Proceedings of CONF-FMCE 2026 Symposium: Smart City and Infrastructure Engineering
DOI: 10.54254/2755-2721/2026.CH38165

15-Minute Employment Accessibility of Autonomous-Vehicle Feeders: A Case Study of a Shanghai Pilot Demonstration Zone

Jiewen Yu

College of Transportation, Tongji University, Shanghai, China
2352661@tongji.edu.cn

Abstract. The 15-minute city is often invoked for commuting, while demonstration zones present autonomous-vehicle (AV) feeder services on open test roads as a last-mile rail solution. This paper evaluates a Jiading station area in Shanghai, taking the Anting core at Shanghai International Automobile City as the study area and the Baiyin Road–Jiading New Town corridor as a spatial control. Using network travel times and equal-weighted office and industry points of interest (POIs) as an employment proxy, we measure 15-minute employment accessibility for walking, walk–transit and AV feeder constrained to open test roads, and use a detour ratio to describe local network constraints. Median walk opportunity is 21 POIs in the Anting core and 37 in the control corridor. Adding rail increases the means by 0.19 and 0.40 POIs, respectively. When in-vehicle travel is restricted to name-matched Notice 694 open roads, the mean AV-feeder gain relative to walk–transit is near zero. Transfer and waiting already consume most of the 15-minute window. The study provides a unified cumulative-opportunity framework for station-area commute evaluation and shows that feeder gains are sensitive to the time threshold.

Keywords: employment accessibility, 15-minute city, cumulative opportunity, autonomous-vehicle feeder, last-mile

1. Introduction

The 15-minute city treats everyday opportunities as reachable within a short travel time [1, 2]. Local guidelines specify walking distances of about 800–1000 m, rail station areas of about 500–800 m, and nearby employment as community-scale standards [3]. Life-circle assessments, however, mainly record daily-service coverage and only weakly represent employment opportunity [4]. Demonstration zones present autonomous-vehicle (AV) last-mile feeders on open test roads as a rail access scheme [5, 6]. In Jiading these feeders are framed around employees commuting between station areas and workplaces, yet existing studies report waiting, fleet size and matching rather than 15-minute employment opportunity. This paper therefore uses one cumulative-opportunity measure: how many office and industry points of interest (POIs) are reachable on foot in 15 minutes; how many more by walk–transit; and how many more still by open-road AV feeder. The setting is a Jiading station area where open-test-road, slow-mobility and life-circle policies overlap, with the

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.CH38165

Anting core at Shanghai International Automobile City as the study area and the Baiyin Road–Jiading New Town corridor as the spatial control. AV feeder uses normative speed and waiting and is constrained to open roads named in Shanghai Municipal Commission of Transport Notice 694 (2020), hereafter Notice 694. The paper measures walk cumulative opportunity, the walk–transit increment and detour ratio, and AV-feeder accessibility relative to walk–transit.

2. Related work

Accessibility is the potential to reach opportunities [7, 8]; for commuting it is a count of employment-type destinations inside a network-time threshold, and Euclidean buffers overestimate active-travel access [9]. Cumulative opportunity is the main indicator here; gravity, two-step floating catchment, space–time and utility measures are reviewed elsewhere [10-12]. The 15-minute city emphasises short active-travel windows [1, 2], but applied life-circle assessments mainly record daily-service coverage [4, 3], while Shanghai job-accessibility studies more often use thresholds longer than 15 minutes [13, 14]. Terminal-access work shows that first- and last-mile conditions change transit job accessibility, station-area walkability and feeder provision [15-18, 6], yet it does not report a common workplace-opportunity count at 15 minutes across walking, walk–transit and open-road AV feeder. AV last-mile studies centre on waiting, fleet size, matching and network design [19-24]. Policy overlays bound Anting and Baiyin Road without showing that feeders raise that short-window count.

