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How Do Taxis Work in Beijing?

An Exploratory Study of Spatio-Temporal Taxi Travel Pattern Using GPS Data

A thesis submitted in partial satisfaction
of the requirements for the degree
Master of Urban and Regional Planning

By

Yifan Zhang

2014

ABSTRACT OF THE THESIS

How Do Taxis Work in Beijing?
An Exploratory Study of Spatio-Temporal Taxi Travel Pattern Using GPS Data

by

Yifan Zhang

Master of Urban and Regional Planning
University of California, Los Angeles, 2014
Professor Rui Wang, Chair

Taxis play an important role in urban transportation by fulfilling people's demand for auto services without turning them into auto owners. In this thesis, I use Geographic Positioning System (GPS) data generated by 12,000 taxis in November, 2012 to analyze the spatio-temporal travel pattern of taxis in Beijing. ArcGIS and python programming are employed for data processing and computing. The result of the passenger pick-up and drop-off analysis on November 30th, 2012 confirms the geographical imbalance phenomenon mentioned in previous studies. The thesis also examines taxi driver's behavior by income and finds that drivers of higher daily incomes operate in larger territories. Additionally, time and monetary costs of the same trips made in transit mode and taxi mode are compared using travel time estimated by Google Maps. In extremely smooth traffic, when people consider their time worth more than an average

of 30 Yuan an hour, they are likely to use taxis instead of transit.

The thesis of Yifan Zhang is approved.

Leobardo Estrada
Martin Wachs
Rui Wang, Committee Chair

University of California, Los Angeles
2014

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Introduction

For many cities, taxis played an important role in urban transportation. They fulfill people's demand for auto services without turning them into auto owners. In Beijing, there are about 66,000 taxis, five times the number of taxis in New York City, which has 13,237 taxicabs. In 2011, 7% of urban trips in Beijing were made in taxis.

The booming auto ownership in Beijing, which happened in the past decade, forced the government to implement quantity control policies, such as a lottery system for license allocation adopted in 2011. On the other hand, the number of taxis has remained unchanged for years while the demand is rising. Scholars have argued that the quantity of taxis should be controlled because the empty cruise mileage they generate contribute to congestion and air pollution. Meanwhile, people in Beijing are complaining about how hard it is to get a cab. In peripheral areas where legal cabs do not serve adequately, illegal taxis have dominated the market.

Previous researches mainly discussed the taxi market and regulations in China, or used travel demand model analysis to estimate the needs for taxis. Few studies systematicallyfocused on the taxi service in specific cities using GPS or travel survey data. This thesis seeks to fill this gap using taxi GPS data for exploratory analysis of taxi use in Beijing, which can be used to establish a baseline for future studies.

1. Taxi as an Urban Transportation Service

1.1 Defining Taxi

The term "Taxi" most commonly stands for vehicles for hire, available for engagement on the street. For those available by pre-booking only or available from a depot, the terms used to include FHV (for hire vehicle), livery vehicle, car service, and black car. Taxi buses(US term: shuttle) and limousines are also considered taxis (Cooper, Mundy, &Nelson, 2010).

On-demand taxi service, or hailing cabs, is considered the traditional "taxi" service and mostly exists in dense urban areas. Because of urban sprawl in the United States, in most cities the taxi markets are now dominated by pre-arranged taxi service. Hailed taxis only exist at a taxi stand, or an airport (Kaing, 2012).

Time saving seems to be the primary reason for people to take taxis. Darbera (2010) surveyed taxi riders across seven European capital cities and found the most frequently cited reason of taking a cab to be time saving. Time saving is also the top reason in a survey conducted by a Chinese website; 66% of respondents claimed that they took taxis for time saving, compared with comfort, privacy and other considerations. Convenience and comfort are important reasons as well. Other reasons included parking in dense urban areas, which could be expensive and hard to find. Generally, taxis provide the utility of automobile without having to be the owner of a car. For tourism industry, taxi is also an important element.

Taxis are usually considered a complementary part of urban transportation. The industry itself, however, tends to be much more intricate in many cases.

Do planners have prejudices about taxis? Kaing (2012) surveyed 133 transportation planners and concluded that planners view the taxi industry as neither friend nor foe. According to survey results, planners considered taxis as primarily serving the wealthy and exacerbating congestion and air pollution problems. However, they are at least open to accepting taxis as an important mode of transportation in what are increasingly sprawling, medium to low-density metropolitan areas.

