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Uncovering how online attractiveness mediates and moderates the impact of multi-scale transportation accessibility on non-work mobility

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ABSTRACT

The role of information and communication technology (ICT) in substituting or complementing offline mobility has been widely studied. However, how online attractiveness influences the impact of transportation accessibility at different scales on non-work mobility remains unclear. This study explores the mediating and moderating effects of online attractiveness on multi-scale transportation accessibility using social media data and mobile phone signaling data in Beijing. The results reveal that online attractiveness mediates the relationship between multi-scale transportation accessibility and non-work mobility, with a stronger effect observed on weekends compared to weekdays. The highest mediation effect was found for proximity to subway stations. Furthermore, the study uncovers a dual moderation effect of online attractiveness, enhancing the advantages of highly accessible locations such as areas near subway stations and street-facing storefronts while complementing less accessible areas, including non-central locations and non-ground floor commercial spaces. Two robustness checks confirm the reliability of these findings. This study enriches the understanding of the dynamic interaction between transportation accessibility and online attractiveness in the digital era. The insights also provide valuable guidance for location selection and operational strategies for businesses and urban planners.

1. Introduction

The importance of transportation accessibility and destination attractiveness to non-work mobility has been frequently emphasized across the fields of transportation, tourism and leisure, and urban planning (Vickerman, 1974; Ewing and Cervero, 2010; Miller, 2018). Transportation accessibility, defined as the “opportunity for interaction” (Hansen, 1959) and as the measure of overcoming the cost of physical friction (Ingram, 1971), considers various transportation modes and exerts a significant influence on mobility patterns and trip generation (Vickerman, 1974). Meanwhile, attractiveness, which heavily depends on the perceived quality of the services, acts as a pull force, shaping individuals’ potential demand for tourism and leisure travel and activities (Andrianto and Sugiama, 2016). Consequently, in the context of non-work mobility—encompassing maintenance and leisure activities while excluding residence- and work-related mobility (Kröger et al., 2018)— both accessibility and attractiveness jointly determine trip generation, mobility behaviors, and spatial interactions. Accessibility influences the ease and feasibility of travel (Ewing and Cervero, 2010; Cervero and Kockelman, 1997; Gutiérrez-Roig et al., 2016), while attractiveness stimulates motivation and desire to visit specific destinations (Ismail and Rohman, 2019; Kim et al., 2023).

The advent of information and communication technology (ICT) has profoundly reshaped the relationship between accessibility and attractiveness, leading to a significant shift in their roles in influencing non-work mobility. Online attractiveness, refers to the appeal of a particular entity or location in online platforms or digital spaces, which is shaped by electronic word-of-mouth (eWoM) on various social media platforms (Jalilvand et al., 2011; King et al., 2014). Regarding its pivotal role in influencing individuals’ spatial imagination and reshaping their spatiotemporal behaviors and mobility patterns (Minazzi, 2015), a growing body of research has focused on exploring how online attractiveness contributes to the spatiotemporal reallocation of activities, emphasizing the role of ICT in enhancing non-work mobility (Mokhtarian et al., 2006). However, transportation accessibility remains a crucial factor, continuing to influence mobility patterns and travel

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decisions. While the effects of online attractiveness and transportation accessibility differ across various spatial scales from region and city to neighborhood and streets (Dadashpoor and Yousefi, 2018), these two factors interact to define modern non-work mobility.

In recent decades, research has increasingly focused on the interactions between transportation accessibility and online attractiveness, and their combined effects on non-work mobility. From a transportation perspective, studies often integrate online attractiveness as a supplementary indicator to measure synthesized accessibility, aiming to simulate mobility patterns and non-work activities (Shen and Karimi, 2016; Wang et al., 2022; Liu and Jiang, 2021). This integration stems from the understanding that accessibility not only refers to physical proximity to transportation networks but also the closeness of potential destinations (Santana-Santana et al., 2020). In this context, attractiveness serves as a weight, influencing the selection of these destinations for mobility. On the other hand, scholars from the tourism and leisure field highlight the role of transportation accessibility in enhancing travelers' experience and satisfaction, which in turn boosts a destination's online attractiveness (Kim et al., 2023; Hellervik et al., 2019; Andrianto and Sugiama, 2016). They argue that improved accessibility reduces the impedance created by the built environment (Vickerman, 1974), making travel more convenient and appealing. This ease of access ultimately encourages travelers to choose certain destinations, reinforcing their attractiveness both online and offline. Despite the different approaches across disciplines, there is growing consensus within the academic community on the importance of measuring both accessibility and online attractiveness to predict mobility patterns and evaluate regional vitality.

By combining perspectives from transportation and tourism, a new framework can be established to understand the interaction between transportation accessibility and online attractiveness. From the tourism perspective, transportation accessibility enhances a destination's attractiveness (Beatriz Santana-Santana et al., 2020), thereby influencing mobility through improved location attractiveness. This highlights the potential for online attractiveness to mediate the impact of transportation accessibility on mobility. On the other hand, research in the transportation field emphasizes the complementary or substitutive role of online attractiveness, particularly in disadvantaged areas such as suburbs (Xu et al., 2019), suggesting that online attractiveness may also moderate the effects of transportation accessibility, while scale differences are underscored (Dadashpoor and Yousefi, 2018). Integrating these two aspects, this study proposes the following hypotheses grounded in prior research: (1) Online attractiveness mediates the effect of transportation accessibility on mobility; (2) Online attractiveness moderates the relationship between transportation accessibility and mobility; (3) The interaction between multi-scale transportation accessibility and online attractiveness is not consistent, reflecting the dual role of ICT in moderating accessibility's impact on non-work mobility. However, existing research has primarily focused on the integrated effects of accessibility and attractiveness on mobility (Shen and Karimi, 2016) or emphasized the positive role of online attractiveness in promoting non-work mobility (Li and Duan, 2018; Zhang et al., 2022). There remains a lack of in-depth exploration of the relationship between multi-scale transportation accessibility and online attractiveness (Fig. 1).

To address this research gap, two key questions guide this study: (1) Does online attractiveness mediate and moderate the impact of transportation accessibility on non-work mobilities? (2) How does the role of online attractiveness vary across different scales of transportation accessibility? To answer these questions, this study measured transportation accessibility from three scales: macro-scale road network accessibility, mesoscale proximity to subway stations, and micro-scale walkability to shops. Data from three widely used social media applications (Apps) in China—TikTok, Dazhong Dianping, and Sina Weibo—were utilized as proxies for online attractiveness. Mobile phone signaling data was employed to assess the non-work mobilities of the corresponding social media users. Mediation and moderation effect models were applied to analyze the interactive relationship between online attractiveness and transportation accessibility.

The remainder of this paper is structured as follows: Section 2 reviews the key concepts and relevant studies on transportation accessibility and online attractiveness; Section 3 introduces the research framework and methods for measuring multi-scale transportation accessibility, online attractiveness, and non-work mobility; The results are presented in Section 4, followed by robustness checks in Section 5 to ensure the reliability of the findings. Finally, Section 6 concludes the study and discusses its limitations.

2. Literature review

2.1. Accessibility and attractiveness and their impact on non-work mobility

Accessibility, which influences mobility patterns, trip generation, and spatial distribution (Vickerman, 1974), has long been a central focus in transportation research. From a transportation perspective, accessibility integrates two key dimensions: the positioning of locations relative to destinations and the characteristics of the transportation networks connecting those points (Wilson, 1971). Scholars have further refined this concept by categorizing accessibility into various dimensions, such as destination accessibility, distance to transit, and design under the "5Ds" framework (Ewing and Cervero, 2010), or access

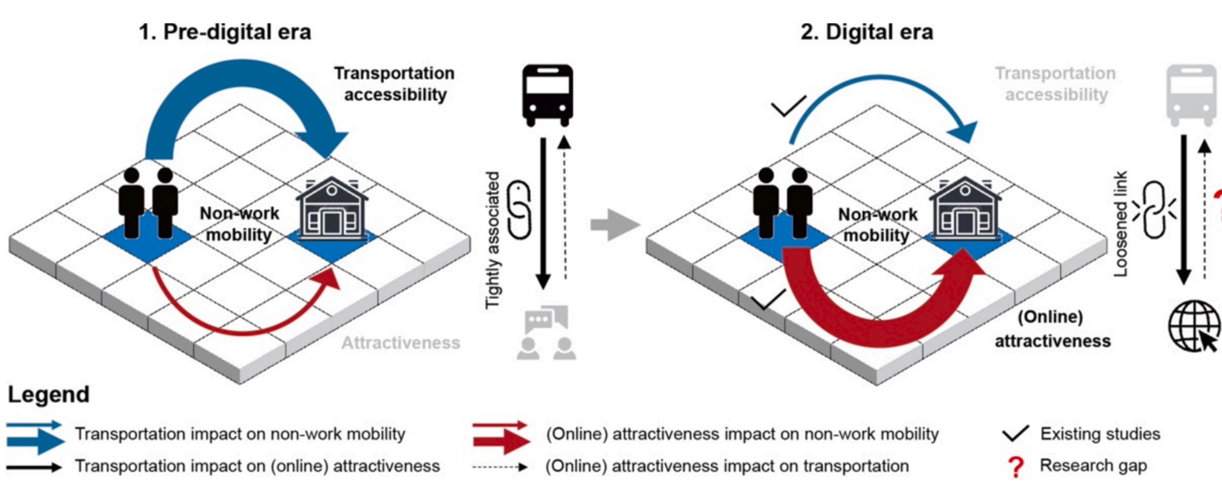

Fig. 1. Diagram illustrating existing studies and research gaps.

to activities, access to stations, and network accessibility (Levinson et al., 2017; Miller, 2018). These classifications incorporate human behavior, land use, and the network structure to provide a more comprehensive understanding of accessibility.