3. Data and methods

3.1. Study area and data

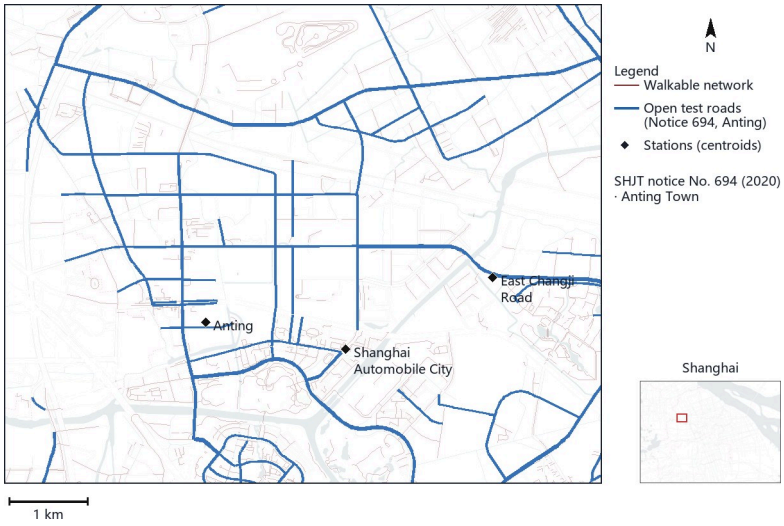


Figure 1. Observed basemap and test-road extent of the Anting core. Blue lines are Anting Town road names in Shanghai Municipal Commission of Transport notice No. 694 (2020) matched to OpenStreetMap [5]; diamonds mark representative station centroids. Unmatched segments are mostly internal factory roads

The study area follows the overlay of open-test-road, slow-mobility and 15-minute life-circle documents [5, 6, 3] (Figure 1-2). The Anting core is the national pilot town at Shanghai International Automobile City, with representative stations Anting, Shanghai Automobile City and East Changji

DOI: 10.54254/2755-2721/2026.CH38165

Road. The Baiyin Road–Jiading New Town corridor is the spatial control (Baiyin Road smart street and New Town living area). The Anting box is longitude $\in$[121.10,121.28], latitude $\in$[31.25,31.36]; the control box is longitude $\in$[121.225,121.275], latitude $\in$[31.318,31.358]. The period is the weekday morning peak, 7:30–9:30; the analysis unit is a 500 m cell.

The walkable network is an OpenStreetMap extract with expressways removed; edge weights use $v_w = 4.8\text{km/h}$. Employment opportunity O_j is an office or industry POI with $O_j = 1$ (827 origin cells in the Anting core; 83 in the control). Stations, exits and AV stops are distinct geometries: rail nodes carry Line 11 in-vehicle time; walk access and egress use representative-station centroids as exit proxies; pickup p' (drop-off p) is the open-road node nearest the cell (station). First-train intervals on the study segment are 2 min (Anting–Automobile City), 3 min (Automobile City–East Changji; Baiyin–Jiading New Town) and 5 min (East Changji–Shanghai Circuit). The AV feasible domain matches Notice 694 names to OSM by exact name [5]: 64/134 names in the Anting box yield 200.2 km in 17 components; the control matches 13 New Town names (47.0 km). Unmatched names lack exact OSM geometry and remain outside the feasible domain.

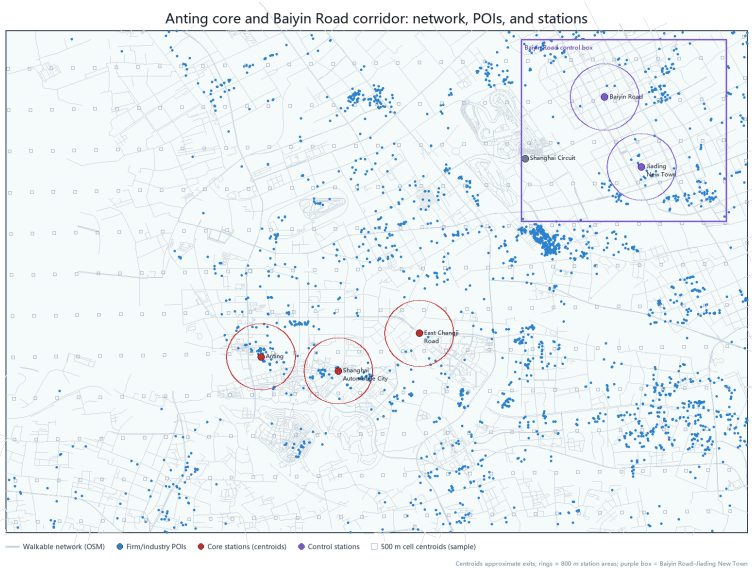


Figure 2. Analysisbox layers: walkable network, firm/industry POIs, representative station centroids and approximately 800 m station areas. The purple box is the Baiyin Road–Jiading New Town spatial control

