DATA-DRIVEN DYNAMIC ACCESSIBILITY TO PUBLIC SERVICE IN MULTI-MODAL TRANSPORTATION NETWORK WITH UNCERTAINTY

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ABSTRACT

Conventional accessibility of public service is concerned about the coverage of alternative public service resources, which is a static indicator without consideration of individual demands and travel time uncertainties. A data-driven dynamic accessibility method is proposed in this paper to investigate the effects of travel time uncertainty on accessibility to public service with consideration of multi-modal transportation network topology and on-time arrival probability. Travel behaviors of travelers taking taxi and metro for access to the public hospital in Guangzhou, China are investigated for evaluation of the place-based accessibility. With the use of Floating Car Data of taxi and Smart Card Record from Metro in Guangzhou, the variation of travel times by taxi and metro for access to the Guangzhou general hospital are analyzed. Empirical results reveal the dynamic impacts of travel time uncertainty on the place-based accessibility coverage area by mode, on-time arrival probability and time of day.

Keywords: Accessibility, Taxi GPS, Smart card, Travel time uncertainty, Travel behavior

1. INTRODUCTION

Accessibility analysis are widely adopted for land use planning (Kwan and Weber, 2008), evaluation of transit service (Terayama and Odani, 2017; Lee and Miller, 2018), management of public resources (Kwan, 2009; 2013; Neutens et al., 2010a; Páez et al., 2010). It is well known that high-level accessibility to public resources is essential for improving urban life viability (Chen et al., 2018). The existing accessibility can be categorized into two types, namely place-based accessibility and individual-based one. Place-based accessibility (Delafontaine et al., 2012; Chen et al., 2016; Järv et al., 2018) concerns about the proximity to desired activity locations from some locations in a traveler's daily life, such as working place or home (Neutens et al., 2010b). There are various measures to calculate the place-based accessibility. The classical one is cumulative opportunities measure, which is defined as the number of opportunities (e.g. hospitals, service centers) within a specified cut-off travel time. Nevertheless, this definition has been criticized for ignoring individual complexities as well as travel time uncertainty. Therefore, more efforts on individual-based (or person-based) measures have been addressed in the recent years (Neutens et al., 2010c; Moniruzzaman et al., 2015).

Lättman et al. (2018) developed the perceived accessibility aimed at capturing the individual perspective of accessibility with a certain travel mode. Moniruzzaman et al. (2015) examined the relation between trip distance and socio-demographic attributes and accessibility features of lower income older adults in Metro Vancouver. Neutens et al. (2012) investigated four place-based and six individual-based measures for evaluating urban service delivery, the results showed that different measures provided quite different insights into how equally service delivery is distributed among the population.

From viewpoint of traffic engineering, accessibility is also strongly related with transportation system. For instance, the connectivity, efficiency, and vulnerability of road network are all have strong impacts on the accessibility of public services. The most common topic of this filed is dynamic space-time accessibility considering uncertain or unreliable travel time. In the previous literatures, Carrion and

Levinson (2012) and Taylor (2013) provided detailed reviews of concepts and applications of travel time reliability. The uncertainty of travel time has been divided into: variation between seasons and days of the week, variation by changes in travel conditions for weather and incidents, and variations attributed to each traveler's perception. Furthermore, both inter-personal and intra-personal day-to-day variability are tested by Neutens et al. (2012), the results showed that the space-time constraints on a particular day of the week affect the average level of accessibility.

In recent years, the availability of individual mobility data also contribute to the transition from static place-based accessibility to dynamic individual-based accessibility. The mobile phone tracking data (Chen et al., 2018), floating car data (FCD) (Li et al., 2011; Wang et al., 2018), smart card records (SCR) for bus and metro can be easily collected in this big data era. This paper concentrates on the average dynamic accessibility of individuals accessing public hospital, in which the reliability of taxi and metro is analyzed by computing mean value and standard deviation (STD) of travel times of trips with the destination to hospital. Empirical results show some insights on dynamic accessibility for multimodal networks.

