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An informal transportation as a feeder of the rapid transit system. Spatial analysis of the e-bike taxi service in Shenzhen, China

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Abstract

Despite recent Chinese legislative restrictions on the use of electric two-wheelers (e-bikes), this transportation method is still very popular in Chinese cities. In China, e-bikes currently provide an informal transportation service (e-bike taxi). Very little research has been conducted to study how this informal transportation service is organized. This study aims to fill this gap by offering an understanding of the spatial distribution of informal transportation providers in relation to rapid transit systems and urban villages. Using remote-sensing and geographical information systems (GIS), this study demonstrates that in Shenzhen, this common Chinese e-bike taxi-cab service survives in a tight relationship with the existence of rural areas within the city’s urban fabric. Auxiliary field observations and in-depth interviews provide this study with information regarding service features and spatial distributions at the district scale. This paper shows how this informal transportation service is enlarging the catchment area of the rapid transit system and thus reducing the social exclusion of rural enclaves in the city. The findings that are reported in this study may be useful for planners and policymakers from the perspective of regulating this informal transportation service for its integration with the existing transportation infrastructure.

1. Introduction

Over the past five decades, the urban areas of developing countries have undergone rapid growth in size. In these contexts, local administrations commonly employ mass rapid transit systems as primary transportation infrastructures. Mass rapid transit systems are widely considered the most efficient and cost-effective modes of transportation, and they serve a large portion of the fast-growing urban population. However, in cases of newly constructed public transit infrastructures superimposed upon pre-existing informal settlements, last-mile public transportation provision is frequently inadequate. In these cases, informal transportation services function as feeders of the mass transit system and offer quick and low-cost on-demand supply (Cervero and Golub, 2007). On the one hand, these paratransit¹ services enlarge the coverage area of mass transit systems and are beneficial for both low-income transit dependents and low-skilled service providers. On the other hand, they cause traffic congestion and accidents. This article provides empirical evidence of informal transportation serving as a flexible supply of last-mile transportation demand in areas where public services fail to meet the demand of the marketplace by looking at the stationing points of informal transportation in the areas served by the Shenzhen Metro (SM). The study focuses on the most popular Chinese informal transport system in relation to Chinese urban informal settlements, namely, e-bike taxis (dake zai) and ‘villages in the city’ (cheng zhongcun). The primary aim of this paper is to understand the association between mass rapid transit systems, informal transportation services and

Abbreviations: EBT, e-bike taxi; EBT-IS, e-bike taxi informal stand; SM, Shenzhen Metro; VC, village in the city.

¹ In the literature, the meaning of the term ‘paratransit’ often overlaps with the definition of ‘informal transportation’. It conventionally refers to an informal or formalized mode of passenger transportation that is flexible in terms of routes or schedule and is normally operated by small-to medium-sized buses. In this paper, the term ‘informal transportation services’ is used to mean “paratransit-type services provided without official sanction” (Cervero and Golub, 2007) and is preferred to ‘paratransit’, as the services under analysis here are informal and operated by e-bikes and not by buses.
informal settlements. A proposition underpinning this study is that the analysis of the informal transportation supply offers an understanding of a demand that needs to be formally addressed.

This paper is divided into six sections. The section following the introduction reviews the literature regarding informal transportation services in developing countries, with a specific focus on the last mile, electric two-wheelers and the e-bike taxi service. In Section 3, Shenzhen is introduced as a case study for empirical analysis. Section 4 focuses on the materials and methods employed in this study. Section 5 discusses the results with respect to the evidence of a last-mile issue. Section 6 concludes with a discussion on the policy implications of the empirical evidence herein presented.

