boundary lines were deleted, and only those with their center points located within the study area were retained). The center point of each grid serves as the target measurement point.

3.2 Data foundation

The basic data of this article mainly includes the urban rail transit line and station data (provided by Chengdu Rail Transit Group Co., Ltd.), bus line and station data (provided by Chengdu Public Transit Group Co., Ltd.), non-motorized transportation network data (non-motorized transportation road network data, greenway data, etc.), and public transit operation information obtained through Baidu Map's public transit route planning API.

The 13 urban rail transit lines in the central urban area of Chengdu have a total of 287 stations, including 64 transfer stations. With the Subway Line 5 as an example, operation information of selected stations is shown in Tab. 3. There are 1 706 bus routes and 12 859 bus stops, including 6 044 transfer stops. Taking Bus Routes 265 and 107 as examples, the operation information of selected stations is shown in Tab. 4.

Tab. 3 Operation information of selected stations on Chengdu Subway Line 5

Station	Station sequence	Waiting time/s	Operating time/s	Transfer line	Transfer time/s
Shenxianshu Station	27	150	194.38	7	75
Shiyang Overpass Station	28	150	175.80	0	0
No. 1 Hospital Station	29	150	94.00	0	0
Jiaozi Avenue Station	30	150	71.61	0	0
Jincheng Avenue Station	31	150	107.42	9	103
Jinchenghu Lake Station	32	150	178.22	0	0
Dayuan Station	33	150	124.04	0	0

Tab. 4 Operation information of selected stops on Chengdu Bus Routes 265 and 107

Line	Direction	Station 1	Station 2	Operating time/s
Bus Route 265	Bus Route 265 (104 Youku Station–Military General Hospital subway station)	104 Youku Station	Hongxingshequ Station	103.55
Bus Route 107	Bus Route 107 (Luoguoxiang Station–Qingbo Bus Stop)	Jinfeng Road North Station	Huangzhong Road Station	251.83
Bus Route 107	Bus Route 107 (Luoguoxiang Station–Qingbo Bus Stop)	Jinfeng Road North Station	Shuhan Road Station	415.03
Bus Route 107	Bus Route 107 (Luoguoxiang Station–Qingbo Bus Stop)	Jinfeng Road North Station	Yipintianxian Subway Station	595.42

3.3 Collection of public transit travel paths

Public transit route planning was conducted for 100 169 grids in the central urban area of Chengdu, forming a database of shortest travel routes between two points in the central urban area based on grids. Each record includes the starting and ending grid numbers, a description of the shortest public transit route (combination sequence of different transportation modes), the mode of public transit, and the shortest travel time. To reduce the computational workload and preserve data distribution characteristics, the area was resampled, converting the 100 169 200-m grids into 11 136 600-m sampling points. Meanwhile, it was assumed that the round-trip time between any pair of grid points was the same, resulting in a reduction of the final computational workload from 5.017 billion to 62 million operations. Based on the 600-m sampling points, a total of 1.24 billion public transit travel routes were formed in the central urban area. Some of these public transit travel routes are shown in Tab. 5.

To verify the rationality and accuracy of public transit route planning, Baidu Map's public transit route planning service was selected to manually verify 1 000 sampled travel paths. It was found that the accuracy rate of public transit route planning based on the staged simulation method of the travel process reached 88%, and the accuracy of travel time (within an error of 10 minutes) reached 82%. This method is generally applicable to calculating public transit travel time in the central urban area of Chengdu.

3.4 PTAL map

Based on the set of public transit travel paths in the central urban area of Chengdu, the travel time matrix of any 600-m

Tab. 5 Selected public transit travel paths in Chengdu's central urban area

Grid No. of the starting point	Grid No. of the ending point	Travel path	Travel time/s	Travel mode
71 522	66 185	Take Subway Line 2 from Baicaolu Station to Xipu Station	1 035	Direct access to urban rail transit
40 784	40 191	Take Subway Line 9 from Taipingsi Temple Station to Huaxing Station, and transfer to Subway Line 10 to Jinhua Station	2 324	Transfer from urban rail transit to urban rail transit
40 191	40 785	Take Bus Route 806 from Cuma crossing of Jinhang Road to Hejiaxiangzi Station in Sanyuan Village	1 607	Direct access to bus
70 516	66 260	Take Bus Route 193 from Tianling Road East Station to Shuling Crossing Station, and transfer to Bus Route 650 to Changshengliudui Station	1 856	Transfer from bus to bus
66 176	71 522	Take Bus Route 726 from Baiye Road Middle Station to Baicao Road Station, and transfer to Subway Line 2 to Xipu Station	1 705	Transfer from bus to urban rail transit
66 248	71 585	Take Subway Line 3 from Panda Avenue Station to Botanical Garden Station, and transfer to Bus Route 653 to Tianxin Street Station	1 952	Transfer from urban rail transit to bus
66 260	75 850	Take Bus Route 193 from Shuling Road Station to Tianling Road West Station, and transfer to Subway Line 3 from Military General Hospital Station to Jinshuihe River Station, and then transfer to Bus Route X101 to Hexie Square Station	3 058	Transfer from bus to the urban rail transit, and then transfer to bus
40 191	40 192	None	170	Only walking