2. STATISTICAL DESCRIPTION OF TAXI GPS DATA AND SMART CARD RECORDS

Guangdong general hospital is selected as the target object for the place-based accessibility analysis in this paper, which is the largest hospital in Guangdong Province. It can be directly reached by Guangzhou Metro Line No. 1 as Martyrs' Park Station is just under the hospital. Certainly, the hospital can be also accessed by bus, taxi, private car, or even bicycle, which depends on the real situation and preference of potential patients. Anyway, travelers or potential patients tend to understand the reliabilities of on-time arrival at the target hospital within a certain time duration by different transportation modes, and then they can make right choices considering their own situations.

To this end, two types of real data are adopted in this study, namely taxi GPS data and Metro smart card data. There are totally 15,170 taxis in Guangzhou with around 80 million GPS records per day. For representing the taxi trips with direct destination to the target hospital, we have chosen a total of 10,872 GPS trajectories of 5,699 taxis with passenger(s) to calculate their corresponding in-vehicle travel times during a total of 10 working days (6-10 and 13-17, March, 2017) for access to the Guangdong general hospital. As taxi drivers are always familiar with the local road network, we can assume that the travel time of taxi with passenger(s) is equivalent to a private car started from the same place. In addition, more than 54,000 records out of 9 million SCR data are used for evaluating the place-based accessibility coverage area of the metro system.

The fundamental method for computing on-time arrival probability and accessible area is given as follows.

Step 1, data pretreatment of raw data (i.e. FCD and SCR) of ten working days (from 6^{th} to 17^{th} March, 2017).
Step 2, computation of in-vehicle travel times for those valid taxi trips (i.e. alighting passengers at the target hospital).
Step 3, computation of travel times for those valid OD pairs (i.e. with destination to Martyrs' Park Station) by Guangzhou metro but excluding access and egress time to the metro stations.
Step 4, estimating mean value, median, and STD of valid trips taking taxi or metro, respectively.
Step 5, estimating on-time arrival probability within a given time duration of all travelers with destination to the hospital taking taxi or metro, respectively.
Step 6, evaluating the accessibility coverage area with a certain on-time arrival probability (α) within a given time duration (T_0) by three steps. Firstly, determine the set of individuals N (i.e. the departure points) with travel time less than T_0. Secondly, extend the set N into EN by slowly increasing travel time T_0 to meet the condition of $\frac{EN}{EN+N} = \alpha$. Finally, determine the accessibility coverage area by drawing the boundary of the existing set of N and EN.

3. EMPIRICAL COMPARISON OF TRAVEL BEHAVIORS BETWEEN TAXI AND METRO

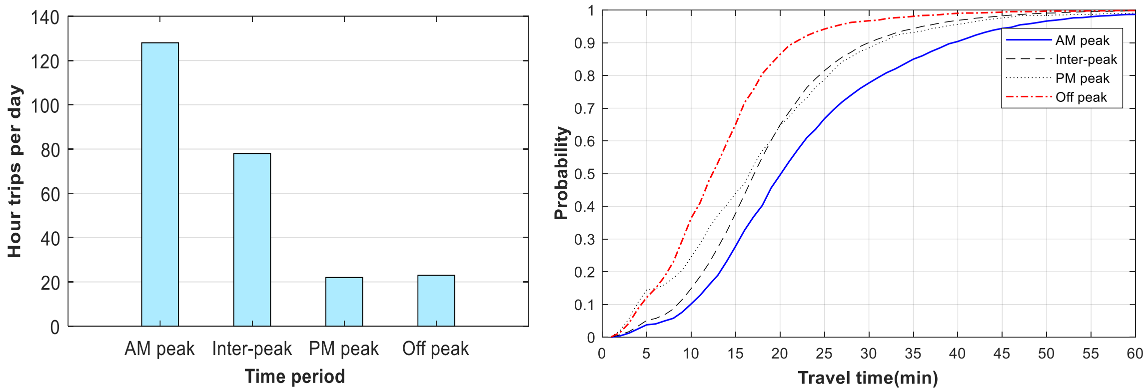

Figure 1. a) Average number of trips per hour; and b) accumulated percentile of travel time by taxi