2. Literature review

2.1. Informal transportation services in developing countries

Informal transportation services are indigenous paratransit services that lack official endorsement. They are beneficial for transit-dependent populations and provide low-skilled jobs (Cervero and Golub, 2007; Iles, 2005). Informal transportation services on two-wheelers are common in many developing countries, particularly in Africa, Latin America, and South and Southeast Asia. Unlicensed taxicabs that consist of a motorcycle with a carriage are a common practice in China, particularly in small towns and villages (J. Xu, 2010). A growing body of studies has focused on the informal transportation services of two-wheelers in Africa (Del Mistro and Behrens, 2015; Diaz Olivera et al., 2016; Kisaalita and Sentongo-Kibalama, 2007), Latin America (Golub et al., 2009; Hagen et al., 2016), South Asia (Kumar et al., 2016) and Southeast Asia (Guillen, 2009; Mateo-Babiano et al., 2011; Oshima et al., 2007; Phun and Yai, 2016). Very few studies have investigated this subject matter regarding either the use of electric vehicles or in China (C. Y. H. Wu and Loo, 2016; J. Xu, 2010). The illegality of such informal services greatly impedes the availability of official data and complicates field investigations.

2.2. Informal transportation services and the last mile in South and Southeast Asia

Despite the large body of literature on these topics, a limited number of studies have been conducted on the addressing of last-mile issues through informal transportation services. Many studies have focused on the role of paratransit as a feeder of the transit system (Del Mistro and Behrens, 2015; Loo, 2007; Phun and Yai, 2016; Shimazaki and Rahman, 1996; Tangphaisankun et al., 2009). Others have discussed the essential role of indigenous transport modes in offering flexible service provision to supplement the existing transport system and their capacity to adapt to peculiar contexts and settings (Iles, 2005; Mateo-Babiano et al., 2011). Although the functioning of paratransit is well documented, there is still a paucity of scientific research on the association between informal transportation services and the last mile. Iles (2005) observed that the low capital investment for purchasing, operating and maintaining the vehicles employed drives the high competitiveness of such services. When operated for the use of individual travelers, informal transportation services are very effective in filling the gaps in public transportation service provision, meeting a demand not supplied by public transportation in terms of cost-effectiveness, or in areas devoid of public transportation (Cervero and Golub, 2007; Iles, 2005). In these contexts, unlicensed operators on electric two-wheelers address last-mile issues, potentially reduce social exclusion and enlarge the coverage area of transit stops.

2.3. Electric two-wheelers

Electric two-wheelers, or more commonly “e-bikes,” are a common means of transportation in China, where over the last two decades, they have recorded astonishing growth (Fishman and Cherry, 2016; Weinert et al., 2007). E-bike industry started to develop during the 1980s, emerged in the 1990s, and became a globally significant sector in the early 2000s. With over 200 million e-bikes, China is by far the largest market in the world; a market dominated by small Chinese firms (e.g. Jiangsu Xinri, Yadea Technology Group, and Zhejiang Luyuan) stimulated to innovate by a fierce domestic competition (Ruan et al., 2014; Wells and Lin, 2015). There are no direct positive policy intervention at support of this sector from the Chinese government; differently from Taiwan and many European countries (e.g. Austria, Belgium, France and Netherlands) China is not subsidizing the purchase or the use of e-bikes as well as the construction of a dedicated public infrastructure (Zuev et al., 2019). The rapid expansion of this sector of the Chinese market is due to various factors, such as a rising income level (C. Cherry and Cervero, 2007) and policy regulations—specifically, the ban on internal combustion motorcycles in various cities (C. J. Yang, 2010)—as well as demographics, the built environment and infrastructure (Weinert et al., 2007). E-bike sales are forecasted to increase in the rest of the world, while slowing down in China, partially as a consequence of the bans on their use in several major Chinese cities such as Beijing, Guangzhou, Shenzhen, and Xiamen (Zuev et al., 2019). E-bikes have several benefits when they are adopted to replace motor vehicles: they lower urban air pollution at the local level (C. R. Cherry et al., 2009; Rose, 2012) and can reduce diseases that are associated with sedentary lifestyles (Gojanovic et al., 2011; Simons et al., 2009). E-bikes allow users to mitigate various factors that normally disincentivize bike employment, such as topography, distance, climatic conditions and air quality (Campbell, 2012; Heinen et al., 2010), and they allow users to reach their final destinations in more comfortable conditions (Popovich et al., 2014).