3.2. Methods

The evaluation has three layers at the same 15-minute threshold (Table 1): walk $A_i^{\text{walk}}(15)$; the walk–transit increment $A_i^{\text{walk-transit}}(15)$ with a detour ratio; and AV-feeder $A_i^{\text{AVfeeder}}(15)$ relative to walk-transit on Notice 694 matched roads. Travel impedance is network shortest-path time c_{ij}^m. Because first- and last-mile settings change transit job accessibility, the metric includes walk access, waiting and transfer.

DOI: 10.54254/2755-2721/2026.CH38165

3.2.1. Multimodal travel times

Travel impedance is network shortest-path time c_{ij}^{m} [25]. Let the mode set be $m \in \text{walk}, \text{walk} - \text{transit}, \text{AVfeeder}$.

For walking:

$$c_{ij}^{\text{walk}} = \frac{d_{ij}^{\text{walk}}}{v_w} \tag{1}$$

where d_{ij}^{walk} is the shortest distance on the walkable network and v_w is walking speed.

For walk–transit:

$$c_{ij}^{\text{walk}-\text{transit}} = t_{i\to e}^{\text{walk}} + t_{e}^{\text{transfer}} + t_{e\to s}^{\text{rail}} + t_{s\to j}^{\text{walk}} \tag{2}$$

where $t_{i\to e}^{\text{walk}}$ is walking time from the cell to the nearest exit proxy (representative-station centroid in the main results), t_{e}^{transfer} is a uniform transfer and waiting penalty, $t_{e\to s}^{\text{rail}}$ is in-vehicle time, and $t_{s\to j}^{\text{walk}}$ is walking time from the destination exit proxy to the opportunity. If the opportunity lies inside the origin-station walk catchment and not using rail is better, the cost reverts to (1).

For AV feeder:

$$c_{ij}^{\text{AV}} = t_{i\to p'}^{\text{walk}} + t_{i}^{\text{wait}} + t_{p'\to p}^{\text{AV}} + t_{p\to e}^{\text{walk}} + t_{e}^{\text{transfer}} + t_{e\to s}^{\text{rail}} + t_{s\to j}^{\text{walk}} \tag{3}$$

where p' is the node on the open-test-road network nearest the cell centroid and p is the node nearest the station; $t_{i\to p'}^{\text{walk}}$ is walking time to pickup, and feeder is unavailable for that cell if this exceeds 800 m; $t_{p'\to p}^{\text{AV}}$ is computed only on Notice 694 matched segments, and the station is unreachable if no path exists; $t_{p\to e}^{\text{walk}}$ is residual Euclidean walking from drop-off to the station centroid. Speed and waiting take the normative parameters in.

3.2.2. Cumulative-opportunity accessibility

The primary indicator is cumulative-opportunity accessibility [7, 8]. Under a POI employment proxy and without capacity-competition data, a fixed-threshold count is preferred to gravity, two-step floating catchment or utility formulations as the main result. For origin cell, opportunity j and mode m:

$$A_i^m(t_0) = \sum_j O_j 1(c_{ij}^m \le t_0), t_0 \in 10{,}15{,}20\text{min} \tag{4}$$

Main results take $t_0 = 15\text{min}$, with 10 min and 20 min as threshold contrasts. Equation (4) is Hansen location-based accessibility under a binary impedance. A linearly decaying form $f(c) = 1 - c/t_0$ for $c \le t_0$ is used only as a functional contrast and is not reported as the main result. Summaries are box-wide means and a station-area cut within 800 m of a representative-station centroid [3, 6, 26]. Box-wide means remain primary.

DOI: 10.54254/2755-2721/2026.CH38165

3.2.3. Descriptive last-mile diagnosis

For each cell centroid to the nearest exit proxy, network distance d_i^{net} and Euclidean distance d_i^{Eucl} are computed, and the detour ratio is

$$\rho_i = \frac{d_i^{\text{net}}}{d_i^{\text{Eucl}}}, d_i^{\text{Eucl}} > 0 \tag{5}$$

ρ_i is defined only where a walk-network path to a representative station exists within a 25 min cutoff.