For investigating the dynamic features of people's travel behavior, we divided one day into four time periods, namely AM peak from 7:00 to 9:00, Inter-peak from 9:00 to 17:00, PM peak from 17:00 to 19:30, and Off peak from 19:30 to 24:00. The average amounts of trips per hour are illustrated in the left graph in Figure 1, which show that more trips (i.e. 128 trips) occurred during AM peak. This statistically interprets more traffic demands by taxi during AM peak rather than PM peak although we cannot confirm these travelers by taxis are patients or not. More details of these trips can be investigated in Figure 1 b). For example, the medians of four different time periods vary from 12 to 25 minutes if we check the accumulated percentile of 0.5.

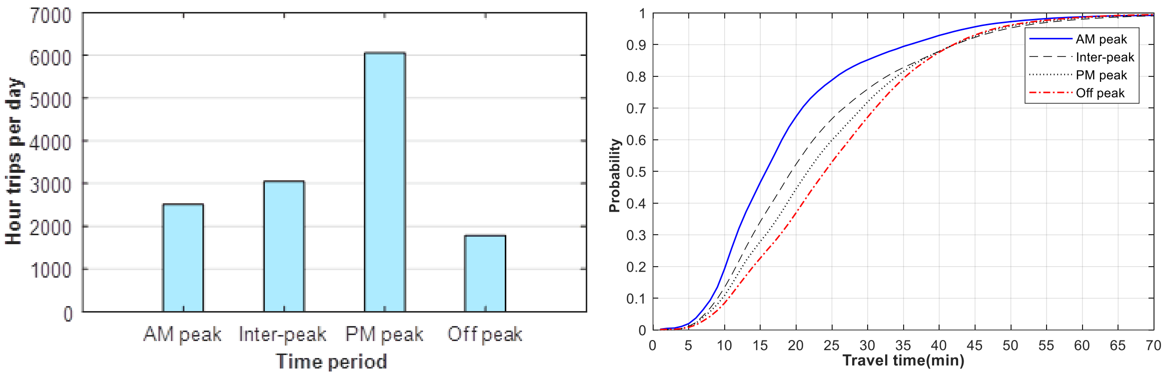

Figure 2. a) Average number of trips per hour; and b) accumulated percentile of travel time by Metro

The graphs in Figure 2 shows that more travelers taking metro at PM peak to access Guangdong General Hospital, and the four medians vary from 15 to 25 minutes. Furthermore, two graphs at the right hand of Figure 1 and Figure 2 show distinct difference of distribution of travel times between taxi (or private car) and metro.

Note that the operation of metro system is quite different from that of taxi or private car for two aspects. On the one hand, the operation lines are fixed for metro. On the other hand, there are possible transfer(s) during travelers' trips which may result in the variation and fluctuation of individual's travel time. It is interesting to examine whether transfer has negative impact on reliability of travel time or not. Some statistical parameters are computed and listed in Table 1, the results proved that metro trips with transfer spend more time to access the target hospital (see the second and third column), and the standard deviation of trips with transfer are obviously longer than those trips without transfer. Note that these results are derived from different individuals from various departure places (or referred to as their origins of travel). It will be more comparable if we compare the corresponding travel times from the specific fixed OD pairs.