Despite these advantages, e-bikes represent a growing concern in terms of safety. A growing body of studies shows a negative attitude towards safety (Yao and Wu, 2012) and aberrant behaviors, particularly at intersections (Du et al., 2013; C. Wu et al., 2012; J. Yang et al., 2014). Evidence of a correlation between the growth in e-bike use and an increase in associated injury episodes (Du et al., 2014; Feng et al., 2010) contributed to the wide ban on their use in many Chinese urban areas. Chinese e-bike users are mostly middle-income and low-income, and this mobility mode is mostly used for commuting on travel time minor than 40 min (An et al., 2013). In China e-bikes appear to compete with public transports, traditional motorcycles, traditional bicycles, and walking. They promote mobility-dependent lifestyles, becoming an intermediary mode to automobiles (X. Lin et al., 2017, 2018; Ling et al., 2015).

2.4. E-bike taxis (ETBs)

Despite the recent government bans and a large provision of bike-sharing services, in China, e-bikes are still used to provide an informal transportation service known as the EBT service. The perseverance of this service, which is still offered regardless of its current illegal condition, can be understood as an indicator of a consistent demand and therefore a lack of alternative transportation provisions. E-bike is a generic term that refers to various types of vehicles with different performances and cosmetic designs (Fishman and Cherry, 2016). This study focuses on the hybrid style of e-bike, which undergoes a series of modifications to be employed as a taxicab (Fig. 1). Within the scope of this paper, the stationary points for an EBT operator are called “e-bike taxi informal stands” (EBT-Is), which are normally stationed in front of transit stops or in other strategic locations where they are available to potential clients. They are recognizable because of their cosmetic design and common e-bike modifications.

3. Shenzhen case study

Located in the South-East coastal region of China, Shenzhen is one of the fastest-growing urban areas in the world. The statutory condition that fostered this rapid transformation was the establishment of a special economic zone in 1980. This designation made Shenzhen the first experimental ground for the attraction of foreign direct investment following the Chinese Economic Reform that was promulgated by the Chinese government under
the leadership of Deng Xiaoping. Located on the north-east side of the Pearl River Delta (PRD), adjoining the Hong Kong Special Administrative Region, Shenzhen changed from a rural area with a population of 20,000 to a city with 16 million inhabitants in less than four decades (Chen et al., 2016). The urbanization process and the rapid economic growth of Shenzhen have created a unique socioeconomic and demographic area for the study of mobility patterns (Y. Xu et al., 2015). The scattered Shenzhen urban area, in addition to the humid subtropical climate, discourages commuting by foot. Consequently, the attractiveness of e-bikes and EBTs is increased. Furthermore, to understand the potential of the EBT service, it is necessary to comprehend the hasty expansion of the urban area and its effects on the composition of the urban fabric. The diverse land regimes within the city territory have given rise to a dual urban-rural land ownership system (Lai et al., 2014). The rapid urban development process swallowed rural areas, which became known as ‘villages in the city’ (ViCs) or ‘urban villages’ (Hao et al., 2011; Y. Lin et al., 2014). ViCs are controversial areas that are commonly considered dirty and chaotic environments that lack basic sanitation standards and are often associated with various illegal or informal practices (Li et al., 2014). Conversely, with their narrow streets and mixed uses in street-level retail activities, they create the proper conditions for walkability. The large majority of ViC inhabitants are low-income workers who depend heavily on public transportation.

