Walk the Line:
Station Context, Corridor Type and Bus Rapid Transit Walk Access in Jinan, China

Yang Jiang[1]*, P. Christopher Zegras*[1]*, Shomik Mehndiratta*[2]

[1] *Massachusetts Institute of Technology, Dept. of Urban Studies and Planning*
[2] *World Bank*

ABSTRACT

This paper focuses on the relationship between bus rapid transit (BRT) station context and corridor type and the distance people will walk to access the system (i.e., catchment area). In China, the station catchment-area radius has always been assumed to be about 600 meters, across all types of corridors and stations. Nonetheless, we would expect the actual catchment areas to vary, in part depending on the walking conditions, which may be affected by both the BRT corridor and specific station characteristics. Understanding such variation and accounting for it in BRT planning and operations could help improve demand forecasts and inform physical and design interventions to increase system ridership. In this paper, we examine station area walking catchment area variation and contributing factors in a particular empirical setting, Jinan China. Specifically, we hypothesize that certain contextual urban form features and station and right-of-way configurations will increase the walk-access catchment area; that is, that urban design influences users' willingness to walk to BRT. We base our analysis on 2,155 user surveys, conducted at 19 BRT stations along Jinan's three existing BRT corridors. The survey included questions on the individual's basic socioeconomic and demographic characteristics as well as approximate trip origins and destinations and walking routes. We derived station area walking distances using a geographic information system (GIS) map. We then used ordinary least squares regression to analyze the influence of aggregate station- and corridor-area characteristics on trip distances, controlling for disaggregate trip and trip-maker characteristics. The results indicate that people walk further to BRT stations on the "integrated-boulevard" corridor when the walking environment has certain features (median transit-way station location, shaded, busy and interesting, better orientation) than otherwise. None of trip and trip maker characteristics, with the exception of income and alternative mode availability, plays a significant role in determining BRT walk access distance. We discuss the implications of our findings in terms of urban planning, BRT ridership forecasting, transit planning, and designing station access routes.

1 Introduction

Bus rapid transit (BRT) represents likely one of the most widespread (or widely acclaimed) urban public transportation "revolutions" of recent decades. Although plans (largely unrealized) for BRT-type systems can be found in the United States urban contexts as far back as the late 1930s (Levinson, *et al.*, 2003), BRT first became widely recognized in the transportation community with the pioneering "southern" case of Curitiba (Brazil) (Zegras & Birk, 1994). Essentially, what has generally become known as BRT aims to emulate more up-front-capital-intensive rail-based systems on key performance characteristics – including reliability, comfort, and speed – by utilizing segregated and dedicated rights of way, pay-before-boarding at dedicated stations/stops, advanced traffic control and management measures for bus priority, enhanced system marketing and branding, etc. BRT's popularity has increased globally, due to its promise for delivering a relatively low-cost, rapidly implemented, flexible, and high service quality solution to the transportation needs of developing cities (Wright & Hook, 2007).

Public transportation almost certainly will play an important role in moving towards more sustainable urban futures for our planet. In that sense, BRT offers a number of opportunities and challenges. Among those include a number related to integrating BRT with the built urban environment. Can BRT deliver on possibilities for transit-oriented development? How can BRT corridors and stations be integrated into the urban fabric to induce ridership? Does the urban environment have an effect on the willingness of users to walk to access the system?

In this paper we endeavor to shed some light on answers to these questions. Specifically, using the empirical case of a recently implemented BRT system in the city of Jinan, China, we examine built environment factors which apparently influence station walk access distances. The remainder of this paper includes five additional sections. The following section examines the potential relationships between BRT and station and urban design. Section 3 presents the research context and approach, including a description of the survey used in the analysis. Section 4 presents the results of the survey data analysis, including users' perceptions of the walking conditions, descriptive statistics revealed from the survey, and multivariate regression attempting to explain the factors influencing station walk access distances. Section 5 presents some planning implications of the analytical results as well as some limitations of the current analysis. Section 6 presents the conclusions.

2 Backdrop: Bus Rapid Transit (BRT) and the Role of Station and Urban Design

System planners and designers face a number of challenges when considering BRT implementation and its effective integration into the urban built environment. A basic challenge relates to predicting ridership levels and, towards that end, better understanding relevant influencing characteristics. Theory suggests that BRT ridership will be influenced by relative local and regional accessibility benefits, as well as individual- and trip-specific attributes. For example, all else equal:

- a larger number of BRT stations in a network will increase patronage at all stations, due to network economy effects (i.e., the addition of stations anywhere in a network increase the attractiveness of other stations connected to the same network);
- higher-frequency routes will have larger catchment areas (Alshalalfah & Shalaby, 2007; O'Sullivan & Morrall, 1996), as higher frequencies increase the route's system-wide accessibility and thus individual station attractiveness;
- station "function" will influence catchment area size, as, for example, a "local" station will differ in the system-wide accessibility it provides relative to an "express" station, and similarly a transfer station will differ from a terminal station (e.g., O'Sullivan and Morrall, 1996);
- related to the previous, larger station spacing will increase an individual station's catchment area, subsequently increasing walking access distances (e.g., Cervero, et al., 2009);
- more pleasant, safe, secure, direct walking paths will increase the walking distance to any specific station, by lowering the user's real or perceived walking time; and,
- a greater concentration of destinations near BRT stations might increase or decrease the walking distance to the station, depending on the specific form of the resulting density gradient.

The latter two conditions may also decrease the attractiveness of alternative modes (e.g., making driving slower), further increasing the relative desirability of BRT and, thus, walk access distances. Regional location of the station, amount of feeder roads within the station catchment and the number of bus lines to the station might also influence people's access walking distance to BRT. Furthermore, we would expect individual user characteristics, such as age, gender, physical ability, income, attitudes, etc. to influence walking distances, due to effects on walking speeds, the individual value of time (Rastogi & Rao, 2003), endurance, etc. Trip-specific characteristics, such a trip purpose, time-of-day, weather, etc. will also influence walking distances as people may be willing to walk longer distances for work trips, or shorter distances at night or during a rainstorm. Finally, climate, culture and other more general context-specific attributes may influence walking distances to stations as: some cultures may have a higher (or lower) pre-disposition for walking and public transport use, the city may more generally have policies and investments favoring such modes vis-à-vis others (or vice versa), walking distances may be lower in extremely hot (or cold) climates, etc.

With this background, identifying the size of the area of influence around BRT stations becomes important: knowing this size, and the physical attributes which might influence it, will affect ridership demand forecasting and possibilities for quantifying and influencing urban design feedback on demand via transit-oriented development. Ridership estimation is plainly important for evaluating and configuring the system and designing station capacities. Analyses from outside of China provide no consensus regarding a uniform standard for catchment area size, although a common measure seems to be a 5-10 min walking distance (around 400-800m) from the transit station (O'Sullivan & Morrall, 1996). Cervero et al. (2009) adopted 800m (0.5 mile) buffers around stations in calculating catchment-related attributes and included them in estimating ridership based on empirical data from 69 BRT stops in Southern California (USA). The authors hypothesized that a terminal station serves bigger geographic catchments but did not test this in their regression models (Cervero, *et al.*, 2009). Olszewksi & Wibowo (2005) studied mass rapid transit (MRT) stations in Singapore, and found an average walking distance of 608m (Olszewski & Wibowo, 2005). In the China context, Cervero and Day (2008) and Pan et al. (2009) each use a 1-km threshold in models to estimate (rail) transit proximity effects on travel behavior and accessibility of residents in specific neighborhoods, although neither study offers empirical evidence to support the selection of this threshold (Cervero & Day, 2008; Pan, *et al.*, 2009).

When it comes to designing new BRT corridors for accommodating urban growth and influencing longer term transit demand, planners need to understand how *corridor* design itself may affect station catchment area – this knowledge could help increase overall system ridership and boost transit-oriented development (TOD) synergies. In the US context, again, the standard TOD boundary has been set at 400-800m, with some variation across cities (Calthorpe, 1993; Canepa, 2007; Ewing, 1999). Although without a specific empirical justification provided, Rodríguez and Targa (2004) adopt a 1.5 km buffer around the Bogotá (Colombia) BRT system stations and lines to assess the system's effects on residential property rental values (Rodríguez & Targa, 2004).