Overall, the notion of accessibility is generally composed of transportation accessibility and the proximity to destinations that trigger travelers' inherent demand (AlKahtani et al., 2015; Kahtani et al., 2011). Consequently, scholars often analyze these two aspects to enhance accessibility assessment and improve the accuracy of mobility predictions. The measurement of transportation accessibility is dependent on the transport mode (e.g., private vehicles, buses, subway, and walking), which is tightly associated with travel efficiency, comfort, and financial cost, thus affecting the perceived generalized travel cost (Vickerman, 1974; Kahtani et al., 2011; Boto-García and Pérez, 2023) and further affecting the probability of traveling and plays (van der Vlugt et al., 2022). As for the destinations that could attract travelers' inherent demand, scholars usually incorporate considerations such as residences, workplaces, shopping malls, and functional density and diversity (Ewing and Cervero, 2010). Considering the changes in the attractiveness of destinations and the transport network, accessibility undergoes variations over time, enabling it to present a dynamic attribute of locations (Moya-Gómez et al., 2018). In recent years, with the development of ICTs, the impact of online attractiveness on spatial attractiveness and mobility has gained increasing attention. Some scholars have begun to incorporate online attractiveness, as reflected in social media data, into the accessibility calculation to predict overall mobility (Shen and Karimi, 2016).

Attractiveness is closely linked to travelers' preferences and expectations concerning the aesthetics and amenities of recreational spaces and attractions. In tourism, "3A" (Kim et al., 2023) or "4A" (Andrianto and Sugiama, 2016; Ismail and Rohman, 2019) components are crucial for tourism and travel destinations ranging from nature, culture, or a specific site. Higher attractiveness could pull travelers to get to one place, while transportation costs serve as an impediment to reducing travel willingness. Therefore, improving the attractiveness and transport accessibility is vital for tourism destinations. For the former, improving the quality of attractions, amenities, and ancillaries could enhance visitor satisfaction, attitudinal loyalty, and word of mouth (WoM) (Karim et al., 2021; Ismail and Rohman, 2019). Empirical studies showed that even in the digital era, the greater perceived attractiveness of city centers could still enhance in-person activities (Weltevreden and Rietbergen, 2007). Meanwhile, various social media platforms such as Twitter, Facebook, TikTok, Sina Weibo, and Dazhong Dianping are playing increasingly significant roles in influencing travelers' and customers' imagination and expectations of recreational spaces and attractions (Adams, 2009; Zhang et al., 2022; Minazzi, 2015), and further influence their choices, travel decisions, and behaviors. Therefore, there are growing numbers of attractions and shops making use of online information to attract visitors (Li and Duan, 2018; Kou et al., 2022; Shi et al., 2021).

To sum up, transportation accessibility and attractiveness of destinations are two fundamental elements influencing non-work mobility. As ICT exerts an increasingly significant impact on individuals' decision-making and travel behavior, the significance of online attractiveness from social media on non-work mobility is increasingly underscored (Wang and Park, 2023).

2.2. The relationship between attractiveness and transportation accessibility

In addition to highlighting the combined impact of attractiveness and transportation accessibility on mobility (Biernacka et al., 2020), there has been a growing focus on the interaction between these two factors in recent years. Understanding these dynamics is imperative for tailoring strategies encompassing their multifaceted relationship.

The significant role of transportation accessibility in enhancing locational attractiveness is emphasized in most tourism and travel-related studies (Kahtani et al., 2011), suggesting that online attractiveness could mediate the impact of transportation accessibility on mobility. Ariesta et al. (2020) revealed that accessibility could create a positive destination image of attractions, thus stimulating revisit intentions to tourism. Santana-Santana et al. (2020) improved the method to measure the origin–destination route accessibility to suggest the development of accessibility to reinforce the competitiveness of tourist destinations. Iranmanesh and Atun (2018) investigated the impact of multi-scales of accessibility on individuals' spatial interactions through social media. Therefore, improving accessibility in tourism destinations to promote location attractiveness is emphasized in the tourism and leisure field (Davies et al., 2020; Karim et al., 2021; Boto-García and Pérez, 2023). These studies suggest that transportation accessibility can indirectly accelerate the increase of mobilities through attractiveness.

Meanwhile, since online attractiveness has a loosened relationship with the built environment and transportation accessibility (Batty, 2018), the role of online attractiveness in moderating the influence of transportation accessibility on offline mobility is becoming more complicated. In this context, the discussions and debates on the impact of ICTs on urban spatial structure are endless (Dadashpoor and Yousefi, 2018; Tranos and Ioannides, 2020). Some scholars believe that online attractiveness could amplify the advantages of places with better transportation accessibility, thus strengthening the impact of urban centers, subway stations, and areas with better walkability (Weltevreden and Rietbergen, 2007). Some studies uncovered the significance of online information and attractiveness in complementing less visible and accessible locations (Zhang et al., 2020; Liang et al., 2023; Sun and Wang, 2021; Mitchell, 2000). Moreover, other scholars hold the view that ICT can play dual effects on urban structures, serving as both substitutes or complements to geographical accessibility, which varies from different spatial scales and distinct activities (Batty, 2018; Dadashpoor and Yousefi, 2018). These studies indicate that online attractiveness not only enhances advantageous locations but also holds the potential to complement places with lower visibility and accessibility.

In conclusion, existing studies have underlined the importance of transportation accessibility and online attractiveness, and suggested their interactions, while the mediation and moderation effects of online attractiveness in the impact of transportation accessibility on non-work mobility still need deep investigations.

3. Methodology

3.1. Research hypothesis

To delve into the relationship between online attractiveness and transportation accessibility, this study proposes that urban physical spaces serve dual functions in information dissemination and transportation costs as they can physically exchange information, goods, and services (Miller, 2018). A favorable location implies reduced traffic impedance and increased exposure to information, thus enhancing the attractiveness of a space (Alonso, 1964). Traffic costs and attractiveness jointly influence individuals' offline activities. With the advent of ICT, some informational functions of urban physical areas are supplanted by online attractiveness (Batty, 2018). Therefore, online attractiveness could moderate the transportation function of physical spaces, thereby directly impacting offline activities (hypothesis 2). Meanwhile, the traditional transport strength in promoting locational attractiveness still works for online attractiveness (hypothesis 1). Therefore, we assume that online attractiveness exerts both mediation and moderation effects on transportation accessibility in the digital era. However, the variations in the perceived costs for different transportation accessibility may lead to the varied mediation and moderation effects of online attractiveness on multi-scales of transportation accessibility (hypothesis 3) (Fig. 2).

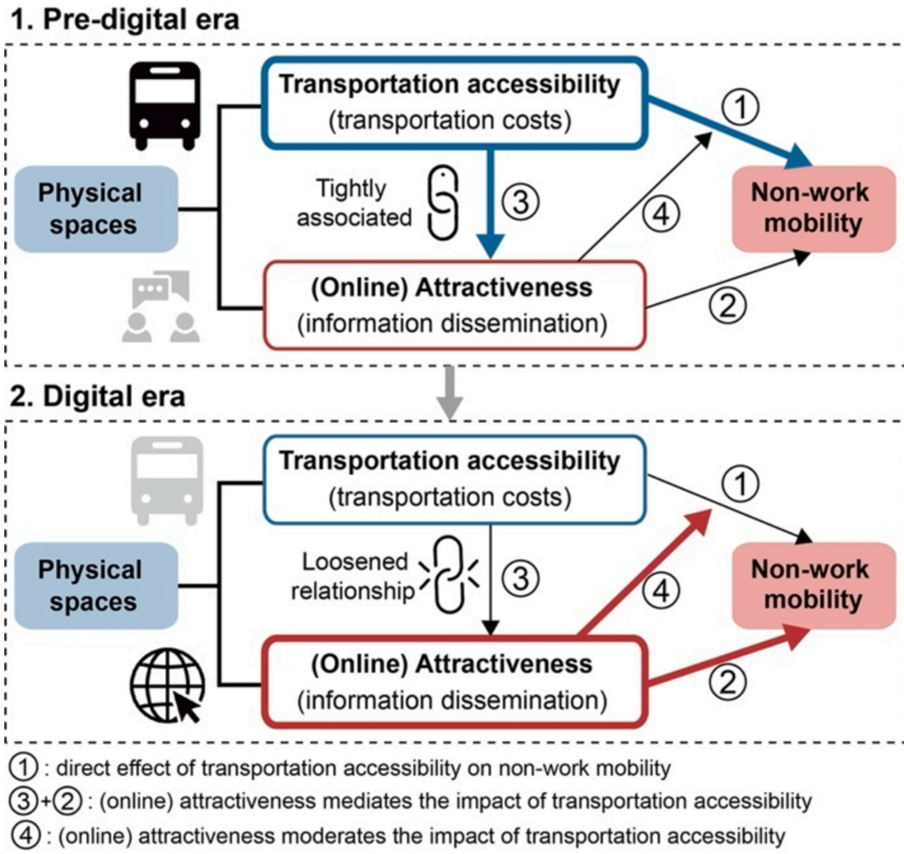

Fig. 2. The conceptual framework.