Some scholars have argued that the value of taxis in urban transportation has been underestimated. Transportation modes other than the car can serve most mobility needs, but a lack of integration between these modes leaves a mobility gap that often can only be bridged through car ownership (Huwer, 2004). Active integration of taxis with conventional fixed-route transit operated more efficiently, effectively, and attracted more riders (Kaing, 2012).

1.2 Type of Taxi firms

Most taxi services are organized in firms rather than operated by individuals. However, exceptions exist, for instance, in Taipei. Classic economic regulatory theories have assumed that the behavior of firms would be that of a long-term interest in the consumer. All individuals, including the employees providing the services, are concerned about how the customer views the services so that these customers come back themselves as well as tell others about their positive experiences. Only the providers with good reputation would survive in the market.

> Individual drivers may treat each customer as a onetime patron, one he or she will never see again, so the temptation is always there to take a circuitous route, charge extra for bags, refuse short trips or credit cards, and even to overcharge if their income for that day is lagging. This is especially true for airport taxi drivers who acknowledge a visitor to the area is less likely to know the local geography and even less likely to return to the area, even if they make a formal complaint about overcharging. (Cooper et al., 2010, p.23)

Taxis have operated in four categories historically: total taxi firm, taxi firm/vehicle lessor, authority and call center lessor, and single permit owner/operator.

In a traditional taxi firm, all capital assets and rights belong to the firm. The company employs drivers to provide taxi service, which is a costly option. Such firms only exist in a few major American cities (e.g. Las Vegas and Reno) today. (Cooper et al., 2010)

As a result, early taxi firms evolve to a new form in which the taxi firm leases its vehicles. Taxifirm/vehicle lessor refers to a form in which the company retains service and bears most costs and leases vehicles to independent contract drivers. Taxi firms retain all the service and obligations of a traditional taxi firm, such as insurance, vehicle ownership, computer dispatching, etc., but elects to lease its fleet vehicles to independent contractor drivers (Cooper et al., 2010).

Authority and call-center lessors lease permits to individual drivers who use their own vehicles. This is similar to the lessor-lessee firm. However, in a lessor-lessee firm, the companies lease both vehicle and the right to operate; in authority and call-center firms, they only lease the right to operate (Cooper et al., 2010).

Single permit owner/operator refers to individual drivers who own permits and vehicles and are not supervised or dispatched by taxi firms. According to the US experience, such taxis are more likely to concentrate at city stands, hotels, and airports (unless otherwise restricted) (Cooper et al., 2010).

In Beijing, the second and third form made up the majority of taxi firms. Single permit operaters are extremely rare because of regulation. Among the 66,000 taxis in Beijing, only 1157 are single permit operaters. The government had strict restrictions on single permit numbers and stopped issuing single permits since 2004.

1.3 Regulation of Taxi Market

Regulators often used different policies for on-demand and pre-arrange taxi service. In New York City and London, for example, companies providing dispatch services are regulated under an open entry system, while a medallion system controls the number of street-hail cabs (Schaller,2007). Compared with prearranged taxi service, on-demand services are strictly regulated. Cooper et al., (2010) summarized typical regulations of the on-demand market into three categories: quantity control, quality control, and economic control.

Quantity control seems to be a controversial part of taxi regulation(Cooper et al., 2010). The total number of taxi permits or taxi firms are regulated to be fixed. In New York, for example, drivers apply for a taxi medallion license in order to operate taxis. In 1937 when the medallion system was introduced in New York City, there were 11,787 medallions issued. (Schaller & Gilbert., 1996)The number remained constant until 2004(New York Taxi Fact Book, 2014).

Quality control included vehicle safety, operator and driver fitness, comfort, appearance of taxis and drivers, insurance coverage, prohibition on refusing passengers and overcharging, etc.(Gilbert & Samuels, 1982; Dempsey, 1996; Cooper et al., 2010).It is the least controversial area of taxi regulation(Cooper et al., 2010).

Economic controls are typically aimed at preventing overcharging. Taxis in most cities have meters, which calculate the fare based on unified fare structure. Without such regulation, unscrupulous drivers might overcharge for their service like many bandit taxi drivers did, especially taking advantage of tourists who are not familiar with the city.