To sum up, previous studies on transit system catchment areas have mostly focused on the influence from the perspective of system quality and/or travelers' demographic characteristics, with conclusions varying across cities and countries. However, with only a few exceptions (e.g, Canepa, 2007), most analyses have ignored the role of corridor type and station context in affecting the transit station catchment area. Walk access distances to the system have rarely been explored, especially in the Chinese urban context. In this paper, we examine the relationships between corridor type and station context on the effective catchment areas of BRT stations in a specific Chinese city, with the objective of answering the following questions:

- What are the observed walk access distances for BRT stations and how do they vary?
- What BRT corridor types exist in China and how differently are they perceived by daily users, in terms of walkability?

- To understand BRT station catchment area size for demand analysis and transit-oriented-development planning, should we account for the type of corridor *and* the station type?

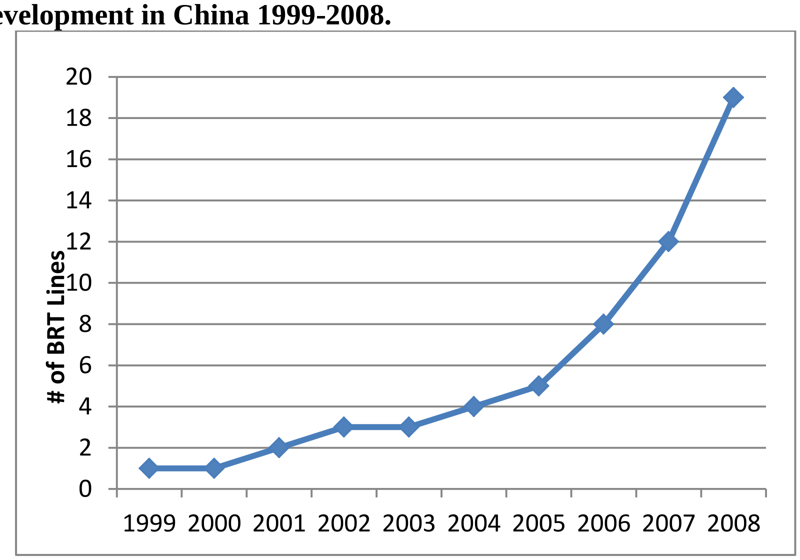
We attempt to answer these questions by looking at the Jinan BRT system which, as of summer 2009, operates on 3 corridors in the city. We expect the findings to lead to a better understanding of how the functions and forms of different types of urban roads affect people's accessibility to public transport, regardless of the quality of public transport services themselves. We also hope to inform the design of BRT infrastructure (stations and corridors) to increase both walking to/from stations and overall system patronage.

3 Research Context and Design

3.1 National Context

Chinese cities' ongoing urbanization, economic growth, and motorization have transformed the nation's urban landscape over the past decade. Transportation infrastructures have undergone rapid and massive transformation, including through new and expanded arterial roads, boulevards, ring roads, access-controlled expressways, etc. In recent years, authorities in many Chinese cities have increasingly recognized the importance of improving public transport conditions, including via investments in rail-based mass transit and, increasingly, in bus rapid transit (BRT). Since at least 1999, Chinese cities have started providing (or planning to provide) "advanced" bus rapid transit (BRT) services, on urban roads (Figure 1). However, the lack of upfront integration of road design, public transportation planning, land-use planning and early-stage public consultation has created challenges to providing high quality public transport services on many of the new urban corridors.

Figure 1. BRT Development in China 1999-2008.



Sources: data extracted from (ITDP, 2009) and (ChinaBus.Info, 2008)

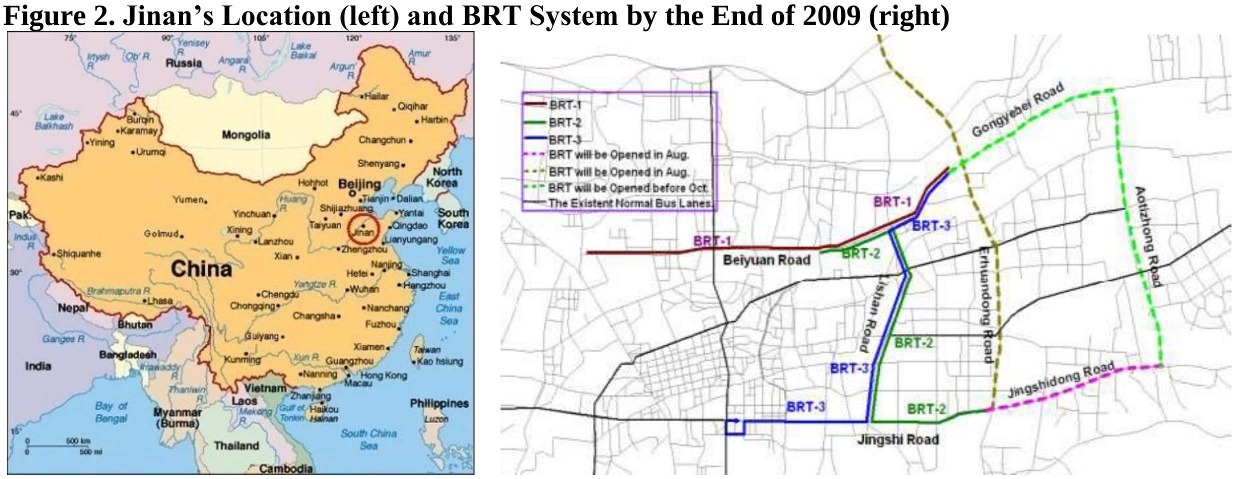
3.2 Jinan Context

Jinan is the capital city of Shandong Province in China (see Figure 2). Lying on the lower reaches of the Yellow River with numerous natural springs, Jinan ("Spring City") is also one of China's most famous historical and cultural cities with an over 4,000-year history. Like many Chinese cities, Jinan is currently undergoing rapid urbanization. During the past two decades, the city's urban area expanded from 117 km^2

in 1986 to 295 km^2 (Jinan Statistics Bureau, 2009) and, according to the Jinan city master plan, the urban district will expand to a built-area of 410 km^2 by 2020. The city's population of 3.5 million people (SBSP, 2009) is expected to increase by an additional 1 million people by 2020 (Jinan Urban Planning Bureau, 2005).

To cope with increasing travel demand and urban growth, Jinan began implementing a Bus Rapid Transit (BRT) system in 2005. The Chinese central government has named Jinan a Bus Rapid Transit Demonstration City (SDUTC, 2008). As of summer 2009, the city had 3 BRT lines on 3 corridors – Jingshi Road, Beiyuan Road, and Lishan Road – running a total of 34 kms with 34 stations (see Figure 2). According to plans, by the end of 2015, Jinan will have over 120 kms of a BRT network (SDUTC, 2010). This ambitious plan of BRT corridor development creates important policy and planning relevance for the city itself. For corridors still in the early planning stages, analysis of the existing system could inform corridor and station planning and design, enhancing demand forecasts and potentially increasing the catchment area size and system utilization. For predetermined corridor types (i.e., where the corridor type is already fixed), analysis of the existing system and its stations could still help improve ridership forecasts and our understanding of the catchment area.

Figure 2. Jinan's Location (left) and BRT System by the End of 2009 (right)



Source: (left) Adapted from (Warriortours.com, 2010); (right) (Wang, et al., 2010) p.4

The specific focus on the Jinan BRT case provides the possibility to examine the effect of three different corridor types, representing different walking environments which are common in Chinese cities, while controlling for city-specific variation. Specifically, in the Jinan case we observe:

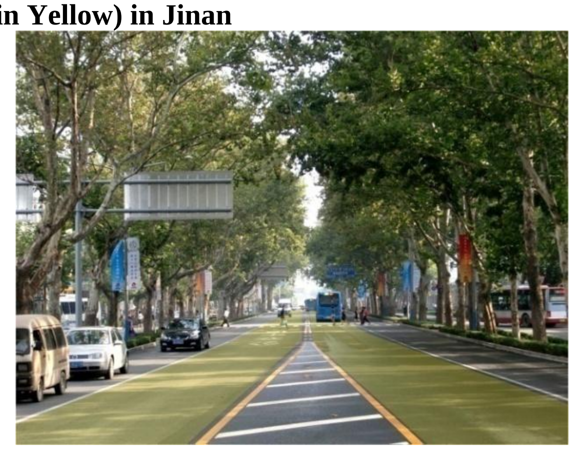
1) The "arterial-edge" type corridor (Jingshi Rd), with curb-side BRT stations and dedicated lanes on a ten-lane arterial. This represents a popular corridor type in China, with the most famous one likely being Chang'an Avenue passing Tian'anmen Square in Beijing. Corridors of this type tend to be very wide and often serve as the city's "front window." Cities sometimes create these high profile arterials to enhance city image, providing a window into efforts to convey modernity (Tao, *et al.*, 2010). Nonetheless, these modern arterials do not necessarily lead to walkable places, as feeder roads tend to be neglected and BRT users and other pedestrians must walk additional distances from intersections to the typically mid-block located stations (Figure 3, top left).
2) The "integrated-boulevard" type corridor (Lishan Rd), with median-lane BRT lanes and large tree-shade-covered sidewalks. Sidewalks usually have active street-edge and are shaded by big trees. Feeder roads are also better integrated with main corridors (Figure 3, top right).