3.2. Study area and research framework

This study is situated within the area of Beijing's Fifth Ring Road (667 km^2), which contains nearly one-third of the residents of Beijing and the majority of recreational and economic activities (Fig. 3). As China's capital and innovative-oriented city, Beijing has advanced transportation infrastructure, the highest internet user rate, and abundant location-based services (LBS). Therefore, investigating the

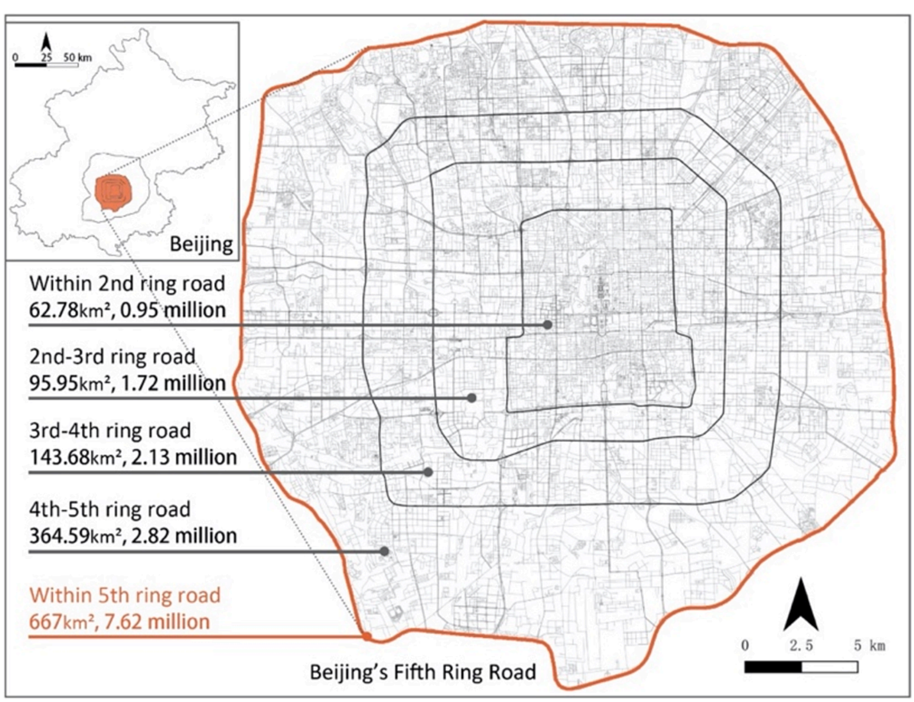

Fig. 3. Study area and residential population within Beijing's Fifth Ring Road. (Data source: Mobile phone signaling data from China Unicom in July 2022).

interactive influence of online attractiveness and transportation accessibility on non-work mobility in Beijing holds significant representativeness for high-density metropolitan.

In this study, online attractiveness is defined as the level of social media engagement that generates eWoM, which, in turn, influences individuals' internal motivation to plan a trip (King et al., 2014; Leung et al., 2013). This engagement includes various forms of user active interaction with content related to travel, such as commenting, check-ins, or creating user-generated content, which can amplify the perceived value and desirability of a destination (Lefebvre, 1991). We leveraged data from the three most used social media platforms in China: uploaded videos on TikTok, shared online comments on Dazhong Dianping, and check-ins on Sina Weibo to depict online attractiveness. As for transportation accessibility, in terms of the different performances of different transport modes at varying scales, which could reflect the ease of overcoming external physical impedance, thus pulling individuals to choose some available places (Vickerman, 1974), this study considered multi-scale transportation from three levels. Specifically, multi-scale transportation accessibility includes macro-scale road network accessibility, mesoscale public transportation proximity (Ewing and Cervero, 2010), and micro-scale walkability to shops (street-facing and ground-floor).

To better investigate the interactive relationship between online attractiveness and transportation accessibility, we used non-work mobility on weekdays and weekends as the dependent variable, which is defined and measured as the frequency of prolonged stays outside homes and workplaces for users potentially influenced by the three social media apps. To eliminate the influence of other factors, we controlled for variables from three aspects- average travel time, individual socioeconomic status, and other built environment elements. We first examined the relationship between transportation accessibility and online attractiveness. Then, we applied mediation and moderation test models to explore the role of online attractiveness in mediating and moderating the impact of transportation accessibility on non-work mobility. Furthermore, we conducted two robustness checks using three apps separately and using everyday data to ensure the reliability of the results (Fig. 4). The research analytic unit was the 250 m *250 m grid, which is consistent with the non-work mobility data.

3.3. Regression models

We employed stepwise regressions using a generalized linear model (GLM) with Maximum Likelihood Estimation (MLE) to examine the mediation and moderation effects of online attractiveness on transportation accessibility. GLMs were chosen for their flexibility and interpretability in modeling the relationships between different variables, particularly when the dependent variable is continuous. The stepwise regression was a widely adopted method to assess the mediation and moderation effects based on the statistical significance and coefficients of mediators and interaction terms. The baseline model

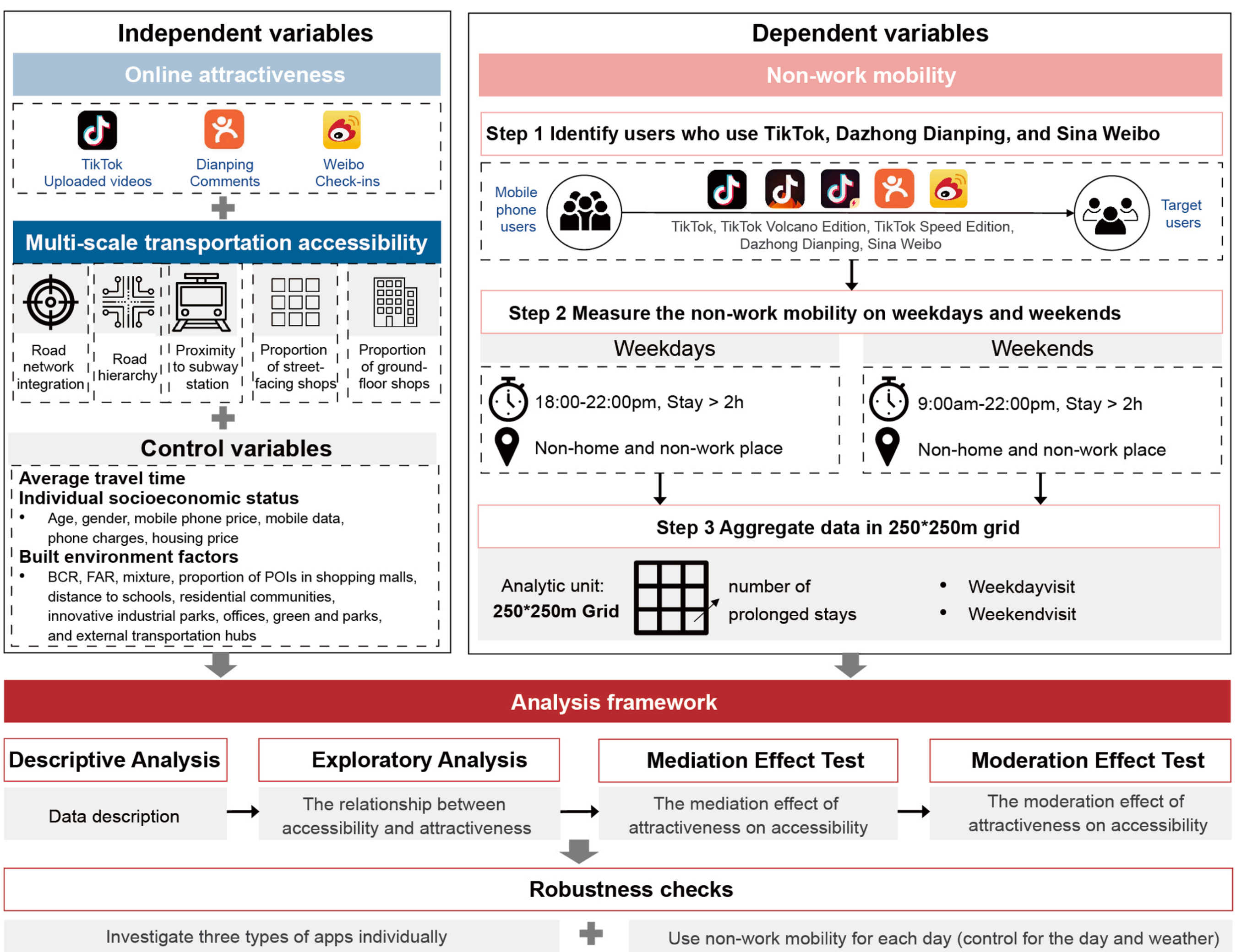

Fig. 4. Research framework.