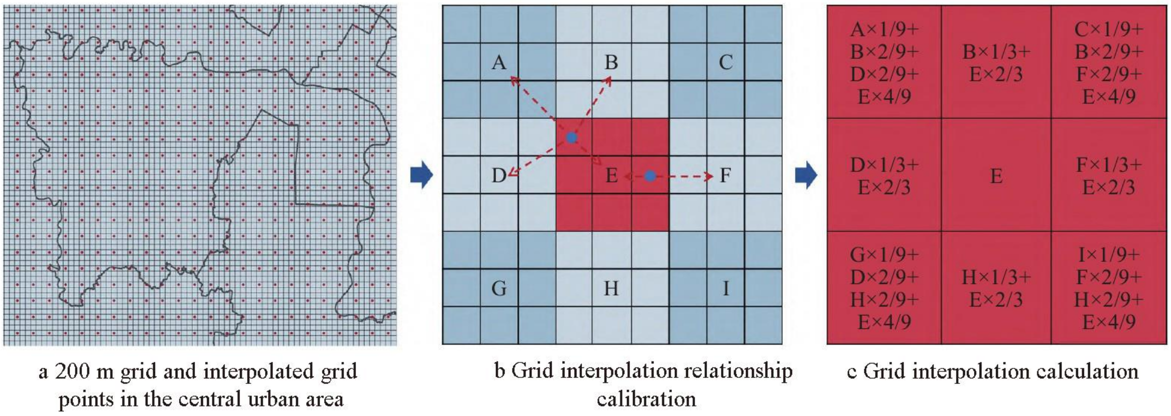


Fig. 5 Relationship calibration of distance-based grid interpolation

grid was generated according to the PTAL map generation process. Then, the number of grids that can be reached within 45 minutes was counted, that is, the public transit accessibility ranges from that point. Finally, the proportion of the public transit accessibility range (the proportion of the area accessible within 45 minutes by public transit to the total area of the central urban area) was calculated, resulting in the PTAL map (600-m grid) of the central urban area of Chengdu.

To accurately reconstruct the 200-m PTAL map of Chengdu and avoid the sawtooth effect, this paper employed distance-based raster relationship interpolation. The interpolation calibration logic is illustrated in Fig. 5. For any 200-m grid, its PTAL value was calculated based on the weighted distance relationship between the 600-m grid it belongs to and the eight adjacent 600-m grids. Taking the 600-m grid area E in the figure as an example (see Fig. 5b), it contains nine 200-m small grids, and the PTAL value calculation formula for each small grid is shown in Fig. 5c.

According to the above interpolation algorithm, a high-precision PTAL map (200 m grid) of Chengdu's central urban area was derived (see Fig. 6). It can be observed that the spatial distribution pattern of public transit accessibility in Chengdu's central urban area is consistent with the characteristics of public transit resource allocation. The proportion of public transit accessible areas is highly coupled with the public transit network, especially the urban rail transit network. The proportion of public transit accessible areas within the belt expressway is generally close to 10%, with the highest proportion located near the Gaoxin District Incubation Park subway station, which is a transfer station for three subway lines and is surrounded by many bus stops. From the perspective of lines, the accessibility level of urban rail transit loops (such as Subway Lines 7 and 9) is generally higher than that of radial lines (such as Subway Lines 2, 10, etc.). In addition, compared to urban rail transit lines serving long-distance travel, the bus mainly plays a role in connecting urban rail transit and serving short-distance travel within the region. Corresponding to the PTAL map, areas with a proportion of public transit accessible range of 3% to 5% are dominated by bus services, which are generally located outside the 800 m service range of urban rail transit and have relatively more bus stops. From the perspective of administrative districts, areas with a higher proportion of public transit accessible range are mainly concentrated within the built-up area, especially in Qingbaijiang District (5%). Currently, there are no urban rail transit lines covering this area, indicating that the bus route layout in the Qingbaijiang District is reasonable and the service capacity is relatively mature.