Why should government regulate taxis? First, the safety of public taxi passengers should be ensured. Additionally, absence of regulation might result in a lower level of service to the consumer. Rates are balanced to protect the user from onerous or arbitrary fares but to still yield the provider sufficient funds to continue in business and make a modest profit. Public image is another important reason for regulating taxi services. Since taxis serve many non-residents in a city, community leaders wanted taxis to convey a positive and upscale image of a city—one of clean, modern, and progressive community values (Cooper et al., 2010).

Deregulation of the taxi market refers to the removal of quantity controls and sometimes economic controls as well. Free market theorists argued that open entry would encourage competition and lead to service innovation (Gilbert & Samuels, 1982; Shaw et al., 1983). In the 1970s, there was a general trend toward transport deregulation within North America(Cooper et al., 2010). Advocates of deregulation emphasized the consumer benefit from a competitive market, such as lower fares and shorter waiting time (Schaller, 2007).However, Dempsey(1996) argued that based on the experience of 21 US cities, the removal of entry restrictions and fare setting led to lower service quality and higher prices. Schaller(2007) also noted that open entry may lead to an influx of new drivers because of low-entry costs. He further pointed out that a central challenge of taxicab regulatory policy is to apply entry controls to walk-up markets without producing the inverse problem of lack of service availability in outlying areas .He also argued that entry policies must be carefully designed based on local conditions, and the effects of regulation depend on market characteristics.

2. Taxis in Beijing

2.1 Suburbanization, Automobiles, and Taxis

With rising income, automobiles are becoming more affordable to residents in Beijing. The astonishing automobile growth rate exacerbated congestion and forced the government to implement a quantity control policy. The city started using a lottery system for private automobile license allocation in 2011.

Figure 1. The number of registered automobiles (in 10,000's) of Beijing, Shanghai and Guangzhou
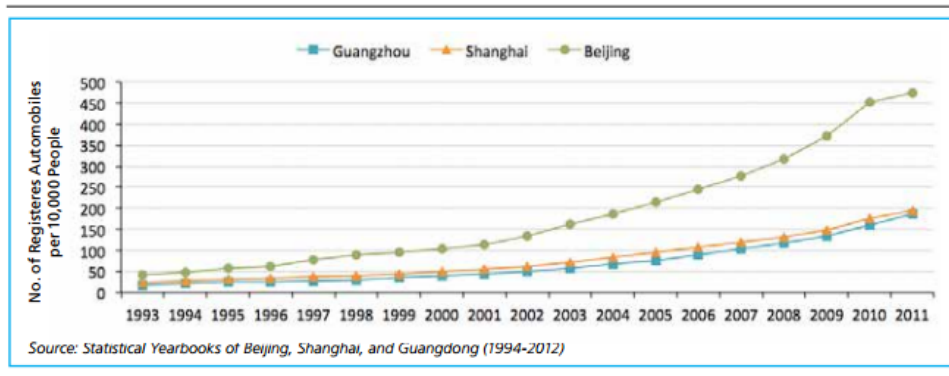
Figure 1. The number of registered automobiles
(in 10,000's of Beijing, Shanghai and Guangzhou).
Source: Statistical Yearbook of Beijing, Shanghai, ans Guangdong(1994-2012)

Moreover, Beijing is gaining reliance on automobile travel because of spatial mismatch and suburbanization. Suburbanization in Beijing started at the end of 1980s. Unlike in the United States, where people relocate to suburban areas for better living quality, people in Beijing relocate because of urban renewal process and the high housing prices in the inner city (Song, 2007). Zhang and Li (2011) used GIS to confirm that population mainly increased in areas 20 to 45 kms away from the inner core of Beijing in the past decade.

Although residential areas spread to suburban areas, jobs are still located in the inner city. As a result, Beijing has an average commuting time of 43.6 minutes (Meng et al., 2011), the longest among all the major cities in China, and much higher than the average commuting time in US cities (Cervero and Day, 2008). People living in suburban areas have longer commuting times than other city averages (Chai et al., 2009). Chen and Meng (2011) surveyed two large communities in the suburban area of Beijing and found the average commuting time to be 54 minutes. The relatively slow progress of public transportation construction in the suburban areas further spurred the need for automobiles. Those who don't own private cars, if not willing to travel on crowded and slow transit, usually depend on taxis, or even illegal taxis, for travel.