3.2.4. Feeder scenarios and comparison indicators

Let the baseline mode be walk–transit and the scenario mode AV feeder. The cell-level gain is

$$\Delta A_i(15) = A_i^{\text{AVfeeder}}(15) - A_i^{\text{walk-transit}}(15). \tag{6}$$

Area summaries use the mean gain $\overline{\Delta A}(15)$ and the share of benefiting cells

$$\eta = \frac{1}{N}\sum_{i=1}^{N} 1(\Delta A_i(15) > 0) \tag{7}$$

AV in-vehicle travel is constrained to Notice 694 matched segments. A right-of-way contrast scales speed on walk geometry rather than adding a citywide driving network.

Table 1. Normative multimodal parameters

Parameter	Value	Note
Walk speed v_w	4.8 km/h	≈ 80 m/min, aligned with local life-circle walking pace [3]
AV speed v_a	25 km/h	Normative urban feeder speed on Class III open-test roads [5]
Waiting time	3–5 min	Midpoint 4 min; order of waiting in AV-feeder studies [1, 7]
Transfer/wait penalty t_e^{transfer}	3 min	Uniform rail access/egress penalty, common to both areas
Primary threshold t_0	15 min	Life-circle commute metric; contrasts 10 / 20 min [3]

4. Results

Main results use the 15-minute threshold: for each cell, office and industry POIs with $c_{ij}^m \leq 15\text{min}$ yield $A_i^m(15)$. Exit proxies are representative-station centroids. Unless noted, means are box-wide; the station-area cut uses the 800 m Euclidean definition above. The Anting core (827 cells; 25 in the cut) is reported first; the Baiyin Road corridor and 10/20 min contrasts follow in Section 4.5.

DOI: 10.54254/2755-2721/2026.CH38165

4.1. 15-minute walk cumulative-opportunity pattern

Walk cumulative opportunity $A_i^{\text{walk}}(15)$ in the Anting core is shown in Fig. 3(a). The box-wide mean is 40.5 POIs, the median 21, the 25th and 75th percentiles are 3 and 57, the maximum is 531, and about 85.4 % of cells have $A_i^{\text{walk}}(15) > 0$; in the station-area cut the walk mean is 49.9. The box-wide mean exceeds the median because the distribution is right-skewed. Walk isochrones from representative stations are shown in Fig. 4(a). At $v_w = 4.8\text{km/h}$, 10, 15 and 20 minutes correspond to network radii of about 0.8, 1.2 and 1.6 km. The three bands expand irregularly along the network and are overlaid on one map: the 10-minute band remains close to station centroids, the 15-minute bands remain disconnected, and the 20-minute bands overlap only locally between stations.

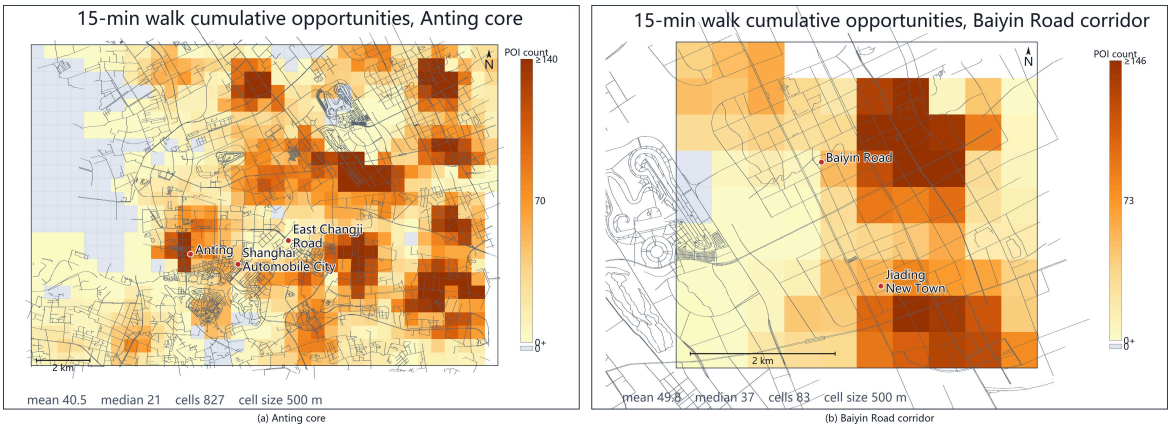


Figure 3. 15-minute walk cumulative opportunity Aiwalk(15) in the two areas. The colour scale is the count of firm/industry POIs reachable in 15 minutes; red dots are rail stations