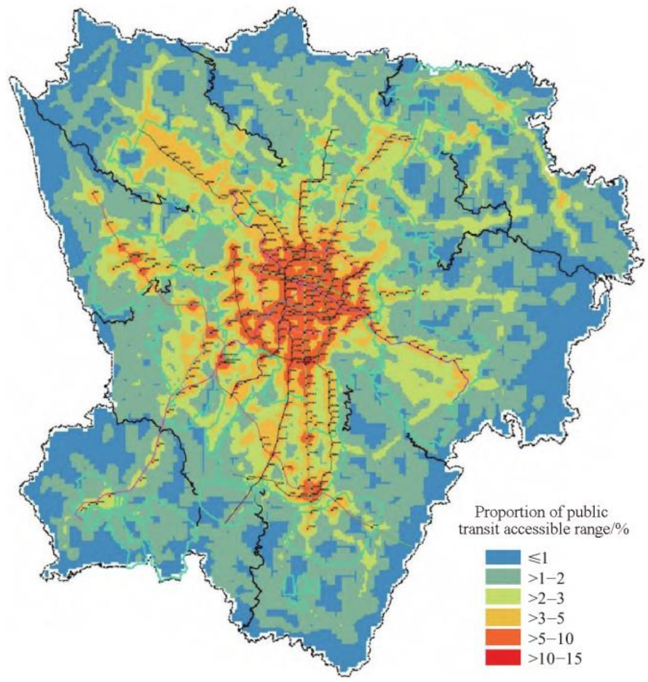
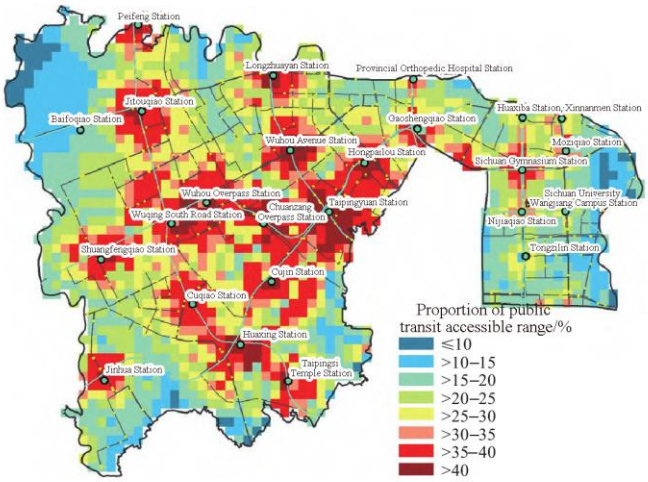


Fig. 6 PTAL map of Chengdu's central urban area

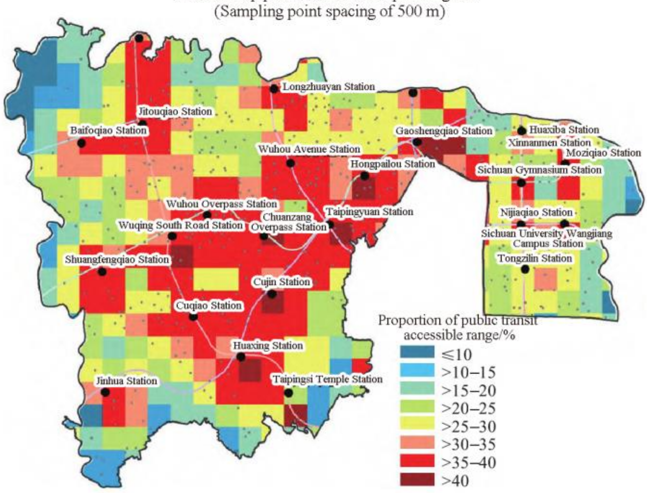
To verify the accuracy of the PTAL map, with Wuhou District in Chengdu as an example, two methods were employed, i.e., utilizing the Baidu Map public transit route planning API and simulating the travel process in stages, to calculate the travel time matrix for the grid sampling points in this area. The morning peak (7:00 to 9:00) from September 9

(Monday) to 13 (Friday), 2024, was selected as the calculation period. Due to the limit on API calls (20 000 per day for enterprise accounts), the grid sampling spacing in Wuhou District was set to 500 m, with 369 grids, resulting in 67 896 API calls and a calculation time of 4 days. However, based on the staged simulation method proposed in this paper for travel time calculation, there was no limit on the number of usage times. Therefore, the sampling spacing was set to 200 m, with 1 887 grids, resulting in 1 779 441 calculations and a calculation time of only 6.6 hours.