Table 1. Comparison of travel time variations for trips by metro with and without transfer

Time period		Median(min)	Mean value(min)	STD(min)	Hourly person trips
Without Transfer	AM peak7:00-9:00	11.58	***13.65***	***23.22***	1,148
	Inter-peak 9:00-17:00	13.02	***14.49***	***9.77***	1,207
	PM peak 17:00-19:30	13.05	***14.66***	***7.15***	2,087
	Off peak 19:30-24:00	14.35	***15.92***	***7.31***	572
With Transfer	AM peak7:00-9:00	20.87	***25.18***	***26.68***	1,366
	Inter-peak 9:00-17:00	25.82	***28.71***	***16.92***	1,834
	PM peak 17:00-19:30	27.72	***29.19***	***13.33***	3,972
	Off peak 19:30-24:00	29.53	***30.47***	***12.02***	1,213

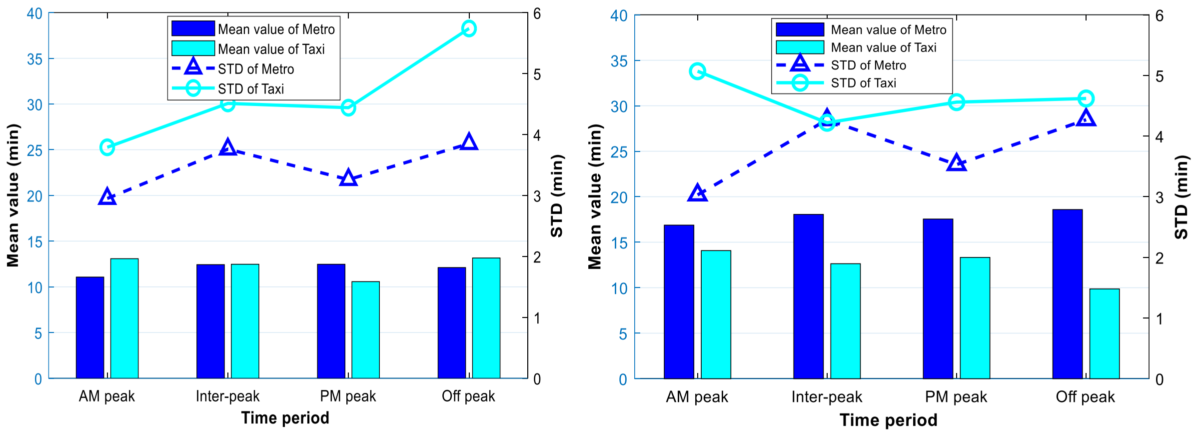

Figure 3. Travel time from a) TiyuXi Lu Station without transfer; and b) Wuyangcun Station with transfer to Guangdong General Hospital

As aforementioned, Guangdong General Hospital can be directly reached from some major metro stations (e.g. Tiyuxi Lu Station) without transfer or other stations with transfer (e.g. Wuyangcun Station on Metro Line No.5). With careful investigation on travel times of the two fixed OD pairs in the bi-modal study network, some insights on travel time reliability can be acquired on the basis of the results shown in Figure 3.

Firstly, the mean values of trips taking taxi as well as metro without transfer are less 15 minutes. This interprets the fact that people lived in Guangzhou prefer to access Guangdong General hospital within a reasonable time duration (around 15 minutes), as there are totally more than 50 top hospitals (or third-grade class-A hospitals) in Guangzhou. The result reflects that the coverage and accessibility of public hospital service in the center of Guangzhou is relatively well. Secondly, transfer in metro station contributes to longer travel time and larger STD of travel time. Finally, reliability of trips taking taxi is lower than metro despite of different departure places and time periods. These characteristics of travel behavior in the bi-modal study network will be further investigated and presented by the corresponding accessibility coverage areas in the following section.

4. COMPUTATION OF ACCESSIBILITY COVERAGE AREAS BY MODE AND BY ON-TIME ARRIVAL PROBABILITY

The median of taxi travel time is obtained as 17.53 minutes if we calculated all travel times in whole day from 6:00 to 24:00 (totally ten days). We take 17 minutes as the standard time duration to evaluate the accessible area with a certain on-time arrival probability. Figure 4 shows a static accessible area for three on-time arrival probabilities. It seems quite clear that lower probability contributes to larger accessible area in our study. Note that this conclusion may vary with different network topologies or specific situations, as we simply use the average reachable opportunities of individuals in this study. It is well known that closer distance may not definitely result in shorter travel time, it is also easy to understand that relative lower probability may not result in larger area.