One of the most extensive rapid transit train systems worldwide serves the city; it was developed in less than two decades and currently covers 285 km (Shenzhen Metro Group Co., 2016). Shenzhen’s subway system is expected to grow exponentially, almost doubling in length by the end of 2020 and reaching 1000 km in 2025 (Shenzhen Metro Group Co., 2016). Shaped on a grid pattern, the SM constitutes the backbone infrastructure for sustainable transit-oriented developments. Additionally, the system provides public transportation to low-income residents of the rural enclaves within the city’s territory.

3.1. Local regulations restricting the use of e-bikes

In compliance with Chinese Central Government directions, the Shenzhen Government has progressively introduced restrictive regulations on the use of e-bikes (J. Xu, 2010). In 2012, the first revision of the “Regulations of the Shenzhen Special Economic Zone on Punishments in Roads and Traffic Control” included two articles concerning e-bikes. Based on this legislative framework, local police seized 1,248,263 motorcycles and electric vehicles between 2013 and 2016 (Shenzhen City Public Security Bureau Traffic Police Department, 2017) (Table 1).

Contemporary with this deterring legislative framework, starting in late 2016, various bike-sharing providers have been offering their services in central urban areas, often near transit stops.

### Table 1

**Summary of Shenzhen transportation legislation concerning e-bikes**

<table>
<thead>
<tr>
<th>Year</th>
<th>Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Revision of &quot;Regulations of the Shenzhen Special Economic Zone on Punishments in Roads and Traffic Control&quot; Art. 36 Authority for road-competent departments to restrict or prohibit e-bike transit Prohibition of e-bike alteration/forgery E-bikes produced and sold must comply with national standards Announcements of prohibited models or accessories must be posted by sellers Art. 112 Sanctions for violations of Art. 36</td>
</tr>
<tr>
<td>2012</td>
<td>Notice of &quot;Electric Bicycles Restriction&quot; by Shenzhen Municipal Traffic Police Bureau Restriction of e-bike use on main roads</td>
</tr>
<tr>
<td>2015</td>
<td>Revision of the “Regulations of the Shenzhen Special Economic Zone on Punishments in Roads and Traffic Control” Art. 114 Revision of the sanction for violations of Art. 36</td>
</tr>
</tbody>
</table>

3.2. **EBTs in Shenzhen**

Despite a recent ban on e-bikes and their illegal status, informal EBT transportation service is still offered in many areas within the city’s administrative territory. The presence of EBTs in Shenzhen—one of the most developed regions in the country—can be regarded as a legacy of the city’s recent rural past, which is still part of its present condition (Hao et al., 2011; Hao et al., 2012). In Shenzhen, the number of legal taxicabs is relatively low compared to that in other cities of similar size and importance, at approximately 1 for every 1000 inhabitants (Shenzhen Local Bureau of Statistics, 2015). In the areas selected for this study, which considers a maximum operating radius of 1 km and uses the 2010 population census as a reference, the ratio of EBTs to the population served is approximately 0.5 EBTs to every 1000 inhabitants on average. This value aligns with the current prevalence of indigenous transport services in developing countries and is an indicator of their important role in providing essential low-cost on-demand services in areas with limited access (Cervero and Golub, 2007; Mateo-Babiano et al., 2011).

4. **Materials and methods**

This research originates from the following two hypotheses: 1) there is a spatial relationship, at the city level, among transit stops, EBT-ISs and ViCs and 2) the distribution of EBT-ISs in relation to the transit stops demonstrates that this informal transportation service addresses last-mile issues. This paper examines this Chinese context to define how this specific
Paratransit system is structured from the perspective of future rationalization. This study employs a combined set of methods (Table 2) for the systematic analysis of the spatial distribution of EBT-ISs in relation to rapid transit stops and ViCs.