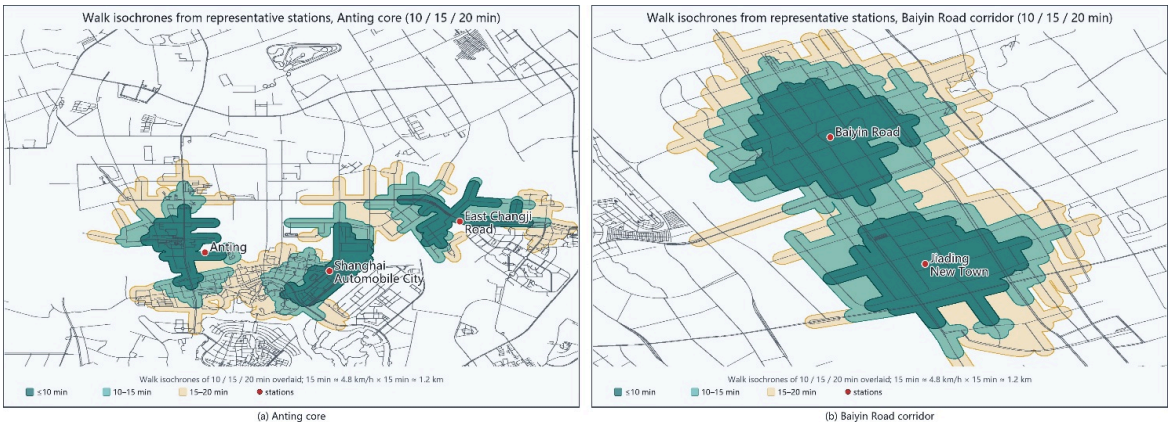


Figure 4. Walk isochrones from representative stations. Each panel overlays the ≤ 10, 10–15 and 15–20 min bands

4.2. Rail-feeder increment at the 15-minute threshold

After walk–transit is included, the box-wide mean of $A_i^{\text{walk}-\text{transit}}(15)$ rises from 40.5 to 40.7 (increment 0.19); the median remains 21. In the station-area cut the mean rises from 49.9 to 56.0 (about +6.2), so rail adds little box-wide but more near stations. Table 2 decomposes the time budget: after a 3 min transfer penalty, 12 min remain; in-vehicle time on the study segment is 2–5 min. Walk access and egress further shrink the residual window for new POIs.

DOI: 10.54254/2755-2721/2026.CH38165

Table 2. Decomposition of the 15-minute commute time budget

Component	Value	Implication
Threshold t_0	15 min	Life-circle metric
Transfer penalty	3 min	12 min remain
Line 11 in-vehicle	2–5 min	Near residual window
AV waiting	4 min	8 min remain; May exceed residual
800 m to open road	≈10 min	
Station-road walk	0.5-2.7 min	Walk after drop-off

4.3. Detour ratio and its spatial distribution

To describe last-mile network geometry, the detour ratio ρ_i is computed for cells with a network path to a representative station within 25 min (Fig. 5; $n = 55$). In the Anting core the mean of ρ_i is 1.43 and the median is 1.25: for half of these cells, network distance is about 1.25 times Euclidean distance. High detour forms local patches around the station cluster rather than an area-wide pattern.

4.4. AV-feeder gain in the 15-minute window

When in-vehicle travel is restricted to Notice 694 matched open roads, box-wide $\overline{\Delta A}(15) = 0.04$ and $\eta = 0.5$ in the Anting core (Table 3); in the station-area cut, $\overline{\Delta A}(15) = 0.64$ and $\eta = 4$. Matched open roads total 200.2 km in 17 components. About 59.9 % of cells reach an open road within 800 m; mean cell-to-pickup distance is 1.09 km; residual station-to-road distances are 43–214 m. After 4 min waiting and 3 min transfer, 8 min remain; at 4.8 km/h, an 800 m walk already takes about 10 min. Without the segment constraint and with geometric speed scaling, box-wide $\overline{\Delta A}\left(15\right)$ is about 0.57.