3) The “below-expressway” type corridor (Beiyuan Rd), with median-lane BRT right-of-way under the viaduct and stations at major intersections. Many cities have elevated ring roads of the type running above this BRT corridor. The corridor lacks a human-scale and streets tend to be more chaotic with poor landscaping, since many of those corridors run in newly developed areas (Figure 3, bottom).

In addition, the unified service planning and operation on three corridors in a single city provide a good possibility to control for the influence of other system performance factors. Currently, the three BRT lines operationally overlap each other on the three corridors, with similar speeds and station spacing. The system allows free transfers between BRT lines at transfer stations. Therefore, even with some corridor-specific characteristics within the system/service operation, BRT riders tend to experience different corridors and the associated system/service effect in one single BRT trip. Therefore, the BRT system with integrated operation on three different corridor types provides a unique opportunity for us to justifiably control for the quality of public transport services themselves when exploring how the functions and forms of different types of urban roads affect people’s accessibility to public transport.

Figure 3. BRT Corridor Types (highlighted in Yellow) in Jinan

1. Arterial-Edge Corridor (Jingshi Rd.)



2. Integrated-Boulevard Corridor (Lishan Rd.)

3. Below-Expressway Corridor (Beiyuan Rd.)

3.3 Research Design

We collected the BRT walk access information in Jinan by interviewing people at BRT stations over a 4-day period in late August 2009. Table 1 shows the variation in the characteristics comprising the station-based sampling frame. Although the initial sample was randomly chosen, many of them were in a hurry and refused the survey, leading to a possible bias of the final sample towards people with lower value of time. The survey was conducted from 7 to 10 AM and 4 to7 PM each day from Wednesday to Saturday, in an attempt to cover peak, non-peak, weekday and weekend periods. In all, we selected 19 BRT stations along the three BRT corridors as our sampling frame (see Figure 4 and Table 1).

Figure 4. Surveyed BRT Stations and Their Contexts

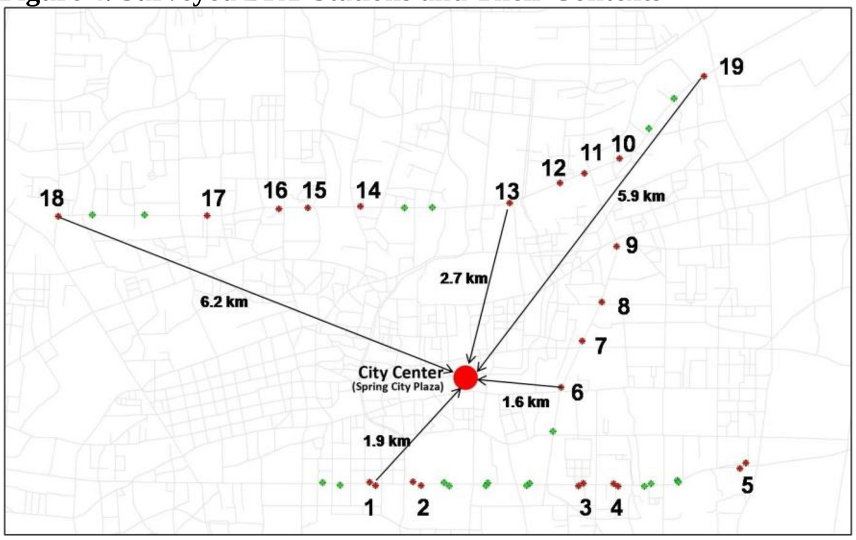


Table 1. Station Sampling Frame

Station ID	Station Function	Distance to City Center (km)	Road Length in 500m Catchment (km)	# Feeder Bus Routes
1	Typical	1.9	15.3	2
2	Typical	1.5	16.7	6
3	Typical	2.4	15.4	1
4	Typical	2.8	18.2	3
5	Terminal	4.5	13.3	10
6	Transfer	1.6	15.9	6
7	Transfer	2.0	15.4	12
8	Transfer	2.4	13.2	1
9	Transfer	3.1	15.5	10
10	Transfer	4.2	16.1	6
11	Transfer	3.6	18.6	6
12	Transfer	3.2	15.8	0
13	Transfer	2.7	12.5	3
14	Typical	2.9	20.2	4
15	Typical	3.2	22.2	0
16	Typical	3.6	20.3	20
17	Typical	4.3	18.6	3
18	Terminal	6.2	13.6	5
19	Terminal	5.9	13.6	4

In the survey, those BRT users who walked to or from a station were asked to point out on a map their approximate origins or destinations as well as their walking routes. Users also reported socioeconomic and demographic information as well as trip-specific (e.g, purpose) and other travel (e.g., availability of other travel modes) information. Finally, respondents were asked to rate the walkability of their walk access with respect to a series of related statements. In total 2,155 BRT users were surveyed, from which there were 1406 valid observations due to incomplete information and non-walk access in excluded cases.

We then recorded the reported walk paths and geo-coded them in a geographic information system (GIS). We also geo-coded the feeder road network around each BRT station. Using GIS utilities, we then calculated relevant distances (e.g., path distances, straight-line distances, total length of feeder roads within 600m-radius buffer area of the station, etc.).

Table 2 presents the data we derived on the physical characteristics related to the corridors and the stations, including the method and units of measurement.

Table 2. Data captured on corridor type, station context and walkability

Data Item Description	Method	Unit of measure
Corridor type	Visual	Categorical
Walkability	Visual (pictures and videos); Rating on statements	Ordinal (Likert-scale): 1-stongly disagree, 5-strongly agree
Station density gradient	Read from local 3D map	Categorical
Station function	Read from local BRT map	Categorical
Feeder road length	Measured in GIS	Kilometers
Distance to city center	Measured in GIS	Kilometers
Number of bus lines to station	Count from local bus map	Numbers

4 Analysis & Results

As mentioned above, just over 70% of the 2,155 BRT users surveyed were valid walk access observations. Approximately half of the people who walked were female and half were male and almost 92% were between 20 and 60 years old (see Figure 5, left). Roughly 82% of respondents had a household monthly income between 1000RMB and 5000RMB (see Figure 5, right). For comparison, the officially reported average income of urban households in the region is 1835 RMB per month (Jinan Statistics Bureau, 2009). Nearly half of the BRT users surveyed were company employees (see Figure 6, left) while 43% of respondents were reporting on a work trip (see Figure 6, right) (to be expected, as the survey was implemented during peak and off-peak hours, increasing the likelihood of having a range of trip purposes reported). The relatively small share of school trips probably results from the survey period – late August, which coincides with official school summer holidays in China. In terms of alternative mode availability, 87% of respondents mentioned they would take conventional bus to make the same trip if the BRT were not available, whereas only 1% of respondents reported having no other choice than BRT. This pattern reflects that in Chinese cities like Jinan, new customers for the BRT system come mainly from previous users of conventional bus.