This study comprises three levels of analysis, namely, the 1) city level, 2) district level, and 3) common characteristics of EBT vehicles and operators. The analysis comprised the following five stages: i) the distribution of ViCs in Shenzhen in relation to rapid transit stops; ii) the presence of EBT services at subway station exits; iii) the spatial distribution of EBT services that surround selected transit stops; iv) the characteristics of the employed vehicles; and v) the operators’ background and behaviors. The spatial distribution of ViCs was based on official data provided by a local government agency (UPLRCSM, 2016). The spatial analysis was conducted by collecting and modelling secondary data, as well as through direct on-site observation. The presence of the EBTs at rapid transit stops was quantified by analyzing remote-sensing images that were provided by the street-view service of Baidu Maps. When this research was conducted—the second quarter of 2017—the available database of the street-view service of Baidu Maps contained images that were captured between November 2013 and August 2016. During this time, SM lines 7, 9 and 11 were under construction. Therefore, these metro lines were not included in the analysis of the presence of EBTs that corresponded with metro-system access. The spatial distribution of EBT-ISs around selected transit stops was defined by using data that were collected through direct observation in the last quarter of 2016 and the second quarter of 2017. The data were collected by surveying all the streets within a 1 km radius from the selected stations. The data are conveyed through proportional symbols and distributive flow maps. Direct observation and face-to-face qualitative interviews were the primary sources of describing the EBT characteristics. ArcGIS was employed for the spatial analysis of the EBT-IS distribution.

5. Calculation and results

5.1. Distribution of ViCs in Shenzhen in relation to rapid transit stops

The distribution of ViCs that was provided by the Urban Planning, Land and Resources Commission of Shenzhen Municipality (UPLRCSM, 2016) was superimposed on the rapid transit network, which allowed a cross-check of spatial interrelation (Fig. 2). At the time of this study, SM comprised 197 stations and 8 lines. In all, 119 stations, which are 60.4% of the total, are within a 0.5 km radius from a ViC. 20.8% (41 station) are located between a 0.5 km and 1 km radius, and only 18.8% (37 stations) are located at a distance of >1 km from the closest ViC. The data are delivered through mapping to graphically visualize the distribution pattern of EBT-ISs (Fig. 4).

5.2. Presence of EBT service at subway station exits

Images provided by the street-view service of Baidu Maps were collected and analyzed to detect the presence of EBT-ISs. Out of 132 considered stations, 50% revealed the presence of one or more EBT-ISs in proximity to one or more of their exits. Overall, 83.2% of the stations are located within a 1 km radius of a ViC, and 55% of these stations are provided with EBT informal transportation services with one or more operators that are stationed around their exits. Only 16.8% of the stations are located >1 km from a ViC, and just 4.6% of them are provided with EBT-ISs (Fig. 3). The distance between the station and the nearest ViC is associated with the presence of EBT-ISs at the station exits. The data breakdown shows a dramatic decrease in the ratio between the numbers of stations with and without EBT-ISs when the distance between the station and the nearest ViC exceeds 1000 m. The ratio of stops with and without EBT-ISs is 1.25 for the stations that are located at <500 m from a ViC, 1.15 for the stations that are located between 500 m and 1000 m from a ViC, and 0.38 for the stations that are located >1000 m from the nearest ViC (Fig. 3).

The data breakdown by metro lines shows a relatively equal distribution of EBT-ISs in the sample group, with a mean average deviation of 7.9% from the arithmetic mean (expected value: 50%). Metro Line 3 has the highest presence of EBT-ISs, while Metro Line 4 has the smallest presence (Fig. 4).

5.3. Spatial distribution of EBT services surrounding selected transit stops

The third level of examination that is presented here is based on the spatial analysis of the primary data that were collected in three selected cases studies. The criteria that were adopted for the selection are 1) stations that were located <500 m from a ViC and 2) the presence of EBT-ISs observed through remote sensing. The selected cases were Xili, Yitian and Ailian Stations. The selected stations commenced operation between December 2010 and June 2011. They are located in different areas of the city, and they are different in terms of size, the number of users and the surrounding built environment. The data were collected during three campaigns on October 2, 2016, May 25, 2017, and May 26, 2017. The first on-site observation was conducted around Xili Station, the second was conducted around Yitian Station and the third was conducted around Ailian Station. All the campaigns were conducted by one or two investigators who were provided with a standard camera and an ordinary bike. An area within an approximately 1-km radius from the selected stations was checked. The scope of the field observation was limited to the operators who were waiting for clients (EBT-ISs), while the EBTs who were carrying a client were not recorded. The data are delivered through mapping to graphically visualize the distribution pattern of EBT-ISs (Figs. 5–7).