Table 3. AV-feeder gain, Anting core

Constraint	$\overline{\Delta A}\left(15\right)$
Notice 694 matched ($\eta = 0.5$)	0.04
Geometric speed scaling	0.57

Note: geometric scaling is not citywide driving.

DOI: 10.54254/2755-2721/2026.CH38165

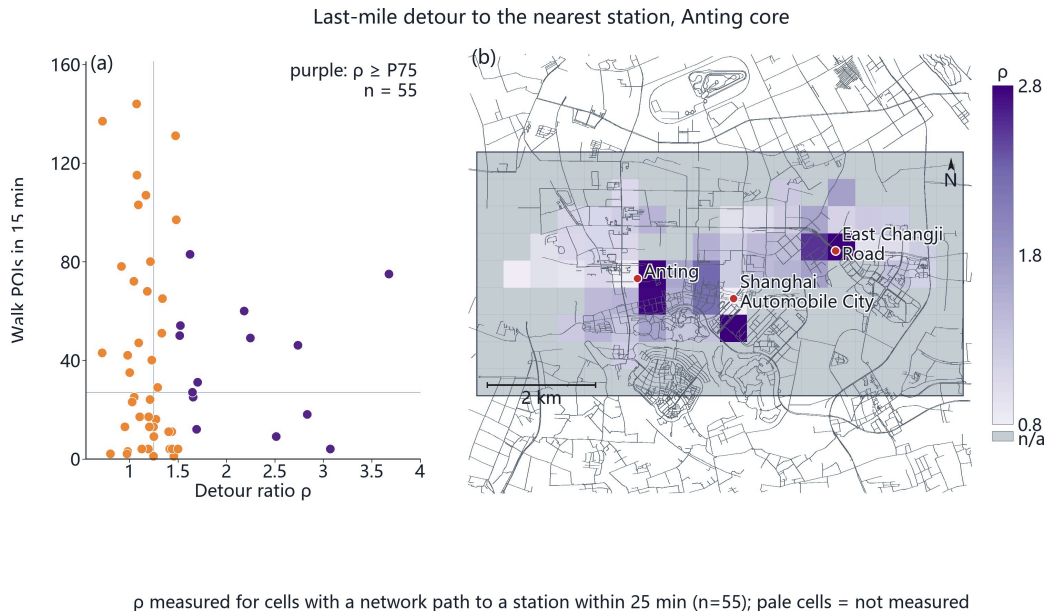


Figure 5. Last-mile detour ratio ρi (network/Euclidean distance to the nearest station) in the Anting core. (a) Each point is a cell with a measured ρi ; dashed lines are medians and purple marks $\rho \geq P75$. (b) Zoom on the three representative stations; purple sequential colour is ρi and pale cells have no measured path within 25 min (n = 55). High detour is local rather than area-wide

4.5. Spatial control and threshold contrasts

The spatial control comprises a replication on the Baiyin Road–Jiading New Town corridor and 10/20 min threshold contrasts for both areas (Figs. 3(b) and 4(b); Table 4).

The Baiyin Road corridor contains 83 cells and 485 POIs (16 in the station-area cut). The box-wide walk mean is 49.8 (median 37; 97.6 % of cells >0), higher than in the Anting core; the station-area walk mean is 52.7. After rail, the box-wide mean rises to 50.2 (+0.40) and the station-area mean to 54.8 (about +2.1); mean ρ_i is 1.31 (median 1.28). Under the open-road constraint, $\overline{\Delta A}(15) = 0$ and $\eta = 0$ both box-wide and in the cut, despite shorter pickups (mean 408 m) and higher 800 m open-road access (83.1 %); the unconstrained gain is about 2.07. The two-station isochrones meet only locally at 15 minutes and begin to overlap at 20 minutes.