Figure 2. Average commuting time (left) and distance (right) for each TAZ in Beijing.
Sample: 221,773 cardholders identified with commuting trips in Beijing
Source: Long Y. (2012)

For the taxi market, especially a market dominated by hailing, information asymmetry often made demand and supply uneven in time and space dimensions. Empty cruise rates might be an index for measuring the inequity of demand and supply. However, empty cruise could also be socially desirable, as it increases the value of the service through lower waiting time (Flores-Guri, 2003). Korean scholars devel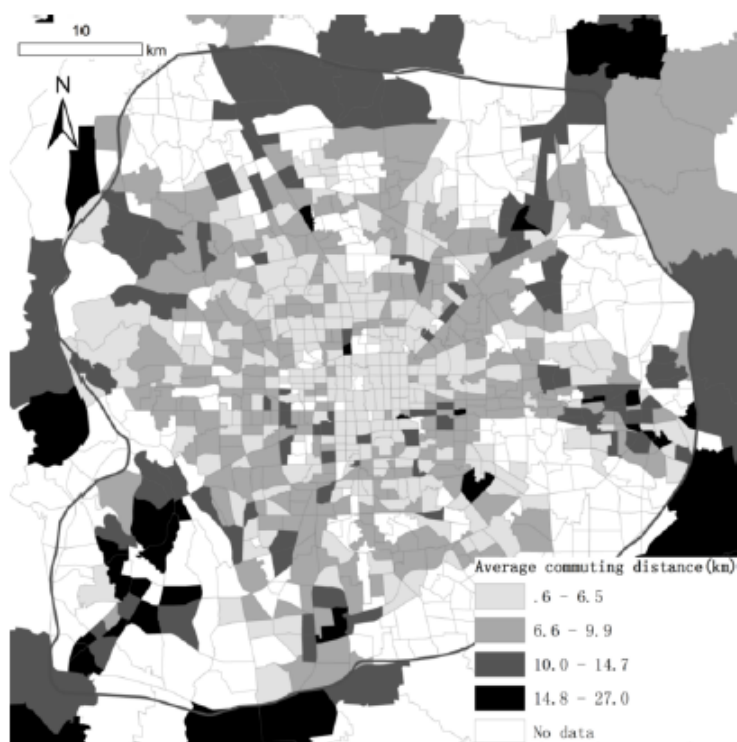oped an agent-based model for asymmetrical demand for taxi service in Seoul, and other researchers developed a predictive model for taxi availability in Portugal (King, Peters, & Daus, 2011). King et al. (2011) also confirmed the asymmetrical nature for taxi trips in New York City by analyzing 200,000 GPS point observations from New York medallion cabs. They found that taxi trip origins concentrated near Manhattan, the densest areas of subway network. Taxi trip destinations were much less clustered. Considering an origin-destination scatter map for automobiles, it would be largely symmetrical between origins and destinations. For private cars, almost all the trips are based on certain purposes. Therefore, when people arrive at different places and finally returned home, each point they arrive is the destination for the last trip and origin for the new trip. However, for taxis, only trips with customer are regarded as meaningful. Thus, only origins and destinations with customer are taken into account here. The one-way travel of taxis allows people to use transit, share rides, and otherwise travel without a car.