(Equation (1)) used non-work mobility as the dependent variable and multi-scale transportation accessibility as the independent variables, controlling other socioeconomic and built environment factors. Then, the study extended the basic model by introducing the online attractiveness indicator to explore the mediation effect of online attractiveness on transportation accessibility (Equation (3)). Before that, we also examined the relationship between multi-scale accessibility and online attractiveness, as the mediation effect model relies on a significant correlation between online attractiveness and transportation accessibility indicators (Equation (2)). Subsequently, interaction terms between online attractiveness and multi-scale accessibility were added to investigate whether online attractiveness exerts positive or negative moderation effects on transportation accessibility (Equation (4)). The specific regression models are outlined as follows:

$$Visit = \alpha + \sum \beta_i Access_i + \sum \beta_j Controls_j + \varepsilon \tag{1}$$

$$Attrac = \alpha + \beta_i Access_i + \sum \beta_j Controls_j + \varepsilon \tag{2}$$

$$Visit = \alpha + \sum \beta_i Access_i + \gamma Attrac + \sum \beta_j Controls_j + \varepsilon \tag{3}$$

$$Visit = \alpha + \sum \beta_i Access_i + \gamma Attrac + \sum \beta_k (Access_i \times Attrac) + \sum \beta_j Controls_j + \varepsilon \tag{4}$$

where *Visit* represents non-work mobility at the grid scale during weekdays or weekends; α stands for the constant term; $Access_i$ represents the *i* th transportation accessibility indicator with β_i as its corresponding coefficient; *Attrac* is an online attractiveness index with γ as its coefficient, and ε denotes the error term; $Controls_j$ represents the *j* th control variable with β_j as its coefficient. $Access_i \times Attrac$ refers to the interaction term between online attractiveness and the *i* th transportation accessibility with β_k represents the coefficient. For the main model, we aggregated the online attractiveness indices for each type of app to create a combined variable, which represents the overall online engagement across different apps. We have chosen AIC (Akaike Information Criterion), BIC (Bayesian Information Criterion), and McFadden R^2 as the evaluation indicators for model performance. In this regard, smaller values of AIC and BIC signify better-performing models, while a larger value of McFadden R^2 indicates superior model performance.

Compared to Equation (1), Equation (3) introduces the mediator of online attractiveness to analyze how the impact of transportation accessibility on non-work mobility is mediated by online attractiveness. Specifically, Equation (3) allows us to examine the direct effect of transportation accessibility on non-work mobility while accounting for the role of online attractiveness as a mediator in this relationship. Compared to Equation (3), Equation (4) further explores whether the influence of different scales of transportation accessibility on offline non-work mobility differs due to varying levels of online attractiveness. It investigates the moderation effect of online attractiveness, testing whether the impact of transportation accessibility on non-work mobility is stronger or weaker depending on the level of online attractiveness. This study also conducted two experiments to check the robustness of the results. First, we separately considered the online engagement of each app and its corresponding impact on the non-work mobility of users. Second, we used the everyday offline non-work activity data from 9 am to 10 pm as dependent variables and added the day-of-week and weather indicators as controls.

3.4. Variables and data

(1) Dependent variables: non-work mobility

To better explore the role of online attractiveness in mediating and moderating the effect of transportation accessibility, this study only focused on non-work mobility, which reflects individuals' preferences for non-compulsory activities and mobility. Non-work mobility is measured by stay frequency for each grid during non-working hours via anonymous mobile phone data from China Unicom, one of China's three largest Mobile Network Operators (see Note S1 in Supplementary Material (SM) for a detailed description of data collection). Since we focused on the online attractiveness derived from social media platforms, we only collected the non-work mobility of local individuals who use these social media apps. Specifically, we identified the users from the population through the data usage label for mobile apps on the operator's backend and extracted their stay information during July 2022. Different versions of three apps were considered in this study, including TikTok (TikTok, TikTok Volcano Edition, TikTok Speed Edition), Dazhong Dianping, and Sina Weibo. After identifying the potential users, we aggregated the frequency of non-work stays for more than two hours (see Note S2 in SM for detailed explanation) in each grid on weekdays from 6 pm to 10 pm and on weekends from 9 am to 10 pm. Subsequently, based on China Unicom's 250 m * 250 m grids, the study extracted a month's offline non-work visits for the targeted user groups during weekdays and weekends. Additionally, to ensure the reliability of the results, we calculated the non-work and non-home stay frequency in each grid longer than two hours from 9 am to 10 pm for each day as the dependent variable to conduct robustness checks.

(2) Independent variable: multi-scale transportation accessibility

Regarding different travel modes, this study measured transportation accessibility from three aspects. For macro-scale accessibility, this study examined the global accessibility of road networks for public or private car driving and cycling based on the integration and choice indicators through space syntax tools. The integration indicator reflects the potential for a space to be reached as a destination, characterizing the degree of proximity to the city center. The choice indicator represents the probability of routes being taken, passed through, or traversed between origins and destinations, to some extent characterizing the hierarchy of urban roads. We selected two standardized parameters, global Normalized Angular Integration (NAIN) and Normalized Angular Choice (NACH) (Hillier et al., 2012), to describe the macro road network accessibility of each grid. The study used the average NAIN (M_NAIN) and NACH (M_NACH) values of roads around the analytic grid to reflect its macro-scale road network accessibility. Higher values of M_NAIN and M_NACH indicate higher macro-scale accessibility, signifying a more significant macro-scale locational advantage. The specific formulas to calculate NAIN and NACH are as follows:

$$NAIN = \frac{(NC+2)^{1.2}}{ATD} \tag{5}$$

$$NACH = \frac{log(ACH+1)}{log(ATD+3)} \tag{6}$$

where *NC* is the node count, *ATD* is the Angular Total Depth, and *ACH* is the Angular Choice within the global radius. These indicators were calculated using *Depthmap*, a space syntax software.

The mesoscale accessibility indicator measures the proximity of the grid to the nearest subway. Proximity to bus stations was excluded as all analytic units have bus stations, resulting in no variation across grids. To ensure a uniform directional interpretation across all three accessibility indicators, where higher values denote better accessibility and locational advantages, this study employed proximity measures rather than direct distance to assess the proximity to subway stations:

$$P\_SubwayS_i = 1 - \frac{D_i - \min(D_i)}{\max(D_i) - \min(D_i)} \tag{7}$$

where $P\_SubwayS_i$ represents the proximity of each grid to the nearest subway station, D_i stands for the distance from grid *i* to the nearest subway, $\min(D_i)$ and $\max(D_i)$ denotes the minimum and maximum values of D_i. A higher value of *P_SubwayS* indicates higher mesoscale accessibility for the grid, implying its advantages in public transportation and ease of cycling or walking for transfer.

Micro-scale indicators assessed the ease of travel from the street to the door of leisure and recreational shops by walking, including retail, food and beverage, sports venues, personal service, and recreational service. Specifically, we calculated the distance of the leisure and recreational shops to the nearest street façade and marked those within 20 m as street-facing shops (SF). Meanwhile, we extracted the floor information of leisure and recreational shops from the address text of each point of interest (POI) and regarded those on the ground floor as ground-floor shops (GF) (see Note S3 and Fig. S1 in SM for the detailed method to identify SF and GF shops). Then, we calculated the proportion of street-facing (R_SF) and ground-floor stores (R_GF) for each grid as the micro-scale accessibility for walking.

(3) Independent variables: online attractiveness

This study considered the three most widely used social media apps catering to local offline activities in China: TikTok, Dazhong Dianping, and Sina Weibo. Dazhong Dianping, founded in 2003, is one of China's leading online platforms. It focuses on user-generated comments and recommendations for local businesses, aiding consumers in making informed choices. Sina Weibo, launched in 2009, is a hybrid of Twitter and Facebook, allowing users to share short messages, images, videos, and links, fostering discussions and news dissemination. TikTok (it operates as *Douyin* in China), introduced in 2016, centers on short-form videos, often accompanied by music and creative effects, leading to viral trends and challenges. Despite their social nature and broad popularity in China, they differ in content focus and user experience, catering to varied interests and contributing to the prosperity of Chinese internet culture. Since the shared eWoM could influence individuals' attitudes and decision-making significantly and, consequently, guide offline in-person activities and mobility, this study integrated the number of videos shared on TikTok (TT_Video) in 2019, online comments on Dianping (DP_Review) in 2019, and online check-ins on Weibo (WB_Checkin) in 2018 to depict the online attractiveness of each grid. We scraped Dianping and Weibo data from their website and acquired the TikTok data through the cooperation.

(4) Control variables

Furthermore, this study controlled average travel time, individual socioeconomic status, and other built environment indicators in each regression analysis to exclude their interference with the performance of transportation accessibility and online attractiveness. Specifically, the average travel time (Ave_Tra-time) is calculated to account for the impact of time consideration for travelers. A range of socio-economic variables (Ind_SES) of travelers are also included. Age and gender groups are involved as demographic attributes of users, mobile data usage (Mean_Flux_all) and mobile phone expenses on data (Mean_Arpu) are regarded as factors to reflect users' preference for online activities, and mobile phone prices (Avg_Cellprc) and housing prices (Mean_Houseprice) are considered as representative of the economic status of users. Moreover, we calculated other built environment factors (Bui-Env factor), including the building coverage ratio (BCR), floor area ratio (FAR), the mixture of land use (Mixture), and proportion of POIs in shopping malls (R_Shopmall) for the built and functional intensity and measured distances to potential origins and destinations such as schools (D_School), residential areas (D_Residential), innovative industrial parks (D_Industry), office buildings (D_Office), green spaces and parks (D_Green), and external transportation terminals (i.e., railway stations, airports, and national express stations) (D_ETTerminals). This comprehensive integration of control variables ensures spatial and socioeconomic attributes are effectively incorporated into the analysis. The methods and data to calculate these variables are presented in Table S1 in SM. For robustness checks, we further controlled for the daily weather, including the daily average temperature, humidity, average windspeed, and precipitation monitored at 5 pm collected from the historical weather platform (https://rp5.ru/) (Table S2 in SM).

Table 1 presents the data description of the dependent, independent, and control variables. Given that both the dependent variables and the online attractiveness values exhibit characteristics of a long-tail

Table 1
Data description of dependent, independent, and control variables (n = 8,198).