Figure 5. Distribution of BRT Walk Access Respondents by Age and Income

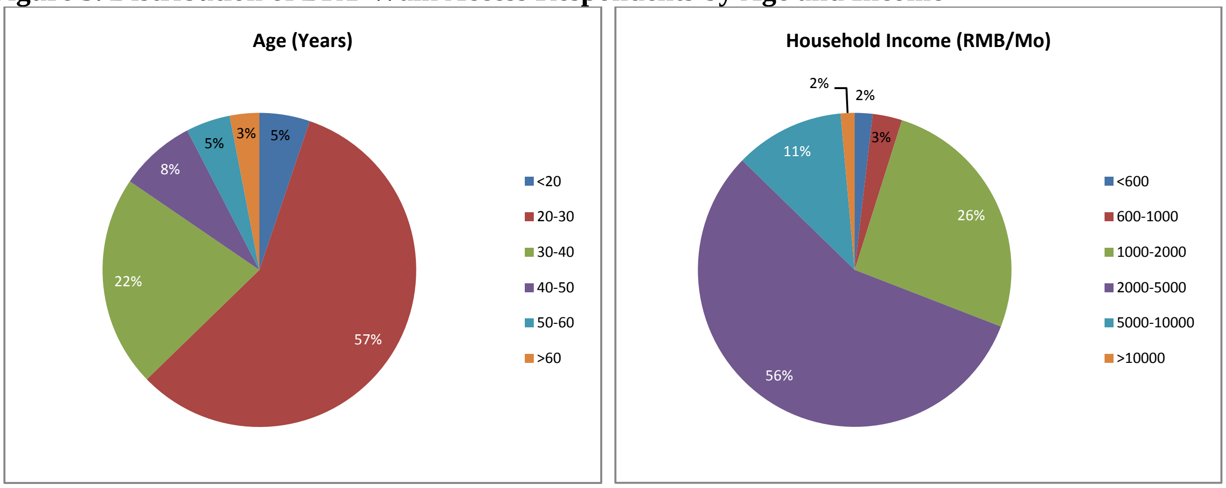
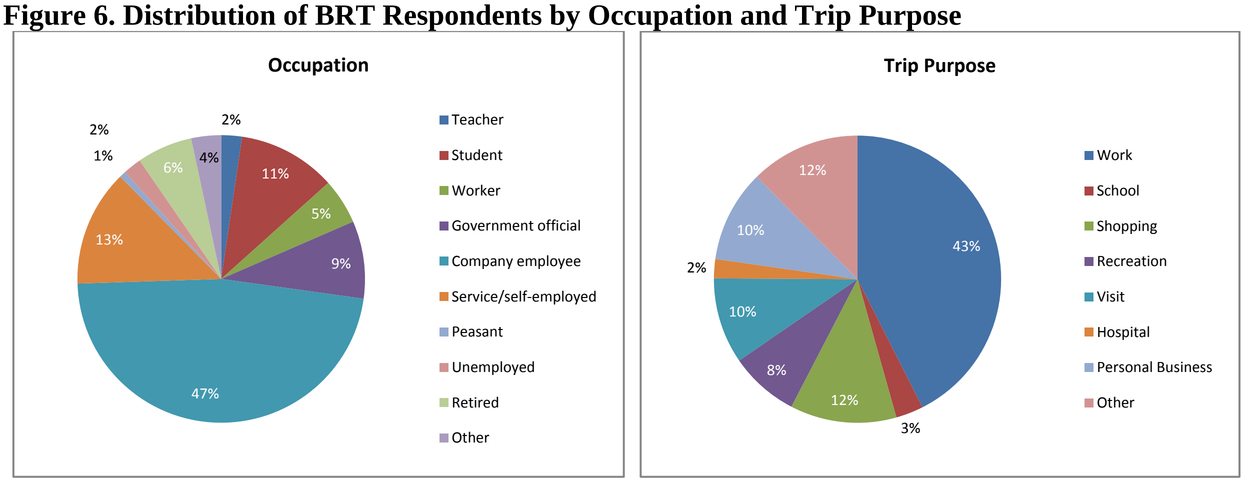


Figure 6. Distribution of BRT Respondents by Occupation and Trip Purpose



4.1 Corridor Walkability

We now examine the walkability across the three BRT corridors, focusing on four major aspects: protection, comfort, enjoyment and directness. We evaluate the first three aspects based on respondents' subjective rating as reported in the survey (see Figure 8). We derived a proxy for the last measure, directness, by using the average ratio of all actual walking distances to the associated straight-line distances from the reported origin/destination to the BRT station. It is important to point out here that technically the measures are carried out for stations on corridors, and attributing them to the corridor presumes transitivity. We don't know whether the stations are "representative" or not of the corridors themselves.

Protection refers to security against traffic and accidents and against crime and violence. We can see that none of the three corridors rates satisfactorily on this point. No more than a third of surveyed BRT users agreed that crossing and walking on sidewalks was safe and easy. This result is not surprising, given our own observations of the corridor conditions. The Jingshi corridor is often quite wide, up to 10 lanes at some crossings, with people having to cross busy traffic with relatively short green-light cycles or using footbridges (Tao et al (2010) report similar problems with general-purpose arterials in the city of Fushun). The Lishan corridor is narrower in the middle section, but also expands at the crossings. Finally, the

Beiyuan corridor has poorly designed or managed light signals at some crossings and presents such serious drainage problems that people often cannot cross the street after a rain.

Comfort refers to the ease of walking (fewer obstacles), including sidewalk quality and street cleanliness. The arterial-edge Jingshi corridor, representing a “city image” project as discussed above, ranks more favorably on comfort indicators than the other two corridors. About 67% of respondents on the Jingshi corridor think the pavement is good, while Lishan and Beiyuan measure 50% and 38%, respectively. Similarly, nearly 50% of respondents on Jingshi agree that streets are clean and that sidewalks have few blockages, whereas such percentages are only 20-30% on the other two corridors.

Enjoyment refers to aesthetic and utilitarian aspects related to the presence of activities and relief from the elements (e.g., shade from sun). On this dimension, the integrated-boulevard corridor, with 70% of respondents agreeing that trees on sidewalks on this corridor made walking pleasant, ranks better than the other two corridors, where less than 50% responded similarly. We dare say that the Jingshi corridor’s function as a window into the “city image” provides a view more pleasing to drivers than pedestrians. For example, big trees along some sections of the Jingshi corridor are set back from the sidewalk, serving more as a backdrop to the lanes, impeding potential on-the-ground store development and interaction activities between pedestrians and the buildings. The scale of the arterial-edge corridor also manifests wide streets and the deep set-back of buildings (see Figure 7). The below-expressway corridor provides a very poor pedestrian scale, overwhelmed by the overhead expressway’s mega-structure

Figure 7. Jingshi Corridor’s Set-Back with Trees


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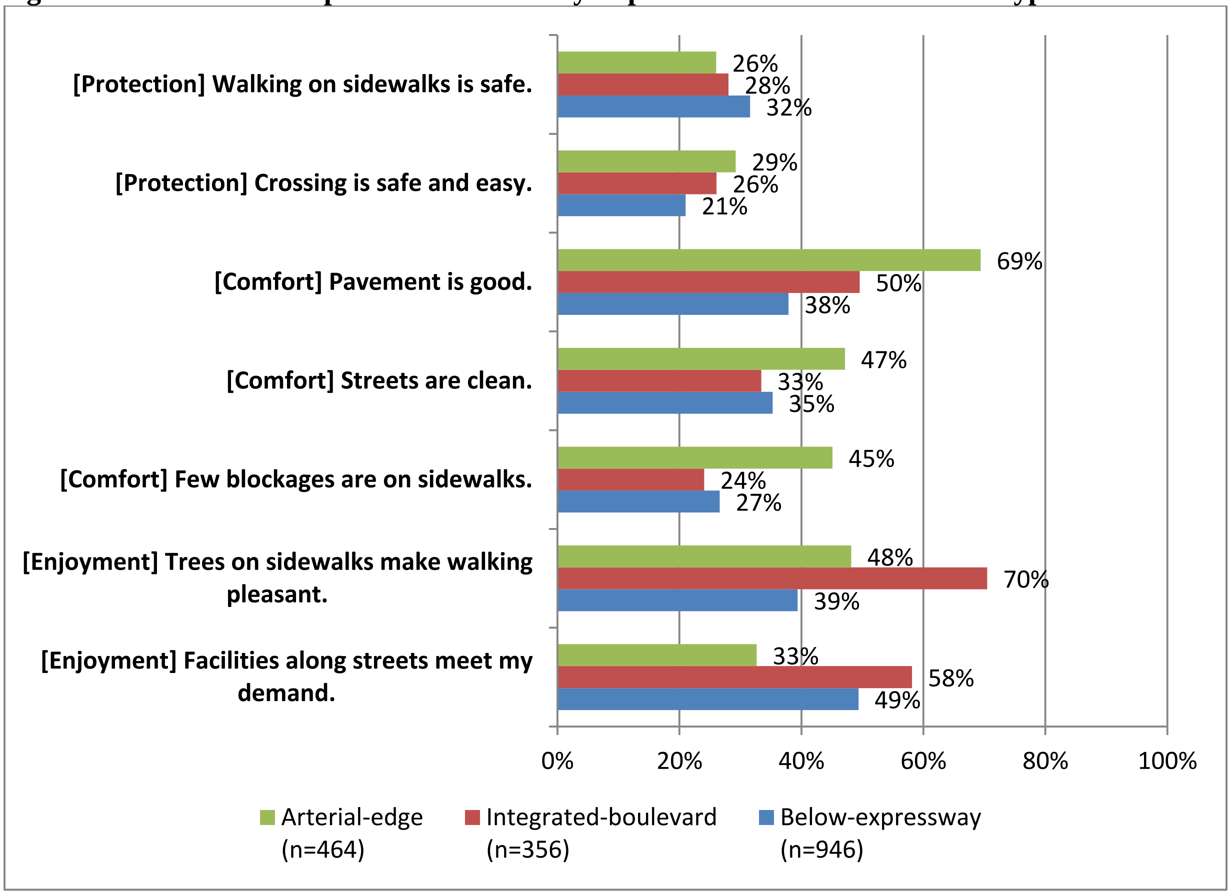
Figure 8. BRT User Perceptions of Walkability Aspects on the 3 BRT Corridor Types