In 2011, taxis accounted for about 7% of total travel demand in Beijing, compared with 33% of private cars, 28.2% of buses, 13.8% of rail transit and 15.1% of bicycles. The number of people traveling by rail transit increased greatly in the past five years. However, the current rail network did not perfectly cover the whole city. Moreover, first and last mile problems existed. The first and last mile problem refers to the extra time and hassle commuters face when they're going from home to a transit station and then from the station at the other end of the trip to a final destination. Traveling by automobile is , and always will be a crucial part of the city's transportation system.
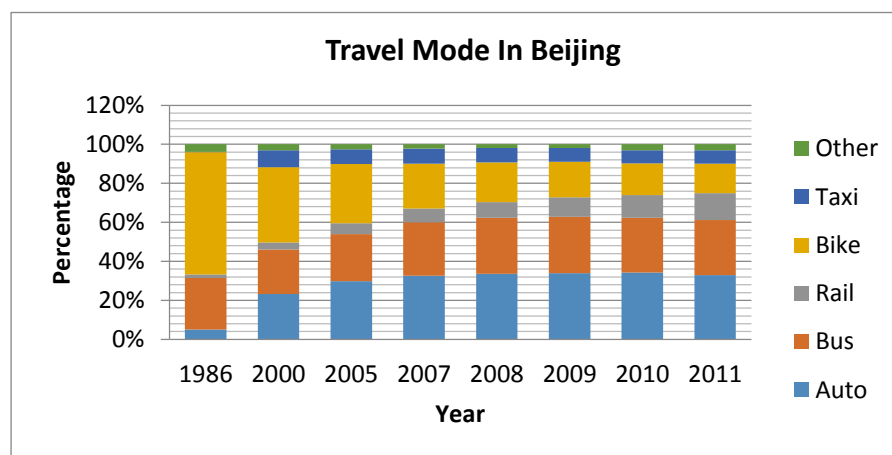

Figure 3. Travel mode change in Beijing.
Source: Beijing Transportation Research Center

2.2 Illegal Taxis

Illegal cabs, or bandit taxis, are not specific to China. Blasi and Leavitt (2006) defined four forms of "bandit" cabs: (1) taxicabs authorized by the city to operate in certain zones but that operate outside their licensed zones; (2) taxicabs legally permitted to operate in other jurisdictions (e.g., Santa Monica) that pick-up passengers in Los Angeles without a permit; (3) taxicabs that lack permits to operate from any jurisdiction but that appear to unsophisticated passengers to be legitimate taxicabs, bearing trade dress and insignia that mimic licensed taxicabs; and (4) individuals driving private cars that do not mimic taxicabs but who transport passengers for hire.
In Beijing, the latter two counted for the majority of bandit taxis.

Bandit taxis could easily be recognized by appearance. Licensed taxis in Beijing must be painted in typical color such as blue and yellow, have a light on the top and a meter inside, and provide formal receipts to passengers. Most bandit taxis are in the form of vans or other unpainted vehicles. Bandit taxis operated in two typical forms in Beijing. The first type of illegal cabs provided community service prearranged by phone. In low density areas, the bandit taxis operated as a group of 40 to 60 and were dispatched by a calling center. Once called, they normally arrived in 5 or 10 minutes. Another form of bandit taxis usually waited for customers in high-demand areas and traffic hubs (e.g., Xidan, CBD, rail station).
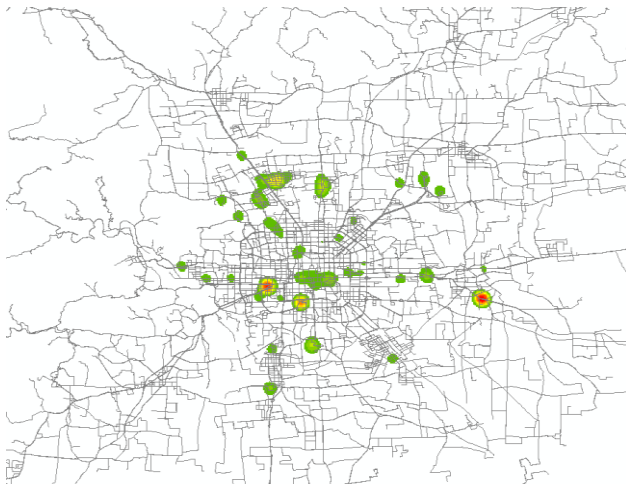
Figure 4. Complain map about bandit taxis.
Extracted from SNS website Weibo.com by author.

Above is a density map of people's complaints about unlawful taxis in Beijing. From June 2012 to June 2013, people tweeted 192 geo-tagged information about illegal taxis on the social network Weibo.com. The territory of illegal taxis is not fully covered by complaints. However, the map provides a rough image of where illegal taxis clustered and indicates demand for legal taxis or other travel modes in those areas. According to the map above, evidently illegal taxis mainly clustered in following areas:

1. Large residential community (or satellite town) in the suburban area of Beijing, e.g.,

Huilongguan Community, Tiantongyuan Community, Tongzhou Community, Wangjing Community

2. Job dense areas in the suburban area of the city, e.g., Shangdi Information Industry Base, Yizhuang Industrial Park

3. Transportation hubs, e.g., CBD area, Tian'an men, Zhongguancun

4. Suburban end of urban rail. e.g., Huangcun Station, Tuqiao Station, Shahe Station, Pingguo Yuan Station, Liang Xiang Station

Since the government stopped issuing new taxi operation permits in Beijing for many years, the bandit taxis cannot become legal taxis. However, in low-density communities in peripheral areas of Beijing, people even prefer bandit taxis to legal cabs, not only because they could be reached easily by phone appointment while lawful taxis are usually unavailable in certain areas but also because of the cheap prices they offer compared with legal taxis.