Based on the travel time matrices obtained from the two methods, PTAL within 45 minutes in the Wuhou District was calculated. The results are shown in Fig. 7. Due to the particular shape of the administrative boundary of the Wuhou District, there is a strong boundary effect in the eastern area, resulting in a relatively low level of grid accessibility near Subway Line 1.



a Baidu Map public transit route planning API (Sampling point spacing of 500 m)



b Staged simulation of travel process (sampling point spacing of 200 m)

Fig. 7 PTAL map of Wuhou District in Chengdu

Comparing the PTAL maps obtained by the two methods, we found that the overall trend of PTAL derived from the staged simulation method of travel process is consistent with Baidu Map's public transit route planning API, indicating that the PTAL map obtained by the staged simulation method of travel process in this paper is reliable in terms of the accuracy. The areas with higher PTALs are still concentrated near urban rail transit lines, and the PTAL of transfer stations is higher than that of non-transfer stations. The highest value appears near the Taipingyuan Station, which is a transfer station for three lines and has many bus stations nearby. In terms of computational efficiency, compared to Baidu Map's public transit route planning API, the staged simulation method of travel process can be used locally offline and is not limited by the number of calls, greatly improving the computational efficiency and achieving a PTAL map with a higher spatial accuracy.

4 Application prospects

Based on PTAL, a series of new application indicators can be further calculated to measure the level of public transit supply service [24], or to evaluate the coordination degree between land use and public transit development [24–26], including monitoring the accessibility of public transit for specific groups or facilities, optimizing urban rail transit and bus transit network plans based on passenger flow conditions, and formulating standards for parking construction or housing supply.

Based on the PTAL map of Chengdu's central urban area, this paper calculated the public transit accessibility of different types of public service facilities, including parks, primary and secondary schools, and general hospitals. The specific calculation process refers to the London ATOS analysis method [2]. We calculated the average travel time from any grid center point in the central urban area to the nearest three parks, three primary and secondary schools, and three general hospitals, respectively, and compared it with other grids in the area, and converted it into the five-level ATOS value using the mean–standard deviation grading method.

As can be seen from Figs. 8a and 8c, the areas with high accessibility to public transit for parks and general hospitals in the central urban area of Chengdu are relatively concentrated, mainly distributed in the five core urban districts, especially within the second ring road. Meanwhile, ATOS of regional parks and general hospitals in more marginal areas is also relatively high, especially for general hospitals, whose ATOS is all above Level B, indicating that the distribution of medical service levels in the central urban area of Chengdu is relatively balanced. As can be seen from Fig. 8b, the areas with high accessibility to public transit for primary and secondary schools are mainly concentrated near urban rail transit lines, and the accessibility level of primary and secondary education resources in the marginal areas of the central urban area is relatively low, indicating that high-quality educational resources in the central urban area of Chengdu are spatially concentrated, and the redistribution effect of the urban rail transit system on educational resources is much higher than that of bus transportation.

In addition, urban resource assessment and analysis can be further conducted by combining data on population, land use, and other factors. For example, the changes in PTAL before and after the opening of Subway Line 19 in 2024, as well as the changes in the availability of various public resources, were analyzed. Based on the future distribution of travel demand in the central urban area of Chengdu and road operating conditions, three types of parking control zones can be designated to fully guide the shift of private car travel demand towards urban rail transit (see Fig. 9).

5 Conclusion

PTAL is a quantitative representation of the relationship between transportation and urban space, which can objectively reflect the coverage and service capabilities of public transit networks. To quickly and accurately measure regional PTAL, this paper proposed a staged simulation method for the travel process, achieving the determination of public transit travel time between any grid points, and further presented the generation process of the PTAL map. Taking Chengdu as an example, this paper used a 200-m grid as the benchmark, and applied the staged simulation method for the travel process to generate the PTAL map. The results showed that the spatial distribution pattern of PTAL in the central urban area of Chengdu is highly coupled with the urban rail transit network, and the accessibility level of the urban rail transit ring line is overall higher than that of the radial lines. Bus transportation mainly serves as a feeder to urban rail transit and for short-distance travel within the region.

From the perspective of computational efficiency, the method proposed in this paper and the Baidu Map public transit route planning API were used to evaluate PTAL in the Wuhou District, Chengdu. The results show that the method proposed in this paper is not limited by the number of calls when it is used locally offline, thus greatly improving the calculation efficiency and achieving higher spatial accuracy in PTAL map production.