Variables	Descriptions	Unit	Mean	S.D.
Dependent variables				
Offline non-work mobility				
logWeekdayvisit	The logarithm of the number of non-work visits on weekdays	—	5.104	1.238
logWeekendvisit	The logarithm of the number of non-work visits on weekends	—	6.222	1.070
Independent variables				
Multi-scale transportation accessibility				
M_NAIN	The average standardized integration indicator of road networks around the grid	—	0.768	0.117
M_NACH	The average standardized choice indicator of road network around the grid	—	0.969	0.176
P_SubwayS	Proximity to the nearest subway station	—	0.852	0.140
R_SF	The proportion of street-facing shops	—	0.449	0.346
R_GF	The proportion of ground-floor shops	—	0.875	0.172
Online attractiveness				
logAttrac	The logarithm of the summarized shared TikTok uploaded videos, Dianping online comments, and Weibo online check-ins	—	6.998	2.333
Control variables				
Ave_Tra-time	Grid-scale average travel time	hour	0.267	0.051
BCR	Grid-scale building coverage ratio	—	0.218	0.114
FAR	Grid-scale floor area ratio	—	1.080	0.804
Mixture	Grid-scale POI mixture	—	1.025	0.455
R_Shopmall	Proportion of POI in shopping malls	—	0.083	0.229
D_School	Distance from each grid to the nearest school	km	0.147	0.203
D_Residential	Distance from each grid to the nearest residential community	km	0.040	0.108
D_Industry	Distance from each grid to the nearest innovative industrial park	km	1.196	0.809
D_Office	Distance from each grid to the nearest office building	km	0.152	0.216
D_Green	Distance from each grid to the nearest green space and park	km	0.364	0.373
D_ETTerminals	Distance from each grid to the nearest external transport terminal	km	2.127	1.319
P_Age0_18	Percentage of travelers aged 0–18 in each grid	—	0.004	0.014
P_Age40_59	Percentage of travelers aged 40–59 in each grid	—	0.346	0.123
P_Ageover60	Percentage of travelers aged over 60 in each grid	—	0.063	0.056
P_Female	Percentage of female travelers in each grid	—	0.375	0.120
Avg_Cellprc	Average mobile phone prices of travelers in each grid	RMB	6,426.677	1,091.063

(*continued on next page*)

Table 1 (*continued*)

Variables	Descriptions	Unit	Mean	S.D.
Mean_Arpu	Average mobile phone expenses of travelers in each grid	RMB	65.859	17.294
Mean_Flux_all	Average mobile phone data usage of travelers in each grid	MB	22,140.857	5,797.891
Mean_Houseprice	Average housing prices of travelers in each grid	RMB	72,239.294	13,947.374

Note: To avoid collinearity, the 19–39 age group and male gender group are excluded as baseline categories for the age and gender variables, respectively.

distribution, the study conducted a logarithm to achieve normal distributions. Since the micro-scale accessibility reflected the walkability of leisure and recreational shops, this study selected grids with these shops within Beijing's Fifth Ring Road as study objects and finally obtained 8,198 samples for this study.

4. Results

4.1. Descriptive analysis

Based on the social media app usage data, as of July 2022, 50.65 % of residents in Beijing utilized Douyin, 37.33 % engaged with Weibo, and 35.16 % accessed Dianping (see Note S4 and Fig. S2 in SM for more detailed user demographics of three social media apps). The overall percentage of individuals using at least one platform amounted to 60.38 %. Given this, the eWoM from these three apps can potentially relocate users' spatiotemporal behavior and reflect the online attractiveness of each grid to influence non-work mobility. We calculated the visit frequency of three app users of weekday and weekend non-work activities for each analytic unit. The results showed that non-work activities within Beijing's Fifth Ring Road accounted for 45.3 % of the whole city, with an average travel distance of 8.36 km. Meanwhile, weekend activities made up 55.1 % and had an average travel distance of 8.04 km. This indicates a larger proportion and a remarkable increase in non-work travel with shorter trips during weekends. Table 2 presents the demographic attributes of users with non-work trips in the Fifth Ring Road on weekdays and weekends. From the perspective of total numbers, individuals with non-work trips on weekends (1,667,552) were significantly higher than on weekdays (509,923). Although the 19–29 and 30–39 age groups had the largest shares on both weekdays and weekends, their proportions decreased slightly on weekends. From the gender perspective, males account for a larger proportion overall. However, the share of female users with non-work trips increases on weekends compared to weekdays. Notably, mobile phone and app usage among older adults and children is relatively low, which means their non-work trips are not well captured by the data. Since this study focuses solely on app users who potentially be influenced by online attractiveness, the non-work trips of non-app users are not considered.

Table 2
The attributes of users of three types of apps with non-work trips within the Fifth Ring Road on weekdays and weekends.

Attributes	Weekday		Weekend	
	Count	Percentage (%)	Count	Percentage (%)
Age				
0–18	2,281	0.45	8,834	0.53
19–29	137,990	27.06	413,331	24.79
30–39	181,852	35.66	544,889	32.68
40–49	105,328	20.66	354,092	21.23
50–59	61,651	12.09	238,711	14.32
60-	20,821	4.08	107,695	6.46
Gender				
Male	301,366	59.10	953,648	57.19
Female	208,557	40.90	713,904	42.81

The spatial distribution of non-work mobility on weekdays and weekends within Beijing's Fifth Ring Road is shown in Fig. 5, which revealed a similar spatial distribution and higher activity levels in the northeast compared to the southwest. Moreover, some clusters were observed in areas close to the Central Business District (CBD) or innovative industrial parks such as Sanlitun, Guomao Jianwai, Zhongguancun, and Wangjing, while clusters on weekends were more pronounced than on weekdays, particularly showing more significant growth in areas requiring long-time stays, such as Beijing Zoo, Shuimofang (Water Park) and Happy Valley (Amusement Park).

Fig. 6 shows the distribution of independent variables, including five multi-scale transportation accessibility indicators and online attractiveness indicators. The distribution of different scales of accessibility exhibits certain similarities and differences. Overall, regions closer to the city center tend to have higher levels of transportation accessibility across various scales. However, there is a noticeable decrease in the proportion of street-facing shops and ground-floor shops for the micro-scale accessibility between the Third and Fourth Ring Roads. Regarding online attractiveness, its distribution resembles non-work mobility, displaying characteristic concentrations in the CBDs and innovative industrial parks.

4.2. Exploratory analysis

Before conducting the regression analysis, we utilized Pearson correlation coefficients and a variance inflation factor (VIF) test to assess multicollinearity in the baseline model. The findings revealed that correlation coefficients were below 0.8 (see Fig. S3 for the coefficient matrix), and all VIF values were less than 3, indicating the absence of significant multicollinearity among the independent variables and ensuring their suitability for application in subsequent regression models. Besides, before examining the mediation role of online attractiveness in multi-scale transportation accessibility, the study analyzed the relationship between online attractiveness and accessibility. The results presented in Table 3 demonstrate significant associations between online attractiveness with accessibility at various scales. Specifically, macro-scale and mesoscale accessibility exhibit significant positive correlations with online attractiveness. In terms of micro-scale accessibility, the proportion of street-facing shops shows a positive correlation with online attractiveness, whereas the proportion of ground-floor shops demonstrates a negative correlation. These findings suggest that, at the macro and mesoscale, increased transportation accessibility aligns with heightened online attractiveness. However, shops situated in non-ground-floor areas seem to exert more effort to enhance their online attractiveness.

As online attractiveness exhibits significant relationships with all transportation accessibility measures, meeting the prerequisite for conducting a mediation analysis, the study further investigates the impact of introducing online attractiveness on non-work mobility to analyze the mediation effect of online attractiveness on different scales of transportation accessibility.

4.3. Mediation effect test

The result presented in Table 4 shows the difference before and after introducing the online attractiveness indicator and the standard coefficients for the model with online attractiveness. The results revealed that the McFadden R^2 for weekend non-work mobility was higher than for weekdays, indicating non-work mobility has a higher reliance on the built environment on weekends. After adding online attractiveness indicators, the McFadden R^2 slightly increases, and the logAttrac indicator is significantly associated with non-work mobility, suggesting that online attractiveness significantly enhances non-work activities. Even with the inclusion of online attractiveness, the relationship between various transportation accessibility and non-work mobility remains significant,

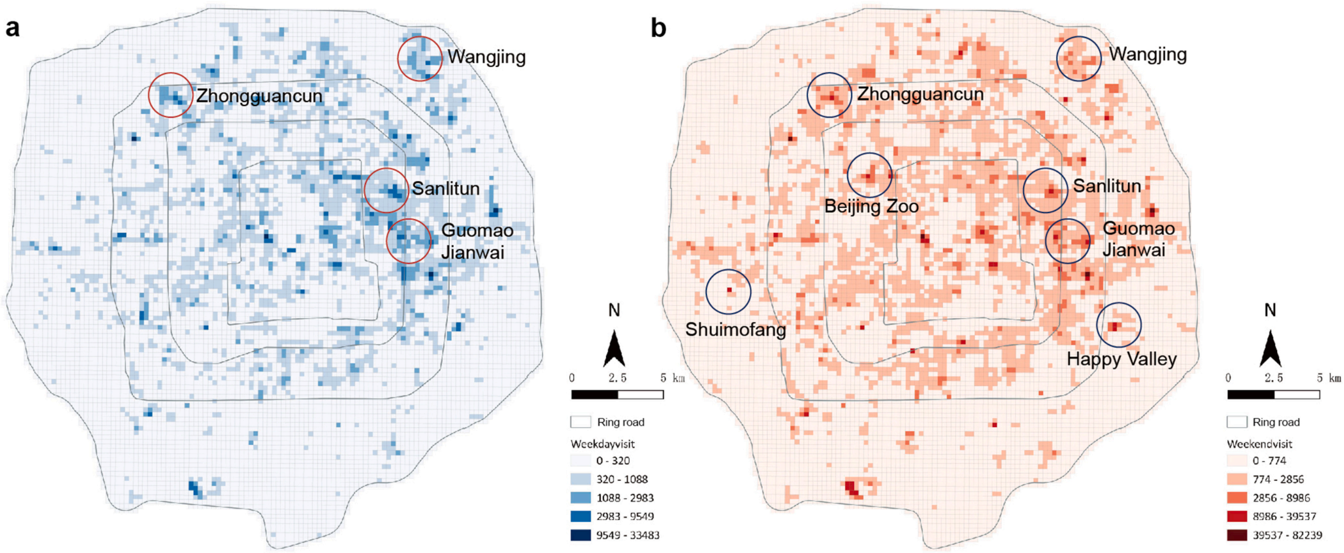

Fig. 5. Distribution of non-work mobility on weekdays (*a*) and weekends (*b*).