Note: [ ] refers to "walkability aspect (see text). Percentage refers to share of surveyed BRT users that agree with walkability-related statements (i.e., scale rating as 4 or 5)

Finally, *directness* refers to a station's relative "detour" factor, measured as an average ratio of the reported walk distance in the sample to the straight-line distance from the origin/destination to a certain BRT station. Averaging these station-specific detour factors based on the corridor type, the results show that the arterial-edge corridor has an average detour factor of 1.59, indicating less directness, whereas the integrated boulevard and below-express way corridors have lower values of 1.36 and 1.33, respectively. This reflects the arterial-edge corridor's access disadvantage due to locating the BRT stations further away from major intersections. Pedestrians have to walk about 17-20% longer to reach the station from the same origin/destination than they would do if the stations are close to crossings.

As summarized in Table 3, the distinct physical arrangements, landscape and street facilities between three corridors indeed lead to different levels of walkability perceived by BRT users. In general the "integrated-boulevard" corridor in Jinan seems to be more walkable than the other two corridors, especially with respect to enjoyment. In the next section, we will further test whether the corridor type has an impact of BRT users' walk access distances.

Table 3. Walkability Comparison between 3 BRT Corridors in Jinan

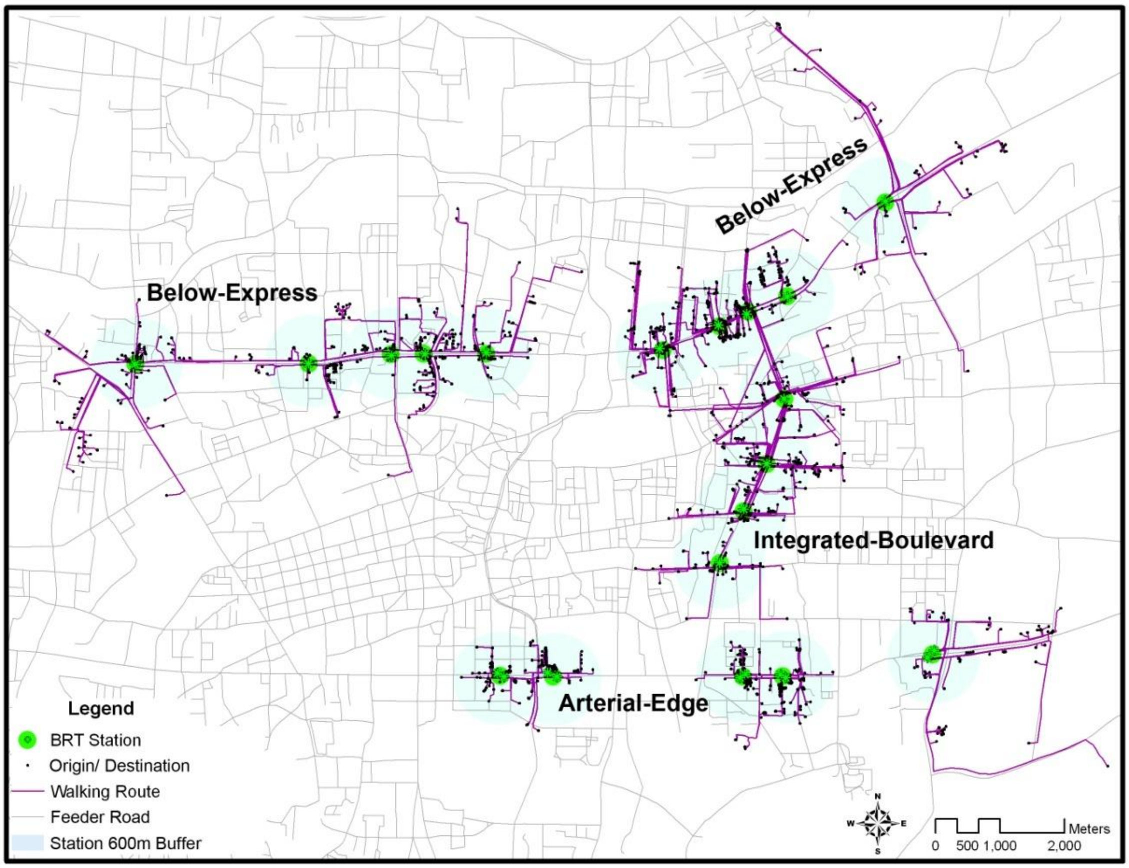
Corridor Type (Name)	Walkability Perceptions from BRT Users			Directness
	Protection	Comfort	Enjoyment	
Arterial-Edge (Jing-shi)	poor	good	poor	poor
Integrated-Boulevard (Li-shan)	poor	average	good	good
Below-Expressway (Bei-yuan)	poor	poor	average	good

4.2 BRT Walk Access Patterns

4.2.1 Descriptive Analysis

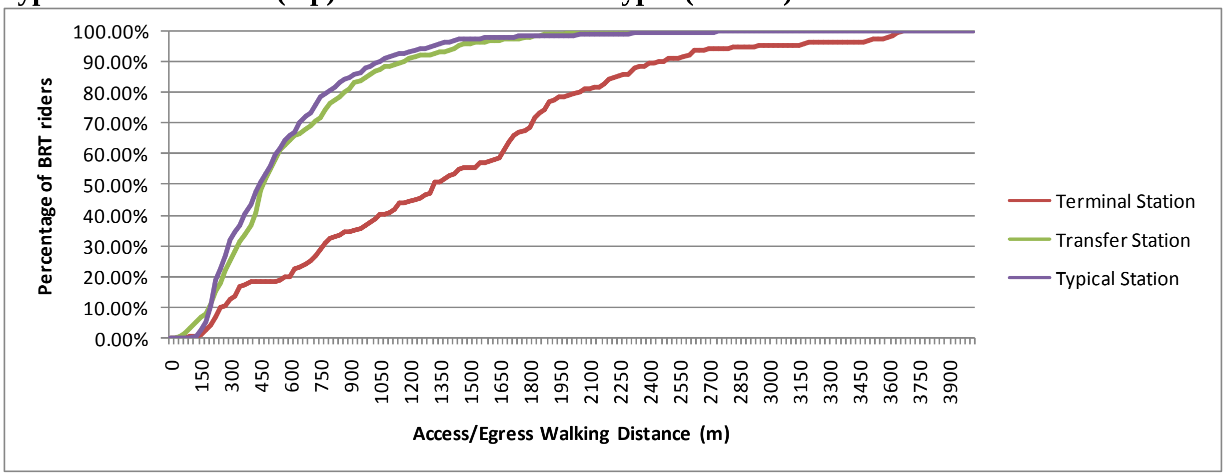
Figure 9 shows the Jinan BRT access walking routes we recorded. Purple lines represent walking paths. Blue circles are 600-meter buffers at each station, represented by green dots. One distinct observation from this map is that the majority of origins/destinations around any of the three *terminal* stations are greatly outside the 600m buffer area. This implies a much longer walk access distance in average at the terminals. Second, the actual catchment area of stations on the arterial-edge corridor (the southern E-W route) looks smaller than those of stations on the other two corridors.