Table 4. Spatial control: cumulative opportunity at 10, 15 and 20 minutes

Area	t_0	Walk mean/median	Rail increment	AV gain
Anting core	10	18.8 / 7	0.06	0
	15	40.5 / 21	0.19	0.04
	20	70.8 / 46	0.63	3.41
Baiyin Road corridor	10	22.5 / 11	0.01	0
	15	49.8 / 37	0.40	0
	20	81.8 / 68	1.73	3.11

DOI: 10.54254/2755-2721/2026.CH38165

Note: Rail increment and AV gain are relative to the preceding mode. The 15-minute AV gain is aligned with the main result in Table 3 (Notice 694 matched roads). The 10/20 min values are recomputed on the same open-road network to observe the direction of the threshold effect.

Feeder increments appear only when the residual window after waiting and transfer is relaxed. Holding $t_0 = 15\text{min}$, 4 min waiting plus 3 min transfer leave 8 min, while an 800 m walk already takes about 10 min; the control corridor's zero 15-minute AV gain despite shorter pickups indicates that the main result is not solely an artefact of the Anting matching rate.

5. Discussion

Life-circle facility coverage cannot replace 15-minute commute accessibility measured with an employment-proxy POI count [3, 4]. Walk medians are 21 and 37 POIs; 15-minute isochrones remain about 1.2 km and separated. After the threshold is compressed to 15 minutes and transfers are counted, the mean walk–transit increment in both areas is less than one POI [13-16]. Feeder gain is zero at 10 minutes and about three POIs at 20 minutes, so 15 minutes is a binding threshold rather than an artefact of grid size. Once the same AV feeder is evaluated with a cumulative-opportunity indicator, 4 min of waiting and 3 min of transfer occupy most of the window [19,-21]. Median detour ratios are only 1.25–1.28, and the control corridor's 15-minute gain remains zero despite shorter pickups, so the consistent constraint is residual time rather than open-road coverage. If the policy target remains a 15-minute commute, the results point first to shortening waiting and transfer and reducing residual walk; expanding test-road coverage or raising feeder speed alone is unlikely to raise reachable POIs within 15 minutes. These implications follow from normative-parameter scenarios. Neither area represents a high-density central-city station area; jobs are equal-weighted POIs; open roads are name-matched (64/134 in the Anting box); waiting and speed are normative (Table 1), not observed.

6. Conclusion

This paper places the life-circle 15-minute threshold, an employment-proxy POI count and open-road AV feeder in one cumulative-opportunity framework. Walk opportunity differs between the two areas, 15-minute isochrones remain separated, and box-wide rail and AV increments are both near zero at 15 minutes—yet rail rises more in the station-area cut, and the control corridor's AV gain remains zero despite shorter pickups. Gains appear only when the window is relaxed to 20 minutes (about three POIs). The principal constraint is the short-window time budget rather than open-road coverage alone: feeder services are threshold-dependent under the life-circle clock, not necessarily ineffective. Future work should test this mechanism with observed waiting, a complete exit inventory, establishment-level job weights and official open-road geometries.

References

[1] Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-minute city": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*(1), 93–111.

[2] Pozoukidou, G., & Chatziyiannaki, Z. (2021). 15-minute city: Decomposing the new urban planning eutopia. *Sustainability, 13*(2), 928.

[3] Shanghai Municipal Bureau of Planning and Land Resources. (2016, August). *Shanghai planning guidance of 15-minute community-life circle*. Shanghai Municipal Bureau of Planning and Land Resources. in Chinese. Shanghai, China.

[4] Khavarian-Garmsir, A. R., Sharifi, A., Hajian Hossein Abadi, M., & Moradi, Z. (2023). From garden city to 15-minute city: A historical perspective and critical assessment. *Land, 12*(2), 512.