5.3.1. Case study no. 1: Xili Station

Xili Station was the first selected case study, and it served as a pilot to test the feasibility of the empirical research. Xili is a sub-district of the

<table>
<thead>
<tr>
<th>Analytical level</th>
<th>Stages</th>
<th>Data source</th>
<th>Analytical methods</th>
<th>Computational software</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Distribution of ViCs in Shenzhen in relation to rapid transit stops</td>
<td>Secondary data from the local government; remote sensing</td>
<td>Spatial analysis</td>
<td>ArcGIS; Microsoft Excel</td>
</tr>
<tr>
<td></td>
<td>Presence of EBT services at subway station exits</td>
<td>Secondary data from the local government; remote sensing</td>
<td>Spatial analysis</td>
<td>ArcGIS; Microsoft Excel</td>
</tr>
<tr>
<td>District</td>
<td>Spatial distribution of EBT services surrounding selected transit stops</td>
<td>Primary data collection</td>
<td>Field observations; spatial analysis</td>
<td>ArcGIS; Microsoft Excel</td>
</tr>
<tr>
<td>EBT</td>
<td>Characteristics of the employed vehicles</td>
<td>Primary data collection</td>
<td>Field observations; face-to-face qualitative interviews</td>
<td>ArcGIS; Microsoft Excel</td>
</tr>
</tbody>
</table>

a Urban Planning, Land and Resources Commission of Shenzhen Municipality (UPLRCSM, 2016).
b Street-view service of Baidu Maps (available at: http://map.baidu.com).
Nanshan District, with a complex urban structure that surrounds the station (Fig. 5). In a radius of 1 km, several different zones can be found such as commercial streets, ViCs, residential compounds, hotels, parks, hospitals, parks and other community services. Xili Station is located underground. Two metro lines serve the station, which has six exits. At the time of the survey, Metro Line 7 was still under construction and only Exits A and F were operating. In the Xili case study, EBTs are diffusely present in the area, not only in proximity to the station. During the survey, 56 EBT-ISs were detected.

The data analysis clearly shows a high concentration of EBT-ISs in proximity to the metro exits (Figs. 5 and 6). Nearly half (44.6%) of the total EBT volume is located within 120 m from the SM station, and 26.8% is located at a maximum distance of 5 m from the station exits. Between 120 m and 375 m from the SM station, no EBT-ISs are detected. In all, 55.4% of the EBTs are diffusely located in the neighborhood and are dispersed at several EBT-ISs, but they show a peak concentration in the range between 375 m and 680 m from the station (Table 3).

5.3.2. Case study no. 2: Yitian Station

Yitian Station is an underground terminal station on Metro Line 3. It is located near the border with Hong Kong in the southern part of the Futian District within a dense mixed-use development. Yitian Station has 4 exits. The data were captured on a weekday in May 2017, and 21 EBTs were identified. The data analysis shows 5 EBTs that are located within 5 m from the SM exits and another 15 EBTs that are distributed in a range between 413 m and 914 m from the station. Two EBT-IS concentration peaks can be found at 413 m and 914 m. Although the EBT-ISs are located within a 1-km radius from the station, this second peak comprises EBTs that serve a different station, and one is located directly in front of a Shawei Station exit on Metro Line 7. Subsequently, these 9 EBTs have not been included further in the analysis, which results in a distribution pattern where 41.7% of the EBTs are located at the station entrance and 58.3% are located at a distance that is >400 m from the station.