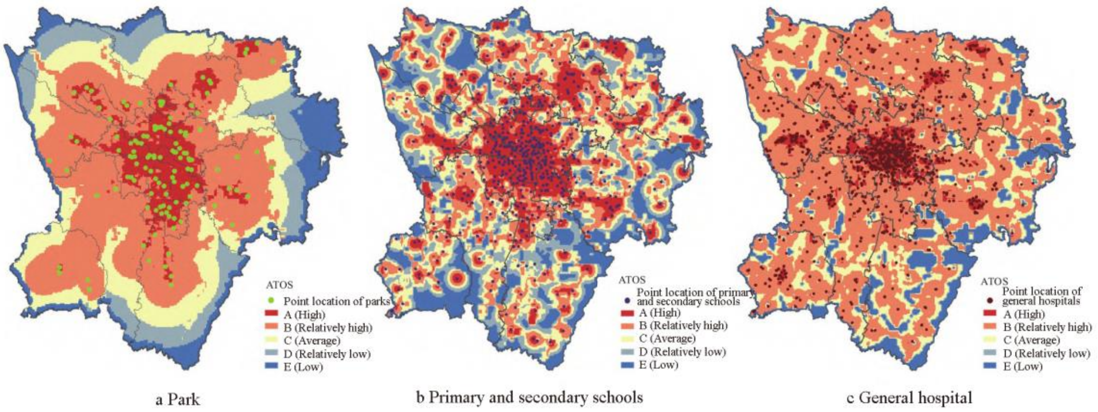


Fig. 8 Public transit accessibility map of public service facilities in Chengdu's central urban area

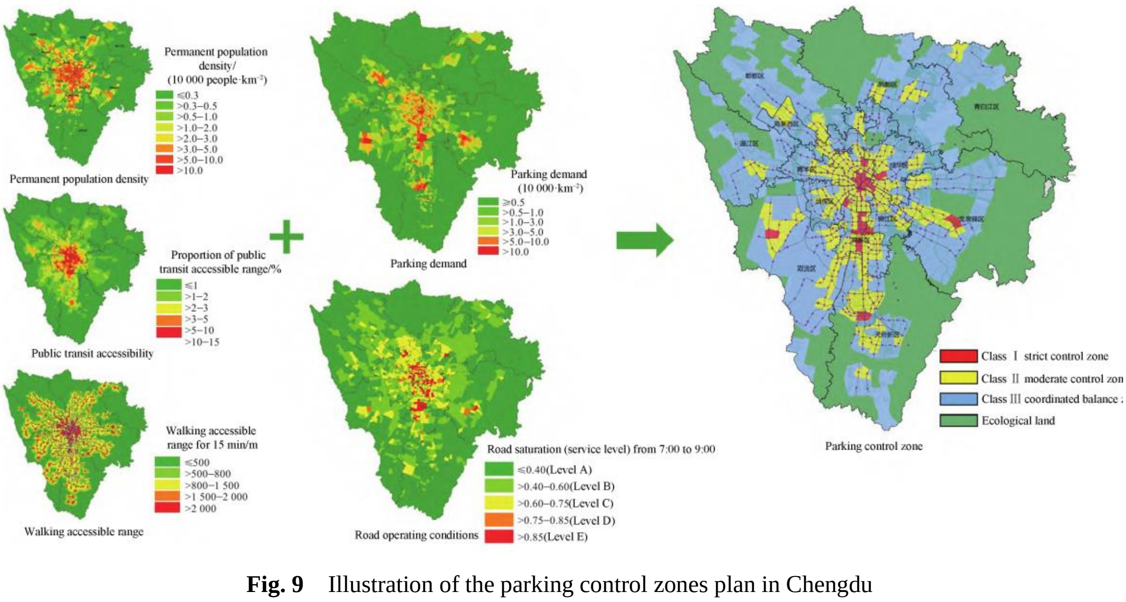


Fig. 9 Illustration of the parking control zones plan in Chengdu

The PTAL calculation method proposed in this paper is oriented towards the division of travel processes. For future considerations, more detailed parameters, such as the road congestion index, can be incorporated into the bus travel process, thereby optimizing the operating times of bus routes during different time periods. Simultaneously, the PTAL calculation method presented in this paper possesses universality, allowing for future exploration of accessibility characteristics across various cities and different public service facilities. It provides theoretical support for promoting the coordinated development of public transit and urban land use space.

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