DOI: 10.54254/2755-2721/2026.CH38165

[5] Shanghai Municipal Commission of Transport, Shanghai Municipal Commission of Economy and Informatization, & Shanghai Municipal Public Security Bureau. (2020). Notice on designating the third batch of open roads for autonomous driving testing in Jiading district [Tech. Rep.]. Shanghai Municipal Commission of Transport. in Chinese. Shanghai, China.
[6] Shanghai Municipal Commission of Transport, Shanghai Municipal Road Transport Bureau, & Shanghai Urban and Rural Construction and Transportation Development Research Institute. (2021). *Shanghai planning guidelines for slow traffic*. Shanghai Municipal Road Transport Bureau. in Chinese. Shanghai, China.
[7] Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*(2), 73–76.
[8] Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography, 12*(2), 127–140.
[9] Vale, D. S., Saraiva, M., & Pereira, M. (2016). Active accessibility: A review of operational measures of walking and cycling accessibility. *Journal of Transport and Land Use, 9*(1), 209–235.
[10] Luo, W., & Qi, Y. (2009). An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health & Place, 15*(4), 1100–1107.
[11] Fransen, K., Neutens, T., De Maeyer, P., & Deruyter, G. (2015). A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers. *Health & Place, 32*, 65–73.
[12] Kwan, M.-P. (1998). Space–time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis, 30*(3), 191–216.
[13] Xiao, W., Wei, Y. D., & Li, H. (2021). Spatial inequality of job accessibility in Shanghai: A geographical skills mismatch perspective. *Habitat International, 115*, 102401.
[14] Zhou, J., & Yang, Y. (2024). Accessible jobs and secured jobs by mode of travel and isochrone: An exploratory study of Shanghai, China. *Transportation Research Record*.
[15] Chen, Y., Xu, Q., Jia, S., Wei, R., Sun, S., & Li, W. (2025). Job accessibility of urban rail transit considering access and egress travel. *Journal of Zhejiang University (Engineering Science), 59*(2), 310–318. in Chinese.
[16] Sharifiasl, S., Kharel, S., Pan, Q., & Li, J. (2024). Assessing the impact of transit accessibility on employment density: A spatial analysis of gravity-based accessibility incorporating job matching, transit service types, and first/last mile modes. *Journal of Transport Geography, 121*, 104053.
[17] Chen, X., Shi, Z., & Hu, Y. (2025). The walkability evaluation and optimization strategies of metro station areas taking Shanghai as an example. *Buildings, 15*(10), 1746.
[18] Zhang, Z., Yang, X., Jiang, C., Lu, L., Li, X., Rong, X., & Huang, Z. (2025). Improving equity through barrier-free transportation: An evaluation of Shanghai metro stations. *Frontiers in Public Health, 12*, 1463824.
[19] Aalipour, A., & Khani, A. (2024). Designing an autonomous mobility-on-demand service for transit last-mile access. *Transportation Research Record: Journal of the Transportation Research Board, 2678*(11), 2181–2194.
[20] Roy, S., Dadashev, G., Yfantis, L., Nahmias-Biran, B.-H., & Hasan, S. (2025). Autonomous on-demand shuttles for first mile–last mile connectivity: Design, optimization, and impact assessment. *Transportation Research Record: Journal of the Transportation Research Board, 2679*(8), 819–840.
[21] Huo, Y., Zhang, Y., Li, X., & Chen, G. (2024). Dynamic ridesharing matching of shared autonomous vehicles as connection to metro. *China Journal of Highway and Transport, 37*(6), 288–301. in Chinese.
[22] Ng, M. T. M., Mahmassani, H. S., Verbas, Ö., Cokyasar, T., & Engelhardt, R. (2024). Redesigning large-scale multimodal transit networks with shared autonomous mobility services. *Transportation Research Part C: Emerging Technologies, 168*, 104575.
[23] Ng, M. T. M., Dandl, F., Mahmassani, H. S., & Bogenberger, K. (2026). Semi-on-demand hybrid transit route design with shared autonomous mobility services. *Transportation Research Part C: Emerging Technologies, 185*, 105578.
[24] Liu, X., Shao, X., & Li, Y. (2025). Eco-friendly integration of shared autonomous mobility on demand and public transit based on multi-source data. *Information Fusion, 115*, 102771.
[25] Pereira, R. H. M., Saraiva, M., Herszenhut, D., Braga, C. K. V., & Conway, M. W. (2021). r5r: Rapid realistic routing on multimodal transport networks with R^5 in R. *Findings*.
[26] Lin, D., Zhang, Y., Zhu, R., & Meng, L. (2023). Assessing bike accessibility to metro systems by integrating crowdedness. *Transactions in Urban Data, Science, and Technology, 2*(2), 159–177.