Table 1. Cost and Benefit Analysis of Bandit Taxi and legal taxi

	Taxi (Lease)	Bandit Taxi (Self-Own)
Fixed Cost	Monthly Contract Fee: 6000 Yuan/Month	Vehicle: Membership fee: 350 Yuan/Month
Variable Cost	Fuel: 6000 Yuan Average	Fuel: 6000 Yuan Average
Revenue	Price: First 3 km, 13 Yuan (2013) 1.3 Yuan per km thereafter, plus 1 Yuan per ride for fuel subsidy	Up to 4km 8 Yuan beyond 4km 16 Yuan inside the area, (normally less than 15 km)
3 Km trip Price	14 Yuan	8 Yuan
10 Km trip Price	30 Yuan	16 Yuan

Source: Chinese Newspaper and Website

2.3 Taxi Regulation

Quantity and economic control permeated the history of taxis in Beijing. Modern taxis in Beijing emerged at the end of 1980s in the unified form of a low-cost van. The 7-seat vans were painted yellow and charged one Yuan per km. The government regulates both price and entry for taxis at that time. Normally, the driver waited until the vehicle was full before it started. Today, drivers are not allowed to take additional customer without the permission of the first passenger. However, in some conditions, drivers would try to persuade the initial passenger to give the second passenger a ride.

Figure 5. Earliest taxis in Beijing.   Figure 6. Taxis in Beijing today.

From 1992 to 1994, entry restriction into the taxi market was relaxed for a while. The government encouraged new taxi firms to enter the market by providing low-interest loans. As a result, the number of taxis in Beijing increased from 16,200 to 49,000. More than 800 new taxi firms were established during these years.

In 1994, the Beijing government re-regulated the market by stopping the issuing of new operating permits to taxi firms since the number of taxis has far outstripped their expectation. Besides, the first-generation vans were replaced by better models because of their discomfort and relatively low speed. Because of the quantity control, the value of taxi operating permits surged. The qualifications of taxi firms at that time were quite uneven. Concerning that transaction of operating permits might lead to market turmoil, the government issued No.129 Ordinance, reaffirming that taxi firms only had use rights of taxi operating permits, and the permits could not be sold. Additionally, the contract rent was raised from 1000 Yuan (160 US dollars) per month to four standards of 3000, 4000, 4500, and 6000 per month, based on different vehicle types and company qualifications at that time. To drivers, the cost of operating taxis has risen significantly ever since. Since 2006, the contract rent baseline was unified as 5175 Yuan for one-shift taxi and 8280 yuan for two-shift taxi. The company could adjust the contract rent in the range of 15 percent.

In 2000, the Beijing government started reshaping the taxi market by annexing existing taxi firms to larger firms and controlling the total number of taxis to 60,000. The numbers of taxi firms were regulated at around 200. Xiali and Jetta are two major type of taxi vehicles and charged different rates at that time. The rate of Xiali is 1.2 Yuan/km and the price of Jetta is 1.6 Yuan/km.

Since 2006, the price of taxis has been regulated at 10 Yuan for the first 3 km and 2 Yuan per km thereafter. The total numbers of legal taxis were restrained to 66,000 and kept unchanged for years because of quantity control. However, the number of "bandit taxis" are as many as or even more than the total number of legal taxis in Beijing.

Starting from June 2013, the rate of taxis in Beijing was increased to 13 Yuan for the first 3 km and 2.3 Yuan per km after that. For distances beyond 15 km, 50% empty cruise fee per km is applicable. The new price regulation aimed at "increasing the revenue for drivers, reducing unnecessary taxi demands, as well as switching people from taxis to transit"(Chinanews.com, 2013).