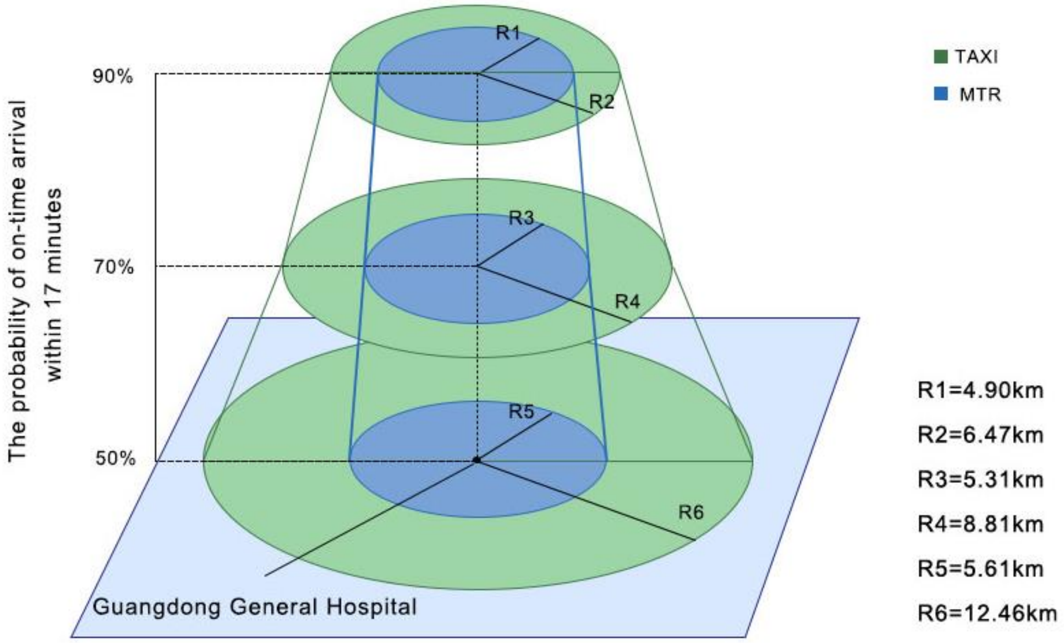

Figure 4. Accessibility coverage area to hospital within 17 minutes for different on-time arrival probabilities

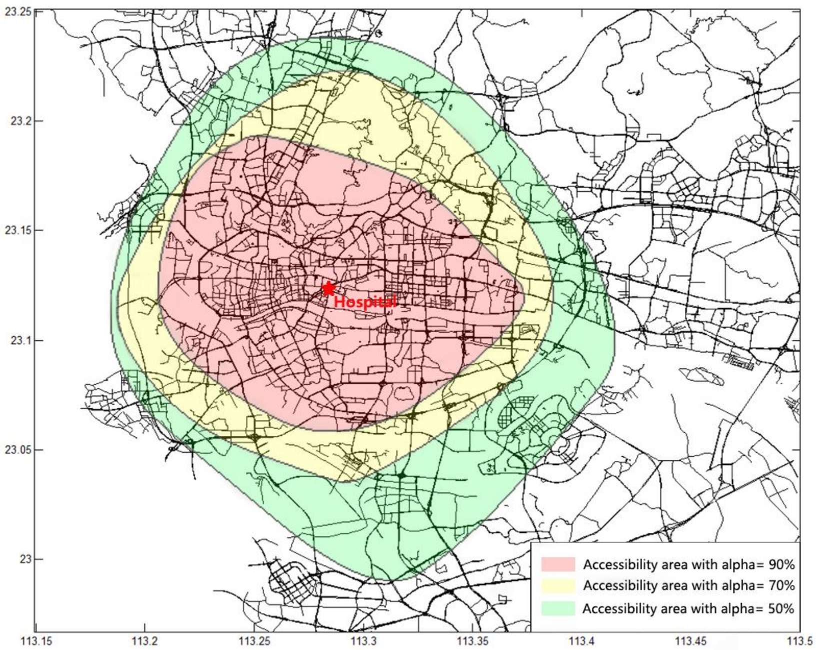

Figure 5. Accessibility coverage areas at certain on-time arrival reliabilities by taxi