indicating that online attractiveness serves as a partial mediator for transportation accessibility. Regarding the performance of different indicators, global integration, proximity to subway stations, and the proportion of street-facing shops exhibit a significant positive correlation with weekday and weekend visits. In contrast, global choice and the proportion of ground-floor shops show a significant negative association. These findings highlight the differentiated relationship between multi-scale transportation accessibility and non-work mobility. In conclusion, the results indicate that online attractiveness partially mediates the impact of multi-scale transportation accessibility and that areas closer to the city center and subway stations, with a higher proportion of street-facing shops and non-ground floor shops on the branch roads, are more popular for non-work visits.

Based on the results in Table 4, we calculated the total, direct, and indirect effects of the multi-scale accessibility to measure the mediation proportions of online attractiveness (Table 5). The mediation effect of online attractiveness on transportation accessibility at different scales shows significant differences between weekdays and weekends. On weekdays, the mediation effect is highest for proximity to subway stations (31.22 %), followed by global integration (22.27 %), with the mediation effects for the proportion of ground-floor shops (18.85 %) and street-facing shops (12.87 %) being relatively lower, and the lowest for global choice (2.25 %). In contrast, on weekends, the mediation proportions of online attractiveness are generally higher, with the highest mediation effect observed for the proportion of ground-floor shops (28.60 %). The mediation effects for proximity to subway stations (25.47 %) and global integration (25.40 %) are similar, followed by the proportion of street-facing shops (22.69 %), while the global choice remains the lowest (−5.36 %). These results indicate that the mediation effect of online attractiveness on macro-scale and micro-scale accessibility is stronger on weekends, while the intrinsic effects of transportation accessibility like proximity to subway stations, are more pronounced on weekdays. This pattern reflects different behavioral tendencies between weekdays and weekends: on weekdays, individuals rely more on the inherent effects of transportation accessibility, while on weekends, these effects are more mediated by online attractiveness.

4.4. Moderation effect test

After examining the mediation effect, the study further analyzed the moderation impact of online attractiveness on multi-scale transportation accessibility. The results, as shown in Table 6, revealed that the inclusion of interaction term indicators (M_NAIN*logAttrac, M_NACH*logAttrac, P_SubwayS*logAttrac, R_SF*logAttrac, and R_GF*logAttrac) resulted in a slight increase in McFadden R^2 for weekday and weekend non-work mobility with variations in the performance at different scales.

The global integration indicator remained positively significant, but the interaction term indicator showed a significant negative correlation on the weekend. This suggests that as online attractiveness increases, the impact of global integration on non-work mobility diminishes, indicating a negative moderation effect of online attractiveness on global integration. The interaction term for the global choice indicator was not significant, implying that online attractiveness does not moderate road hierarchy. This suggests that road hierarchy primarily reflects its direct impact based on transportation accessibility, independent of online attractiveness. After introducing the interaction term, proximity to subway stations remained positively significant, with the interaction term also showing a significant positive relationship. This indicates that online attractiveness enhances the effect of proximity to subway stations on non-work mobility. However, the situation is different for micro-scale accessibility. After including the interaction term, the proportion of street-facing shops remained significant and the interaction term showed a significant positive relationship, suggesting that online attractiveness enhances the effect of street-facing shops. For ground-floor shops, the negative coefficient and significantly negative interaction term with offline indicate the negative moderation effect of online attractiveness, particularly for non-ground-floor shops.

Overall, the findings suggest that online attractiveness plays a dual effect on the relationship between accessibility indicators and non-work mobility. While positively impacting the influence of proximity to subway stations and street-facing shops, it negatively moderates global integration and ground-floor shops.

5. Robustness checks

First, this study conducted separate analyses for each app as a robustness check. For the mediation effect, the study calculated the mediation proportions of online attractiveness for different transportation accessibility on weekdays and weekends for each app. The results, similar to the overall findings (Table 5), show that for both global integration and micro-scale accessibility, the mediation effect is larger on weekends than on weekdays, while for proximity to subway stations, the mediation effect is stronger on weekdays, and the mediation effect for global choice remains the smallest (Table 7). There were differences across the apps as well. The mediation effect of online

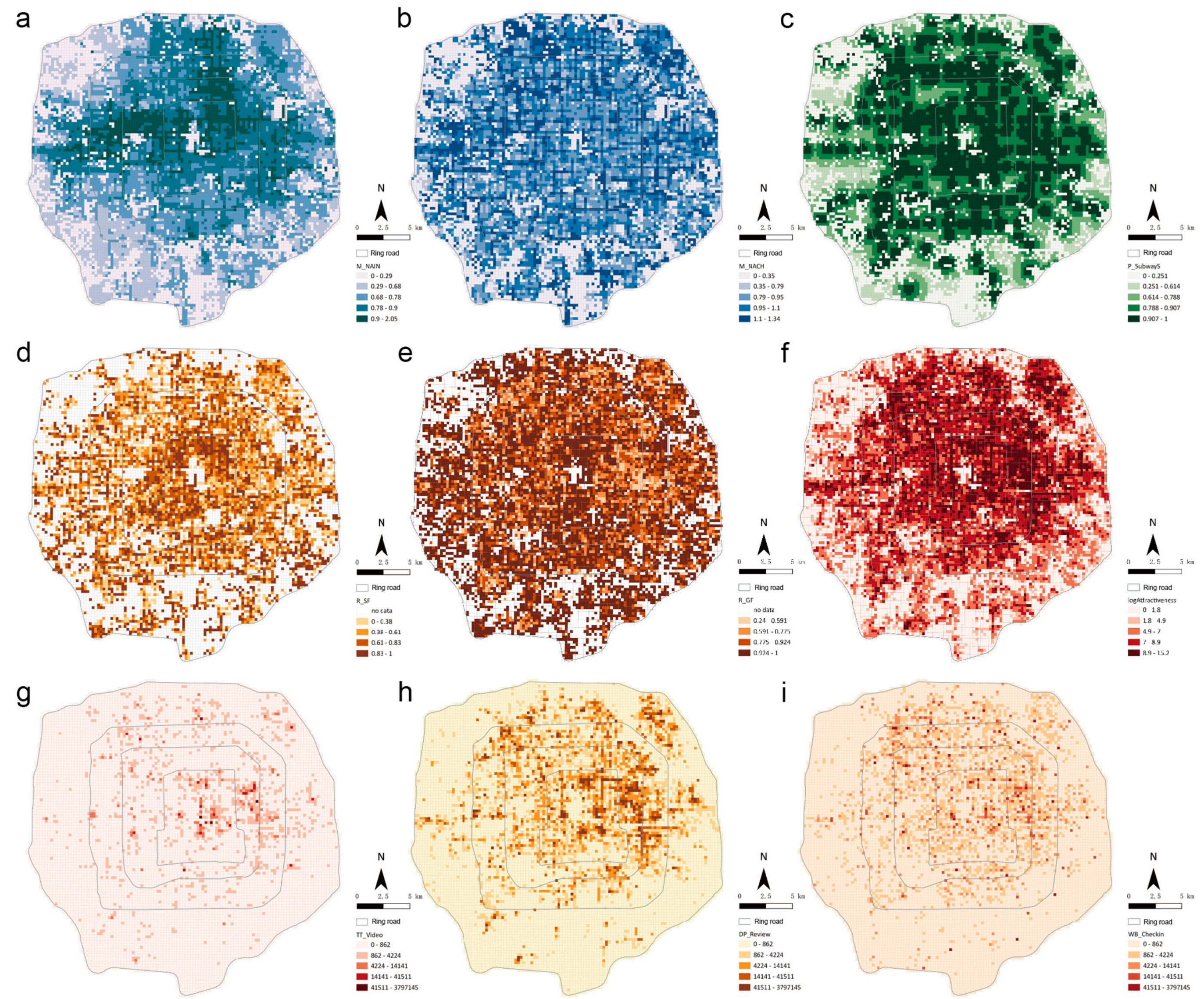

Fig. 6. The visualization of independent variables (*a:* global integration measure of road networks; *b:* global choice measure of road networks; *c:* proximity to subway stations; *d:* ratio of street-facing shops; *e:* ratio of ground-floor shops; *f:* the integrated online attractiveness; *g:* uploaded videos on TikTok; *h:* online comments on Dianping; *i:* online check-ins on Weibo).

Table 3
Correlation between online attractiveness and transportation accessibility.