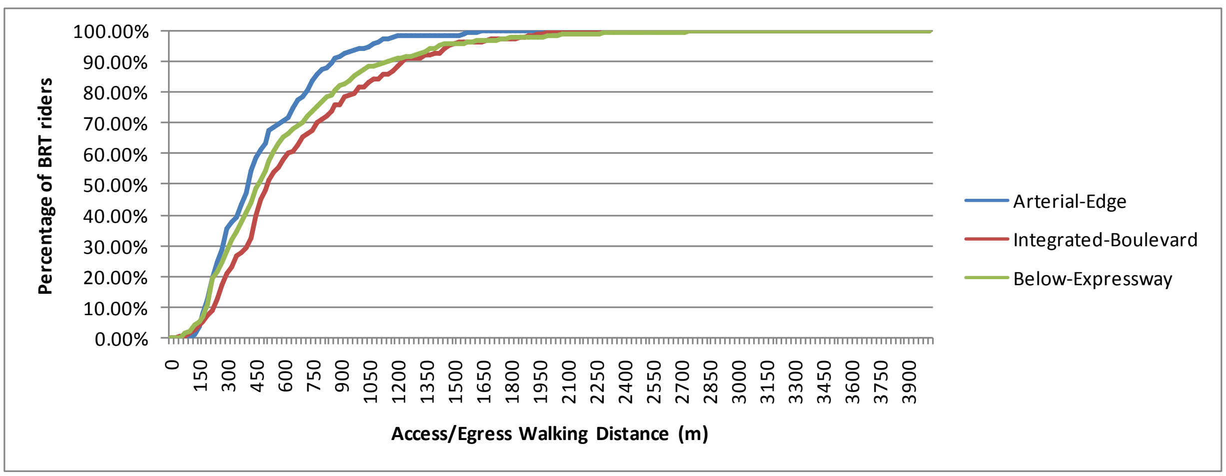
Figure 9. The Map of Jinan BRT Access/Egress Walking Routes



Scrutiny confirms our first impressions. Figure 10 (top) shows the cumulative distributions of walking distance to BRT terminal stations, transfer stations, and typical stations. The distance walked clearly relates to station function – respondents walk much further to terminal stations than to transfer and typical stations. Table 4 shows that the average walking distance to a terminal station was 1392 meters, more than double the average walking distance to a non-terminal station. Planners may typically assume that people will walk on average 600 meters to BRT station, however Figure 10 (top) shows that 80% of respondents walked further than 600 meters to a *terminal* station.

Figure 10. Cumulative Frequency Diagrams of Walking Distances at Terminal, Transfer and Typical BRT Stations (top) and Three Corridor Types (bottom)





Regarding corridor type and walkability effects on BRT walk access, Figure 10 (bottom) shows the cumulative distributions of walking distance to BRT stations on three corridors. The Integrated-Boulevard corridor type appears to have longer average walk distances, which Table 4 further illustrates. BRT stations on the “integrated-boulevard” corridor have an average walk access distance of 649 meters, whereas the average walk access distances to stations on the “arterial-edge” and “below-expressway” corridor are only 475 meters and 580 meters, respectively. This suggests that the “integrated-boulevard” corridor has something making it more attractive for walk access, incentivizing people living further from the station to walk and use the BRT system (even if the BRT service qualities on three corridors are similar to each other).

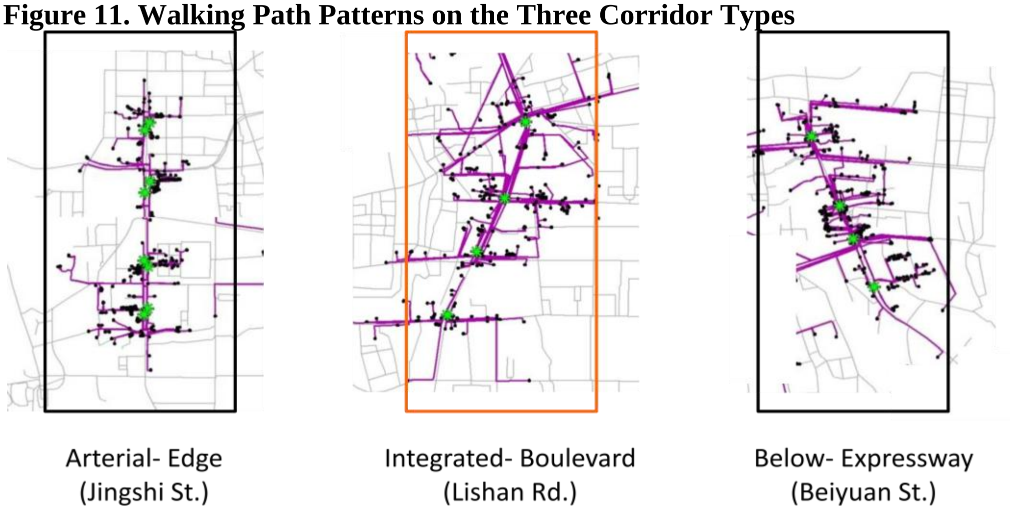
Table 4. Walking distance to BRT stations by corridor type and station function

Statistics	Corridor Type[a]			Station Function			Total
	Arterial-Edge	Integrated-Boulevard	Below-Expressway	Typical	Transfer	Terminal	
Mean	475	649	580	549	586	1392	664
Median	412	520	458	435	458	1311	489
Maximum	1635	2023	2738	2738	2067	5114	5114
Minimum	102	47	36	102	37	97	37
95% Confidence Interval for Mean (Lower Bound)	444	599	546	516	555	1234	636
95% Confidence Interval for Mean (Upper Bound)	505	699	613	578	619	1496	693
No. of Valid Observations	332	271	631	627	607	172	1406

a. Walk distance to non-terminal stations is used in comparison, because there are no terminal stations on the "integrated-boulevard" corridor in Jinan.

In addition to allowing distance comparisons, the GIS data also give us opportunities to compare the physical distribution patterns of the walk access routes. Interestingly, the integrated-boulevard corridor presents a distinct hierarchical walk path pattern (i.e., access flows merge onto a few routes and further connect to the station), whereas the other two corridors display relatively random patterns, as shown in Figure 11. According to our visual survey, we suspect that the integrated corridor creates a few walkable and safe feeder routes, which provide sufficient access means.

Figure 11. Walking Path Patterns on the Three Corridor Types



Station context represents another factor which might also influence people's walking access distance to the BRT. We have demonstrated that the station function (being a terminal station or not) appears to play a role. In addition, the station's density gradient may also play an important role in the catchment area, although previous studies have rarely examined it. Statistically speaking, the need for controlling for the density gradient comes from its influence on the shape of the distribution of the full station-catchment population, from which we randomly drew our survey. A downward sloping density gradient, all else equal, will likely have a shorter average walking distance observed from the survey, not because BRT users around the station are necessarily less willing to walk, but rather because they do not have to when going to stations; we are more likely to find those individuals in the survey than people accessing further away locations. Unfortunately, geo-coded data on relevant land uses (e.g., business activities) and demographics (e.g., population density) are not readily available for Jinan. Instead, we somewhat crudely identified stylized density gradient patterns by using a local 3D map (EDUSHI, 2009): hill pattern (with intensive development right next to a station), flat pattern (with constant density emanating out from the station) and valley pattern (with low density or vacant land adjacent to a station). Figure 12 shows examples of stations with the "hill" and "valley" density gradient patterns.