Although Figure 4 shows some conception of accessibility in multimodal transportation network, the boundary of accessibility coverage area is not realistic. Figure 5 presents the estimated irregular contour, which is fitted by the set of farthest points of valid departure, which can reach hospital within 17 minutes with the given on-time arrival probability. This graph illustrates the uneven extension of reachable area with decreasing on-time arrival probability. With the understanding of this figure, the potential patient located out of these area may change his target hospital if he want to access a hospital for emergency service within 15 minutes with high reliability (i.e. 95% on-time arrival probability). Considering the travel time uncertainties in different time periods, we can draw the corresponding placed-based accessibility coverage areas in Figure 6 by mode and on-time arrival probability. Person trips by metro show more stable accessibility coverage areas, but more complex results are appeared for trips made by the mode of taxi. The accessibilities of these two modes at AM peak or even PM peak are very close each other despite taxi trips with more expensive fares. This is meaningful for those potential patients to understand the effects of travel time uncertainties on on-time arrival probability and then make their travel choices for access to the targeted hospital from viewpoint of their own preferences and demands.

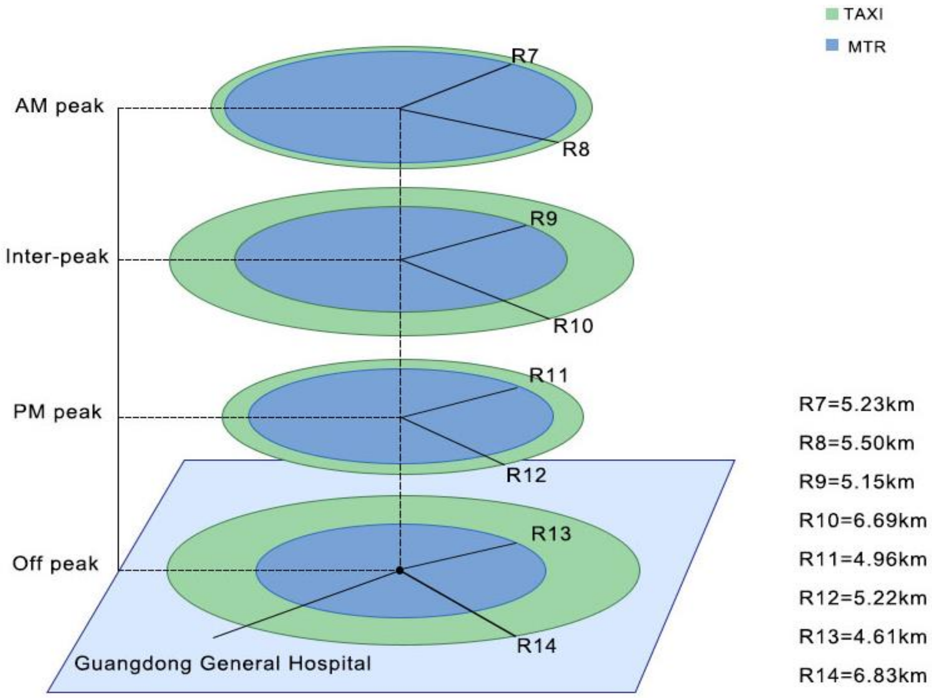

Figure 6. Dynamic accessibility coverage areas within 17 minutes at 90% on-time arrival reliability