N = 8186	Coef.	Controls	AIC	BIC	McFadden R^2
M_NAIN	**2.5999*****	Yes	30710.40	−53260.56	0.240
	(0.1744)				
M_NACH	**0.8145*****	Yes	30865.40	−52872.37	0.233
	(0.1010)				
P_SubwayS	**2.2636*****	Yes	30679.70	−53336.57	0.241
	(0.1421)				
R_SF	**0.2670*****	Yes	30904.95	−52772.16	0.231
	(0.0530)				
R_GF	**−0.8962*****	Yes	30870.70	−52858.97	0.232
	(0.1160)				

Note: **Bold** values indicate significant coefficients. Significance level: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. Standard errors are in parentheses.

attractiveness on transportation accessibility was the largest for Dianping, followed by Weibo, while TikTok had relatively smaller effects. Dianping showed the strongest mediation effect at the micro-scale, while for Weibo, the mediation effect for global integration at the macro scale was more pronounced. In the case of TikTok, the mediation effect for proximity to subway stations was the largest. This highlights the differences in the mediation effects of online attractiveness on transportation accessibility across different scales for each app.

For the moderation effect (Table 8), after including the interaction terms in the models for each app, the original transportation accessibility indicators remained significant, with consistent positive or negative coefficients. The only exception was that the R_SF variable in the weekend model for Dianping was no longer significant. Although some interaction terms exhibited differences in significance between weekdays and weekends, the signs of the coefficients remained consistent across all models. Specifically, the negative coefficients for M_NAIN*logAttrac and R_GF*logAttrac, the significant positive ones for P_SubwayS*logAttrac and R_SF*logAttrac, and the non-significance of M_NACH*logAttrac were observed across the models, which is consistent with previous results in Table 6.

Table 4
Regression model results of mediation effect test.

Variables	logWeekdayvisit			logWeekendvisit		
	Baseline model	logAttrac		Baseline model	logAttrac	
		Coef.	Std. coef.		Coef.	Std. coef.
M_NAIN	**1.4659***** (0.1125)	**1.1395***** (0.1104)	0.1321	**0.9141***** (0.0970)	**0.6819***** (0.0950)	0.0795
M_NACH	**−0.3470***** (0.0652)	**−0.3392***** (0.0634)	−0.0597	**−0.1886***** (0.0552)	**−0.1987***** (0.0538)	−0.035
P_SubwayS	**0.8942***** (0.0778)	**0.6150***** (0.0768)	0.0852	**0.8470***** (0.0660)	**0.6313***** (0.0650)	0.0882
R_SF	**0.2798***** (0.0287)	**0.2438***** (0.0280)	0.0841	**0.1388***** (0.0241)	**0.1073***** (0.0235)	0.0371
R_GF	**−0.5390***** (0.0626)	**−0.4374***** (0.0611)	−0.0751	**−0.3021***** (0.0530)	**−0.2157***** (0.0517)	−0.037
logAttrac		**0.1283***** (0.0060)	0.2947		**0.1081***** (0.0050)	0.2516
Ave_Tra-time	Yes	Yes		Yes	Yes	
Ind_SES	Yes	Yes		Yes	Yes	
Bui-Env factor	Yes	Yes		Yes	Yes	
Number	8082	8082		8186	8186	
AIC	20398.74	19949.26		17964.55	17515.68	
BIC	−66623.81	−66933.64		−69256.22	−69476.35	
McFadden R^2	0.280	0.307		0.344	0.373	

Note: **Bold** values indicate significant coefficients. Significance level: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. Standard errors are in parentheses.

Table 5
Mediation proportion of online attractiveness.

Independent Variables	Total Effect	Direct Effect	Indirect Effect	Mediation Proportion (%)
Dependent variable: logWeekdayvisit; Mediator: logAttrac				
M_NAIN	1.4659	1.1395	0.3264	22.27
M_NACH	−0.347	−0.3392	−0.0078	2.25
P_SubwayS	0.8942	0.615	0.2792	31.22
R_SF	0.2798	0.2438	0.036	12.87
R_GF	−0.539	−0.4374	−0.1016	18.85
Dependent variable: logWeekendvisit; Mediator: logAttrac				
M_NAIN	0.9141	0.6819	0.2322	25.40
M_NACH	−0.1886	−0.1987	0.0101	−5.36
P_SubwayS	0.847	0.6313	0.2157	25.47
R_SF	0.1388	0.1073	0.0315	22.69
R_GF	−0.3021	−0.2157	−0.0864	28.60

Second, this study also applied the model for everyday non-work mobility with results presented in Table 9. The significant positive coefficients of M_NAIN, P_SubwayS, R_SF, logAttrac, and the negative ones of M_NACH and R_GF were similar to the results in Table 4. The study showed positive moderation effects of online attractiveness on P_SubwayS and R_SF, and negative moderation effects on M_NAIN and R_GF, aligning with the above findings in Table 6. The only deviation in this model was the significance of the coefficient for the NACH interaction term. However, it's noteworthy that the direction of these coefficients remained in harmony with the previous results. Overall, these results underscored the robustness and reliability of the findings in this study.

6. Conclusions and discussion

6.1. Concluding remarks

Combining social media data with mobile phone signaling data through app usage labels, this study unveiled the interactive relationship between online attractiveness and multi-scale transportation accessibility and uncovered the differential role of online attractiveness in mediating and moderating the impact of transportation accessibility on non-work mobilities. The main findings could be summarized as follows: (1) The results verified the significant role of online attractiveness in mediating transportation accessibility at various scales, underscoring its highest mediation effect for proximity to subway stations. (2) This study revealed the enhancing effect of online attractiveness in moderating the impact of proximity to subway stations and the proportion of street-facing stores on non-work mobility. (3) The negative moderation effects show the complementary role of online attractiveness for the non-city center and non-ground-floor areas. (4) The results showed less effect of online attractiveness in mediating and moderating the impact of road hierarchy (Fig. 7).

6.2. Academic contribution and practical implications

The findings demonstrated the mediation and moderation effects of ICT and its different performance among various scales of transport accessibility, as stated in previous studies (Dadashpoor and Yousefi, 2018), which could enrich our understanding of the complex role of ICT on mobility. First, online attractiveness demonstrates a relatively significant mediation effect on the global integration of the road network, but it also plays a supplementary role by increasing offline activities in areas with lower integration values. This indicates the dual role of online attractiveness benefiting from ICT: while it enhances the influence of urban centers, it also compensates for areas outside city centers, which could explain the debate on the centralization and decentralization of the spatial structure influenced by ICT (Deng et al., 2021; Dadashpoor and Yousefi, 2018). Second, the mediation effect of online attractiveness on global choice of road network is relatively small and does not exhibit significant moderation effects, indicating that the negative impact of global choice on offline activities primarily stems from its inherent transportation accessibility. This suggests that people tend to engage in non-work activities around areas that are not major thoroughfares or main roads. Third, in terms of proximity to subway stations, online attractiveness acts significantly as a mediator, and in areas with higher online attractiveness, it further amplifies the impact of proximity to subway stations on offline non-work mobility, which reflects the reinforcement of the role of proximity to subway stations in the digital era. This result aligns with earlier research findings indicating that ICT catalyzes altering passengers' perceptions of time savings and changes, potentially fostering increased utilization of subways (Morfoulaki et al., 2015; Sun and Wong, 2022). Fourth, regarding micro-scale accessibility, its inherent transportation accessibility has a limited influence on offline activities, but its interaction with online attractiveness holds vital importance, implying that micro-scale accessibility primarily derives from the attractiveness of information rather than the physical costs of

Table 6
Regression model results of moderation effect test.

Variables	logWeekdayvisit		logWeekendvisit	
	Main Effects Model	Interaction Model	Main Effects Model	Interaction Model
M_NAIN	**1.1395*****	**1.0388*****	**0.6819*****	**0.6620*****
	(0.1104)	(0.1099)	(0.0950)	(0.0955)
M_NACH	**−0.3392*****	**−0.3524*****	**−0.1987*****	**−0.2207*****
	(0.0634)	(0.0634)	(0.0538)	(0.0542)
P_SubwayS	**0.6150*****	**0.8725*****	**0.6313*****	**0.7723*****
	(0.0768)	(0.0844)	(0.0650)	(0.0719)
R_SF	**0.2438*****	**0.2998*****	**0.1073*****	**0.1348*****
	(0.0280)	(0.0287)	(0.0235)	(0.0243)
R_GF	**−0.4374*****	**−0.5036*****	**−0.2157*****	**−0.2546*****
	(0.0611)	(0.0612)	(0.0517)	(0.0522)
logAttrac	**0.1283*****	**0.1397*****	**0.1081*****	**0.1123*****
	(0.0060)	(0.0060)	(0.0050)	(0.0051)
M_NAIN*logAttrac		−0.0226		**−0.0959***
		(0.0456)		(0.0383)
M_NACH*logAttrac		−0.0209		−0.0196
		(0.0256)		(0.0214)
P_SubwayS*logAttrac		**0.1829*****		**0.1084*****
		(0.0283)		(0.0238)
R_SF*logAttrac		**0.0773*****		**0.0305*****
		(0.0110)		(0.0092)
R_GF*logAttrac		**−0.2109*****		**−0.1156*****
		(0.0223)		(0.0190)
Ave_Tra-time	Yes	Yes	Yes	Yes
Ind_SES	Yes	Yes	Yes	Yes
Bui-Env factor	Yes	Yes	Yes	Yes
Number	8082	8082	8186	8186
AIC	19949.26	19741.37	17515.68	17441.14
BIC	−66933.64	−67036.26	−69476.35	−69472.88
McFadden R^2	0.307	0.320	0.373	0.378

Note: **Bold** values indicate significant coefficients. Significance level: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. Standard errors are in parentheses.