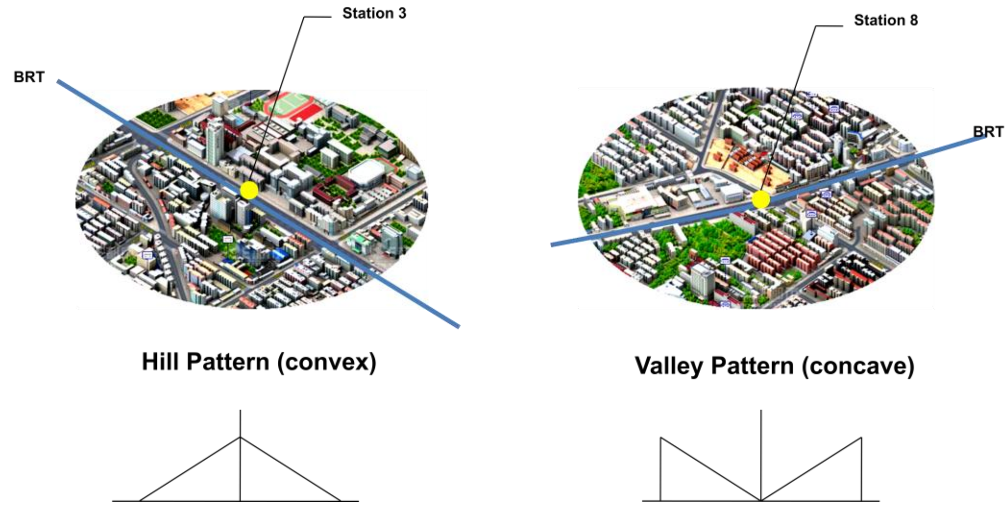
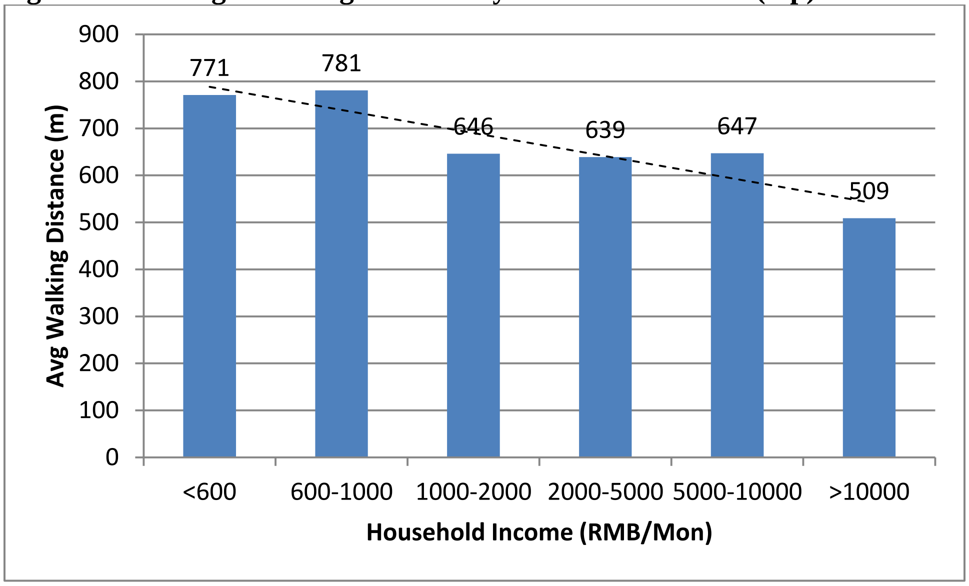
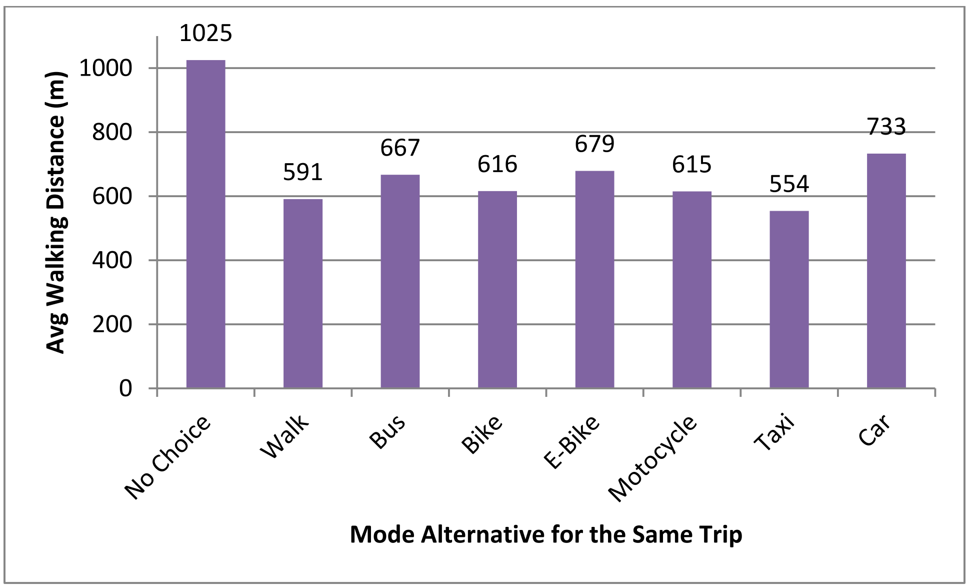


Figure 12. Density Gradient Patterns of Jinan BRT Stations
Source: Adapted from (EDUSHI, 2009)

However, we should be cautious about drawing any conclusions from this direct comparison of walk distances across station functions and corridor types, as other potentially confounding factors exist. For example, income may affect people's willingness to walk, all else equal. As shown in Figure 13 (top), richer people tend to walk less to access BRT stations in Jinan. The availability of alternative modes for BRT users to make the same trip also has influence. Figure 13 (bottom) illustrates that people with no choice other than taking the BRT are willing to walk much longer than those with at least some alternative; among those with an alternative available for the trip, we see less variation in the distance walked. Other potentially confounding socio-demographic and trip-specific factors include gender, age, occupation, trip purpose, trip timing and so on.

Figure 13. Average Walking Distance by Household Income (top) and Alternative Mode (bottom)





4.2.2 Regression Analysis

In order to attempt to isolate the influence of corridor type and station walking conditions on the measured actual walking distances to BRT stations, while controlling for other potentially influencing factors, we specify an ordinary least squares (OLS) regression of the basic form:

$$\mathrm{DIST_i} = f(\mathbf{TM_i}, \mathbf{TR_i}, \mathbf{S_i}, \mathrm{C_i}; \beta) + \varepsilon_i \quad (1)$$

where:

$\mathrm{DIST_i}$= BRT access walking distance of user *i*

$\mathbf{TM_i}$= A vector of socio-economic status variables of trip maker *i*

$\mathbf{TR_i}$= A vector of trip-specific variables of user *i*

$\mathbf{S_i}$= A vector of station context variables associated with trip maker *i*

$\mathrm{C_i}$= the BRT corridor type (dummy) on which user *i* is interviewed

Table 5 presents the results of fitting the regression model from equation (1) on the Jinan survey data. The "control model" includes only the trip maker ($\mathbf{TM_i}$) and trip-related ($\mathbf{TR_i}$) control variables from equation (1). Note the very weak explanatory power of the model (adjusted R2=0.012). Only 3 of 18 variables – low income group, trip with no other modal choice, and trip maker age over 60 – are significant. The coefficients for the first two variables have positive signs, as expected, while the coefficient on "age over 60" is also positive and large. This implies that older adults walk much longer (200m) on average than others to access BRT stations, which may seem counter-intuitive. The null hypothesis that all of the regression coefficients are equal to zero in this model cannot even be rejected at the 0.05 significance level (F=1.882<3.682).

In the "full model" column of Table 5, we then add the corridor type dummies and a series of station context variables to the regression. We can observe a large improvement (21%) in the explanatory power of the model (adjusted R2=0.223). The coefficient on the "integrated-boulevard" corridor variable is positive and significant. This suggests that, all else equal, BRT users on the integrated-boulevard corridor walk 158 meters longer to the BRT stations than those on the "arterial-edge" corridor and the "below expressway" corridor. This likely reflects the superiority of the integrated-boulevard corridor in terms of its walkability perceived by BRT users, as discussed earlier.

Most of the station context variables are also significant. Compared to those measured at typical stations, walking access distances at terminal stations are 373 meters longer. Transfer stations, on the other hand, have the opposite effect, with walk access distances 126 meters shorter than typical stations. One explanation for this result may be that the BRT transfer stations are also usually well connected with conventional bus routes/stops, therefore walking distances are shorter. In terms of the stylized density gradients, the "hill pattern" has a lower walk distance relative to the "flat pattern," as expected, while the "valley pattern" has a higher walk distance, also as expected and described in the previous section. The relative location of the station in the city also has a significant effect: the greater the distance from the station to the city center, the longer the walk access distance (approximately 75 meters additional walk access distance for each kilometer the station is from the city center), all else equal. This is a reasonable result: presuming the city center represents the point of highest accessibility in the city, the further away from the city an individual is (and subsequently the lower her relative accessibility at that location), the more likely she will be willing to walk to access the BRT system.

The trip maker and trip-specific characteristics remain for the most part statistically insignificant in explaining walking access distance, with exceptions similar to those found in the "control model." In the "full model", low income people walk 165 meters longer on average compared to median income people, yet high income people walk as long as the median income people. Occupation and gender do not affect the walk access distance significantly, nor do car ownership, frequency of BRT use, weekend trip-making, making the trip in a group, etc.