5.3.3. Case study no. 3: Ailian Station

Ailian Station is also on Metro Line 3, and it has 4 exits. Differently from the other considered cases, the station is located above ground. It serves a peripheral area of Shenzhen and is located in the fast-growing Longgang District (Fig. 7). In this case, 56 EBTs were detected.
detected, similar to the Xili case study. The analysis emphasizes 21.4% of the EBTs are within 5 m from the station exits, while another 78.6% are distributed in a range between 275 m and 785 m from the station. Two peaks can be noticed; the first peak is between 380 m and 496 m and the second peak is at 780 m.

5.4. Characteristics of employed vehicles

No operator used a standard e-bike to carry passengers. The modifications to the e-bike allow more room for passengers and protection from weather and are relatively uniform (Fig. 1). These modifications are provided by specialized shops that are usually located in ViCs. These modifications are described as follows.

1) The extra seat is stretched to approximately 75 cm, which makes it possible to carry two passengers behind the driver or a single passenger while avoiding body contact. Single passengers often sit with two legs on the same side of the bike, a modality that is especially convenient for passengers who wear dresses or skirts.

2) An approximately 35-cm foot peg is added for passengers. It supports and provides sufficient space for two feet for either two passengers who sit one in front of the other or for one passenger who has both feet on the same side.
3) An extended 1.8 m umbrella is added. It covers the entire e-bike and protects it from weather, either sunshine or rain. The umbrella is retractable and is either hidden in a tube below the bike or closed between the legs of the driver.

5.5. Operators’ background and behaviors

Two on-site in-depth interviews that were conducted in August 2016 provided an understanding of service provider origins and job characteristics. The interviewees were self-employed, lived in the closest village and provided the service in their spare time to increase their wages. Single-trip prices ranged from 5 RMB to 10 RMB. Although according to current regulations, the e-bike speed should not exceed 20 km/h, previous surveys acknowledged that they can reach 30 km/h (Lin et al., 2008). A maximum speed of 40 km/h of an EBT during service was observed on October 23, 2016. While conducting field observations, the following common aberrant behaviors of EBT drivers were noticed:

1) lack of organization among drivers;
2) aggressive driving skills;
3) driving on sidewalks and honking at pedestrians to increase EBT space;
4) driving along roads in the opposite direction of the normal traffic flow;

and

5) none of the drivers used a helmet.

6. Discussion

6.1. Spatial relationship at the city level among transit stops, ViCs and EBT-ISs

The location of transit stops in relation to ViCs shows a high proximity: 81.2% of the stations are located within a 1-km radius from the closest ViC. EBT-IS presence at station exits is different on different lines. Among all SM lines, Metro Line 4 has the smallest number of stops that are provided with EBT-ISs, while at Metro Line 3, the informal transportation service is mostly offered directly at the station exits. Metro Line 4 is the only line of the SM that is operated by the Shenzhen branch of the Hong Kong-based MTR Corporation, and it was one of the first two metro lines to be opened in Shenzhen in 2004. It passes through the Futian District, which is one of the core areas of Shenzhen that includes the main seat of city government and the most important CBD of the city. Metro Line 3, which opened in 2010, connects the peripheral Longgang District to the historical center of the city that is located in the Luohu District. The difference in the number of EBT-ISs between the two lines could be interpreted as an indicator of a higher concentration of
the service in peripheral areas, which is confirmed by the extensive spatial analysis at the city scale (Fig. 2). When considering the selection of residential areas based on paratransit service offerings (Loo, 2007), the presence of EBT services could lead to an increase in ViC attractiveness. Contrariwise, spatial and social marginalization may increase for the ViC residents who are not conveniently connected to the public transit infrastructure.

Table 3
Case No. 1, Xili Station; Distribution of EBT-IS and corresponding street distance to the station exit.