Table 7
Mediation proportion of online attractiveness for different APPs (insignificant mediation effect is presented as empty).

Variables	Dianping		TikTok		Weibo	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
M_NAIN	25.97 %	28.43 %	4.93 %	6.39 %	18.09 %	21.58 %
M_NACH	−1.47 %	−3.25 %	2.11 %	1.47 %	2.75 %	1.19 %
P_SubwayS	35.86 %	27.34 %	12.60 %	12.31 %	15.83 %	13.13 %
R_SF	49.73 %	90.68 %			4.42 %	9.43 %
R_GF	31.54 %	44.68 %	7.28 %	12.32 %		2.93 %

Table 8
Regression model results of moderation effect test for different APPs.

Variables	Dianping		TikTok		Weibo	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
M_NAIN	**1.1349*****(0.1124)	**0.7808*****(0.0970)	**1.1512*****(0.1092)	**0.7411*****(0.0936)	**1.2804*****(0.1168)	**0.8690*****(0.0986)
M_NACH	**−0.3951*****(0.0666)	**−0.2819*****(0.0566)	**−0.3211*****(0.0631)	**−0.2048*****(0.0530)	**−0.3813*****(0.0674)	**−0.2689*****(0.0563)
P_SubwayS	**0.9498*****(0.0898)	**0.8965*****(0.0753)	**0.8265*****(0.0802)	**0.7729*****(0.0674)	**1.1045*****(0.0905)	**0.9516*****(0.0749)
R_SF	**0.1900*****(0.0303)	0.0364(0.0255)	**0.3569*****(0.0284)	**0.1883*****(0.0237)	**0.2810*****(0.0301)	**0.1230*****(0.0249)
R_GF	**−0.4890*****(0.0642)	**−0.2293*****(0.0540)	**−0.5409*****(0.0609)	**−0.2869*****(0.0511)	**−0.6898*****(0.0658)	**−0.3689*****(0.0542)
logAttrac	**0.1412*****(0.0048)	**0.1133*****(0.0041)	**0.1093*****(0.0074)	**0.0908*****(0.0061)	**0.0592*****(0.0042)	**0.0523*****(0.0035)
M_NAIN*logAttrac	−0.0167(0.0320)	**−0.1002*****(0.0269)	0.0012(0.0566)	−0.0625(0.0466)	**−0.1003****(0.0358)	**−0.0824****(0.0294)
M_NACH*logAttrac	−0.0091(0.0196)	0.0092(0.0164)	−0.0253(0.0321)	−0.0190(0.0262)	0.0116(0.0209)	0.0149(0.0172)
P_SubwayS*logAttrac	**0.1473*****(0.0247)	**0.0771*****(0.0206)	**0.1359*****(0.0342)	**0.0838****(0.0283)	**0.1423*****(0.0260)	**0.0480***(0.0214)
R_SF*logAttrac	**0.0368*****(0.0091)	0.0092(0.0076)	**0.1119*****(0.0139)	**0.0558*****(0.0113)	**0.0356*****(0.0093)	0.0130(0.0077)
R_GF*logAttrac	**−0.1565*****(0.0175)	**−0.0827*****(0.0146)	**−0.3034*****(0.0296)	**−0.1783*****(0.0248)	**−0.1244*****(0.0183)	**−0.0632*****(0.0150)
Ave_Tra-time	Yes	Yes	Yes	Yes	Yes	Yes
Ind_SES	Yes	Yes	Yes	Yes	Yes	Yes
Bui-Env factor	Yes	Yes	Yes	Yes	Yes	Yes
Number	7963	8154	8035	8175	7949	8158
AIC	19795.40	17729.11	19625.26	17196.86	20217.44	17966.89
BIC	−65692.64	−68990.40	−66599.23	−69474.84	−65234.65	−68909.61
McFadden R^2	0.322	0.381	0.290	0.356	0.283	0.352

Note: **Bold** values indicate significant coefficients. Significance level: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. Standard errors are in parentheses.

Table 9
The results using everyday non-work mobility as dependent variables.

N = 250295	Baseline model	logAttrac	Attrac interaction
M_NAIN	**0.4919***** (0.0083)	**0.3696***** (0.0082)	**0.3457***** (0.0082)
M_NACH	**−0.0850***** (0.0048)	**−0.0837***** (0.0047)	**−0.0898***** (0.0047)
P_SubwayS	**0.4464***** (0.0057)	**0.3410***** (0.0057)	**0.4282***** (0.0063)
R_SF	**0.0553***** (0.0021)	**0.0412***** (0.0021)	**0.0513***** (0.0021)
R_GF	**−0.2282***** (0.0046)	**−0.1886***** (0.0045)	**−0.2058***** (0.0045)
logAttrac		**0.0495***** (0.0004)	**0.0525***** (0.0004)
M_NAIN*logAttrac			**−0.0128***** (0.0034)
M_NACH*logAttrac			**−0.0092***** (0.0019)
P_SubwayS*logAttrac			**0.0636***** (0.0021)
R_SF*logAttrac			**0.0120***** (0.0008)
R_GF*logAttrac			**−0.0684***** (0.0017)
Ave_Tra-time	Yes	Yes	Yes
Ind_SES	Yes	Yes	Yes
Bui-Env factor	Yes	Yes	Yes
Day-of-week	Yes	Yes	Yes
Weather	Yes	Yes	Yes
AIC	182195.37	169825.50	166272.20
BIC	−3080504.82	−3081955.53	−3082301.54
McFadden R^2	0.563	0.604	0.616

Note: **Bold** values indicate significant coefficients. Significance level: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. Standard errors are in parentheses.

travel. Online attractiveness enhances the impact of street-facing shops but complements the influence on non-ground-floor shops, suggesting that ICT further amplifies the significance of street-facing locations in the digital era but supplements the disadvantages of non-ground-floor areas.

Although this study revealed that transportation accessibility influences non-work mobility through online attractiveness, the different roles of online attractiveness in moderating mobility could provide a new lens for distributing leisure and recreational shops. The results underlined the enhancement of proximity to subway stations and storefronts in the digital era on the one hand, but also underscored the potential development of non-city center and non-ground-floor areas empowered by online attractiveness on the other hand. That means, in the digital era, access to subway stations and walkability along the street are more important, while the non-city center areas and non-ground-floor stores could leverage the advantage of online attractiveness to attract customers. Therefore, this result could inspire service providers to choose locations outside the city, close to subway stations, and on the non-ground-floor areas along branch roads. In this case, such areas could achieve bottom-up vertical mixed land use and improve urban vitality through digitalization and e-marketing. Urban planners and policy-makers could leverage these findings to improve land use efficiency and promote compact city development.

6.3. Limitations

Despite the merits of this study, there are still some limitations. First, this study only used the cross-sectional data in July 2022 in Beijing, failing to conduct the difference in difference (DID) analysis before and after the emergence of social media platforms. Therefore, we cannot assert conclusively that these results reflect a causal relationship, although our inference of causality is derived indirectly from studies correlating the impact of social media on consumer behavior and research on the influence of transportation accessibility on travel. Second, we selected users who had activity on the target apps during the month as potential subjects affected by the online attractiveness of these apps. However, due to limitations in data accuracy, it is difficult to measure whether users actually see the information on certain locations, whether they are influenced by it to engage in offline behavior, and which specific trips are directly influenced by online attractiveness. Therefore, future research will require more detailed surveys, interviews, and longitudinal studies to more accurately identify non-work travel mobility influenced by online attractiveness. Moreover, since we just used one city as an example, the universality of the results should be further investigated in other cities and regions. Future research could apply our methodology to other cities with different urban forms, transportation systems, and digital engagement levels. Additionally, the influence of future transportation modes such as self-driving on the role of multi-scale transportation requires further exploration.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to check the grammar and improve the readability. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

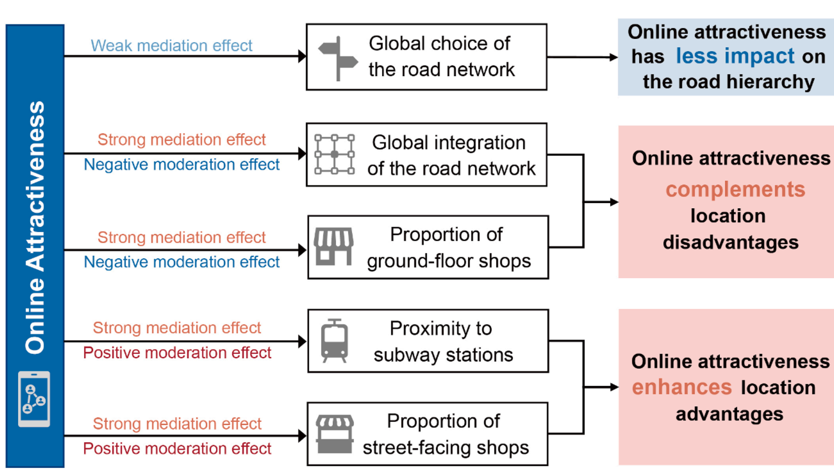

Fig. 7. Comprehensive comparison of the mediation and moderation effects of online attractiveness on multi-scale transportation accessibility.

CRediT authorship contribution statement

Enjia Zhang: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – original draft. **Wenzhu Li:** Conceptualization, Data curation, Visualization, Writing – review & editing. **Ying Long:** Conceptualization, Funding acquisition, Resources, Supervision, Writing – review & editing.

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Appendix A. Supplementary data

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