The age effect remains interesting. On the one hand, people with age of 40-60 walk less than people aged 20-40. On the other hand, older adults (over 60) seem to walk as long as younger people, aged 20-40. However, we should be cautious about drawing conclusions based on this result. While it may be true that older adults have a lower value of time, seat privileges on the system, and enjoy benefits of a free ticket policy which give them an incentive to walk more, the older adult result may also arise from sampling bias. The older adults surveyed were ambulatory – if they had trouble walking, they would have a lower likelihood of being in our sample. Anecdotally, from the survey implementation, we observed that some "super-healthy" elderly even regarded the walk to the BRT as exercise.

Table 5. OLS Regression Models Predicting BRT Walk Access Distance

Variable	Control Model		Full Model	
	Coefficient	T-test	Coefficient	T-test
BRT Trip Maker & Trip Characteristics				
Income <2000RMB	120.371*	1.69	165.651**	2.60
Income 2000-10000RMB	ref		ref	
Income >10000RMB	-133.728	-1.08	-54.418	-0.49
Occupation: Professional	24.397	0.58	-9.133	-0.24
Occupation: Blue Collar	105.998	1.40	-43.635	-0.64
Occupation: Service/ Self-employed	15.386	0.28	-48.788	-1.00
Gender: Female	-29.701	-0.99	2.330	0.08
Age <20	2.552	0.04	-72.527	-1.14
Age 20-40	ref		ref	
Age 40-60	-36.600	-0.79	-73.832*	-1.75
Age >60	200.407**	2.20	26.446	0.32
BRT-Dominant User	19.723	0.63	42.035	1.47
Car Ownership	-26.006	-0.62	6.414	0.17
Trip Purpose: Shopping	-68.515	-1.37	-46.560	-1.04
Trip Purpose: Recreation/ Social	53.361	1.21	22.799	0.58
Trip Purpose: Personal Business/ Other	-59.678	-1.55	-21.551	-0.62
No Alternative Mode Available	470.689**	2.55	415.598**	2.53
Trip Time: Weekend	-7.556	-0.22	-26.062	-0.85
In Group	13.516	0.39	28.053	0.90
BRT Corridor Type				
Integrated Boulevard (Lishan Rd)			158.810**	2.60
Below Expressway (Beiyuan Rd)			-20.432	-0.32
Arterial Edge (Jingshi St)			ref	
BRT Station Context				
Terminal Station			372.886**	3.52
Transfer Station			-126.453**	-2.34
Typical Station			ref	
Density Gradient: Hill			-156.771**	-4.15
Density Gradient: Flat			ref	
Density Gradient: Valley			153.714**	3.52
Number of Feeder Bus Routes			0.583	0.18
Distance to City Center (km)			75.926**	2.40
Feeder Road Length in 600m Catchment Area			-11.127	-1.16
(Constant)	640.032**	12.27	597.833**	3.06
No. Observations	1,233		1,233	
(df)	(18,1214)		(27,1205)	
F	1.882*		14.576**	
Adjusted R2	0.012		0.223	

*p<.10, ** p<.05

5 Implications

There are several implications of this research. First, for cities that are pursuing transit-oriented development, policy makers and developers should recognize a unique opportunity around terminal BRT stations. Our analysis finds that the average radial distance of the walk catchment area for such stations may be as large as 1350m. This means that the catchment area, or the pedestrian zone, of a BRT terminal station may be up to five times as large as the conventional coverage area with an assumed 600m radial distance. However, the location of a BRT station, if not close to road intersections, can reduce the size of the catchment area due to the walk "detour" effects.

Second, in the field of travel demand analysis, accounting for corridor type and station context may improve BRT ridership demand analysis in the China context. Conventional travel demand models assume that transit riders, particularly choice users, are mostly sensitive to a bus stop's service quality and fare levels. The implications for ridership estimation given the likelihood of a varying catchment area, suggests demand analysis should explicitly incorporate station type and context, including pedestrian connectivity, street crossing, and the like.

Third, for urban planning more generally, the research calls for a flexible catchment definition so as to reflect the corridor type and location station context. Based on the model results for Jinan, we develop initial guidelines for radial distance walk catchment areas around BRT Stations. Specifically, applying the relevant model coefficients, we can identify the expected average walk distance as:

$$E(Walk\ Distance) = 600 + 150 * (if\ Integrated\_Boulevard\_Corridor) + 400 * (if\ Terminal\_Station) - 100 * (if\ Transfer\_Station) - 150 * (if\ Density\_Hill) + 150 * (if\ Density\_Valley) + 50 * (Distance\_to\_Center\ in\ km)$$

The final radial distance should be further discounted by a detour factor which is station-location dependent. For example, the "arterial-edge" corridor in Jinan suggests a "discount" of up to 30% for this corridor type. Table 6 presents a rough estimate of the ranges of radial distance according to corridor type and station function.

Table 6. Estimated Variations in Catchment Area Distance Guidelines

	Radial Distance (meters)	
Corridor Type	Terminal Station	Non-terminal Station
Arterial-Edge	600-1000	300-600
Integrated-Boulevard	1000-1500	600-1000
Below-Express	800-1200	400-800

Finally, from the public finance point of view, our analysis suggests that investment should prioritize a few pedestrian access routes to cost-effectively enlarge the BRT station catchment area. This is evidenced by the station context along the Jinan "integrated-boulevard" corridor, where a few walking-friendly routes are apparently intensively used by the majority of BRT riders surveyed accessing those stations. In addition, when investing in an access route, particular attention should be paid on improving the "enjoyment." On Jinan's "arterial corridor" (Jingshi road), the handsome and apparently comfortable walking conditions are not sufficient to incentivize walking further, perhaps because there is little attraction or functionality provided for pedestrians.

The lessons and implications above, while specifically applicable to the Jinan context, should also help other cities develop more public transport-friendly urban road infrastructures, including by helping to prioritize bus-priority measures based on corridor type, identify walk-friendly station-area characteristics, and highlight possibilities for retrofitting existing facilities.

5.1 Research Limitations

We recognize a number of research limitations of this research. First, different corridor design elements may affect walkability in different ways. Unfortunately we could not examine those elements due to the limited number of BRT corridors (only 3) operating at the time in Jinan. Second, the other end of each BRT trip sampled was not taken into account in the statistical analysis; presumably riders consider both access and egress in one trip together when making travel decisions. Third, more accurate station context factors (e.g., absolute density, land use mix, etc) were not included in the model due to a lack of spatial data. Fourth, we could not control for the possible role of the season because the survey was conducted in the summer; people may walk less in the cold winter. Finally, the survey implementation technique certainly resulted in some biases, perhaps over-estimating the actual walk catchment area.

6 Conclusions

In this paper, we examine the general BRT walking access pattern in rapidly urbanizing China, where BRT implementation has been on the rise. Specifically, we hypothesize that contextual urban form features and station and right-of-way configurations can influences users' willingness to walk to BRT and thus affect the walk-access catchment area. We base our analysis on 2,155 user surveys, conducted at 19 BRT stations along the Chinese city of Jinan's three existing (as of summer 2009) BRT corridors. We applied ordinary least squares regression to estimate the relationship between walk access trip distances and aggregate station- and corridor-area characteristics, controlling for individual- and trip-specific attributes.

The results from our analysis suggest that people walk further to BRT stations when the walking environment has certain features (median transit-way station location, shaded corridors, busy and interesting) than otherwise. Among the three BRT corridors existing in Jinan in summer 2009, stations on the "integrated-boulevard "corridor (Li-shan Road) have a 160-meter longer average walk access distance than those on the "arterial-edge" and "below-expressway" corridors, after controlling for other confounding factors. The integrated-boulevard corridor is also perceived by BRT users as the most walkable corridor among the three, although it shares a safety problem with the other two corridor types.

Compared to the station and corridor contexts, we find that trip and trip maker characteristics play a relatively minor role in defining BRT walk access distance. Only low income and BRT-captive people walk more than average. While it is not clear from our analysis whether age has an impact on willingness to walk due to potential sampling bias in the survey, it is possible that older adults do not necessarily walk less. Women are willing to walk as long as men. Occupation, car ownership, trip purpose and time do not significantly affect walk access distance.

Our findings have several implications. For urban planners, BRT stations offer an important opportunity for building transit-oriented development, accounting for and subsequently influencing the walk access catchment area. For travel demand modelers, taking account of corridor type and station context may improve BRT ridership demand analysis. For transit planners, the research calls for a flexible catchment definition so as to reflect the corridor type and location station context. Finally, for transit investment decision makers, the results suggest it may be more cost-effective to provide a few critical pedestrian access routes to transit stations as a way to enlarge catchment areas.

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