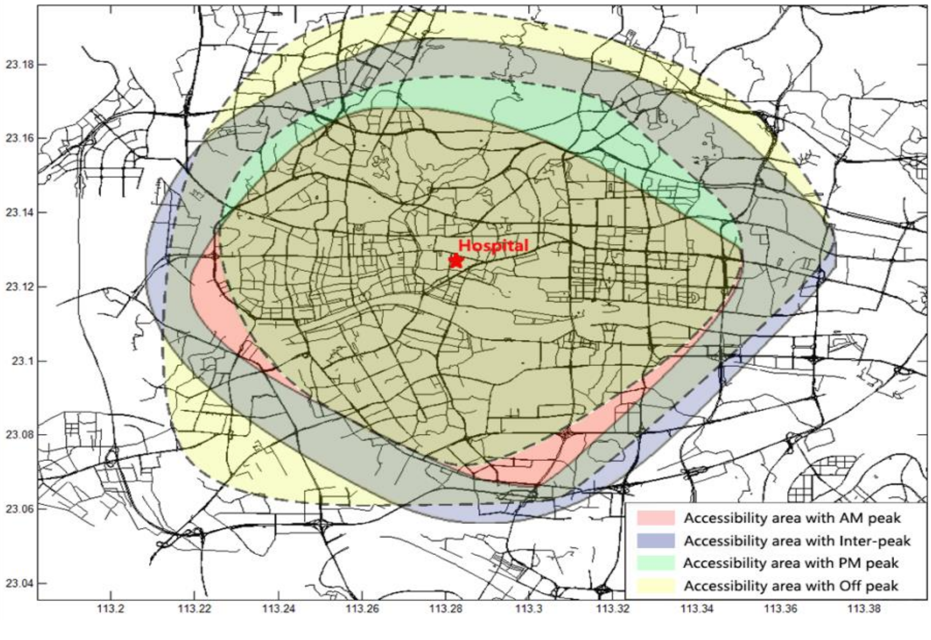

Figure 7. Accessibility coverage areas for 90% on-time arrival probability within 17 minutes by taxi

Figure 7 illustrates the accessibility coverage areas by taxi with taking account travel time uncertainty. Generally speaking, the accessibility coverage areas at two peaks are smaller than those within other time periods, which also reflects real dynamic traffic states in Guangzhou. Most interesting thing is the overlap between different accessibility contours, which is strongly related with the features of the traffic system. The reasons are two folds: one is due to the uneven distributed road network and the other is due to the heterogeneous traffic flows among dispersed links. As compared to the accessibility coverage areas shown in Figure 6, these irregular contours are more realistic and useful for both travelers and patients. That is to say, both the network topology and traffic flow dynamics are integrated in this placed-based accessibility analysis by mode and on-time arrival probability for different time periods of the day.

5. CONCLUSIONS

The level of public service can be evaluated by the coverage of alternative public service resources, which is a static indicator without consideration of individual demands and traffic conditions by time of day. More important indicator is the dynamic place-based accessibility by mode. In this paper, a data-driven dynamic accessibility method is proposed to examine the effects of travel time uncertainty on accessibility to public hospital service with consideration of multi-modal transportation network topology and on-time arrival probability by time of day. With the use of the FCD of taxi and SCR from Metro in Guangzhou, China for ten working days, the variation of travel times by taxi and metro for access to the Guangzhou general hospital are analyzed for different time periods. The results reveal the dynamic impacts of travel time uncertainty on accessibility coverage area by mode and on-time arrival probability over time of day.

However, the proposed method can be further improved on three aspects. Firstly, the analysis of travel behaviors at individual level is to be aggregated into residential zone level, which can alleviate the burden on data collection and provide more practical information service for residents. Secondly, the accessibility contours can be replaced by three dimension figures to represent the real heterogeneity of travel times (i.e. traffic flows) on various road links. Thirdly, the preferences of different groups of travelers on departure time, mode choice, service demand should be considered.

6. ACKNOWLEDGMENTS

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