<table>
<thead>
<tr>
<th>EBT-IS</th>
<th>Distance from SM exit (m)</th>
<th>EBTs at EBT-IS (No.)</th>
<th>Percentage of EBTs (%)</th>
<th>Assembled percentage (%)</th>
<th>Distance from SM exit (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>9</td>
<td>16.1</td>
<td>44.6</td>
<td>&lt;120</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>6</td>
<td>10.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>3</td>
<td>5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>60</td>
<td>4</td>
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6.2. Distribution of EBT-ISs surrounding the transit stops in relation to last-mile issues

As evidenced by the spatial analysis of selected case studies, the majority of EBTs gather either around the station exits or at a >5-min walk, which is a relevant parameter in last-mile or TOD models. This distribution pattern can be found in all the selected cases, with small variations (Table 4 and Fig. 8). Among the various factors that determine the distributions, the location of the ViCs and the commercial strips are among the most important, as shown by the analysis of cases 1 and 3 (Figs. 5 and 7).

7. Conclusion

This paper sheds new light on the spatial features of the EBT informal transportation service, providing a better understanding of the reasons...
behind its persistence in one of the flagship cities in China. This research also shows how the physical form of cities plays a primary role in urban mobility. This study analyzed the spatial distribution of EBTs in Shenzhen in relation to the distances between local rapid transit system stops and the locations of rural enclaves within the urban fabric of the city. The integration of data collected from remote sensing into GIS environment has proved beneficial in the analysis of the dataset and its visualization. Although integration of secondary data being time consuming, the method here adopted is convenient in cases of informal spatial phenomena lacking of official record. The findings demonstrate that the offering of EBT services is highly dependent on the distances between SM stations and VGCs, as the presence of EBT services at rapid transit stops sharply decreases over a threshold distance of 1 km. The spatial analysis at the district scale that was conducted on selected areas shows a particular dynamic in the concentration pattern of EBT services at rapid transit stops. These findings of this study can be generalized to Chinese and Asian cities with similar demographic factors, which are served by a mass-transit system and have topographic conditions favorable to the use of e-bikes. Limitation of this research concern primarily the small number of cases considered at district-level. Further researches may extend this analysis to a wider geographic area.

Even with the recent exponential growth of bike-sharing systems, with those in China being the fastest-growing public transportation systems worldwide (Fishman, 2016), and despite the ban on e-bikes, EBT service remains a highly competitive door-to-door individual transportation service that offers an express connection from an SM exit to the final users’ destinations. The commitment to this informal service is clear evidence of the persistence of a relatively high demand for it and demonstrates that between the rapid transit system and many residential areas, a transportation gap remains to be filled by public services. Although EBT service has many shortcomings, particularly in road safety and service quality standards, this informal service is crucial in providing both on-demand mobility for low-income transit dependents and income opportunities for low-skilled workers, as emphasized by Cervero and Golub (2007). EBTs can perform an important service in widening the scope of rapid transit systems, improving network performance and reducing local atmospheric pollution (Satienman et al., 2006; Shimazaki and Rahman, 1996; Tangphaisankun et al., 2009). Bringing EBT to a halt may result in an increased unemployment rate among those currently operating as EBT service providers and lowered mobility for the people who are dependent on low-income transit (Fujiwara and Zhang, 2013). Certainly, regulating and integrating this informal service will require a series of actions that encompass security standards for electric vehicles, rules for drivers and passengers, street modifications—including the construction of new dedicated lines and formal stands—and contemplation of commuter perceptions and intentions (Gul len et al., 2013; Satienman et al., 2006; Tangphaisankun et al., 2009).

Several positive benefits result from and successful examples exist of the regulation of informal transportation services and the employment of technological innovations (Cervero and Golub, 2007; Golub et al., 2009; Sengers and Raven, 2014). The benefits of policy regulation include a controlled equilibrium between demand and supply, fixed fares and increased safety (Phun and Yai, 2016). The beneficial potential of this system should be considered in extending the catchment area of the rapid transit system and in enhancing the integration of the rural enclaves in the city structure.

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