3. Data

3.1 Taxi GPS Data-Related Research

The global positioning system (GPS) installed in taxicabs made it possible to obtain records for the real-time status of taxis, including speed, position, etc. Such devices were originally used for taxi dispatch systems. Scholars, however, found new research topics using GPS data. Hoque et al. (2012) analyzed taxi mobility patterns using taxi traces obtained from San Francisco Yellow cabs and concluded that half of the trips took fewer than 10 minutes. Santani, Balan and Woodard (2008) used taxi GPS data to verify the efficiency of the taxi dispatch system in Singapore. Liu, Andris, and Ratti (2010) used GPS data to look at taxi driver's behavior in Shenzhen, China. They analyzed the fare-finding strategy of "top drivers" and "ordinary drivers" in terms of income using GPS data. Spatial-temporal results showed that "top drivers" tended to choose similar routes that were not so congested in different periods, while ordinary drivers tended to cruise around CBD areas. Liu and Ban (2012) explored spatio-temporal clusters using taxi GPS data in Wuhan, China, and recognized the congested areas. Yuan et al. (2012) developed an algorithm recommending where a taxi driver should go to find the next customer. Liu, Gao, Xiao and Tian (2012) used GPS data for Shanghai for an intra-urban human mobility study and found that the distribution of taxi trips was not uniform in all directions. The pattern showed a predominance of trips in one direction. Powell et al. (2011) created spatio-temporal profit maps and recommended profitable areas to drivers using GPS data in Shanghai. They claimed that the spatio-temporal profit map could reduce taxi cruising time and increase profit for drivers.

Studies done by Microsoft Research Asia related taxi GPS data with land use and urban planning. Zheng, Liu, Yuan, and Xie (2011) used taxi GPS data to detect whether urban planning in Beijing alleviated or exacerbated traffic problems. They measured traffic problem in Beijing using taxi GPS data as well as extracted and mapped flawed region pairs (i.e. pairs of regions with salient traffic problems). After that they compared the   map of region pairs that had traffic problem generated by 2009 and 2010 data to see whether the urban planning carried out in 2009 increased or decreased the flawed region pairs.   After extracting human mobility patterns from taxi GPS data in Beijing, Yuan, Zheng, and Xie (2012) further identified the land use function of each region using categories of POIs(e.g., restaurants and shopping mall) and human mobility pattern(when people reach/ leave a region and where people come from and leave for).

3.2   Data Description

This study used GIS methods to depict the spatio-temporal travel pattern and spatial strategies of taxis in Beijing. A linear regression model was also used to determine the influence on profit of different kinds of trips.

The dataset contained the GPS trajectory record of 12000 taxicabs in Beijing in November 2012. The GPS points were recorded every 10-60 seconds for a month and stored in a series of text files. The size of the original file is 15 gigabytes. Due to file size and computing speed limitation of ARCGIS, only a portion of them was used for analysis. Thus, the result only partially reflected the spatio-temporal operating pattern of taxis in Beijing. In future work, data for longer periods will be incorporated to increase accuracy.

Variables of the records included:
1. ID of each taxi,
2. Trigger event (0 = customer gets off, 1=customer gets on),
3. Running status (0= empty cruise, 1=taking customer),
4. Time (year, month, day, time),
5. Location (longitude and latitude),
6. Speed, (km/h),
7. Direction (0-360 degree),
8. GPS valid or not (1=valid, 0=invalid).
* Invalid is detected by the GPS device when the signal is blocked. The invalid records are extremely rare in the data.
Additional data included:
1.   The road-network shape file of Beijing.
2.   The neighborhood shape file of Beijing.

Records generated on November 19, 2012 and November 30, 2012 (both weekdays) were used for the clustering analysis in Section 5.1. Text data was converted to shape files and analyzed in ARCGIS.

4. Methodology

4.1 Framing the analysis

Research related to taxi GPS data has gained importance in transportation. In many cities around the world, GPS data are used to explore the spatio-temporal operation pattern or driving strategy of taxis (Veloso, Phithakkitnukoon, Bento, Fonseca, & Olivier, 2011; Tong, Xiang, & Zhu, 2012; Liu et al., 2010; King et al., 2011; Zhou & Li, 2011; Hoque et al., 2012; Liu & Ban, 2012; Santani et al., 2008).
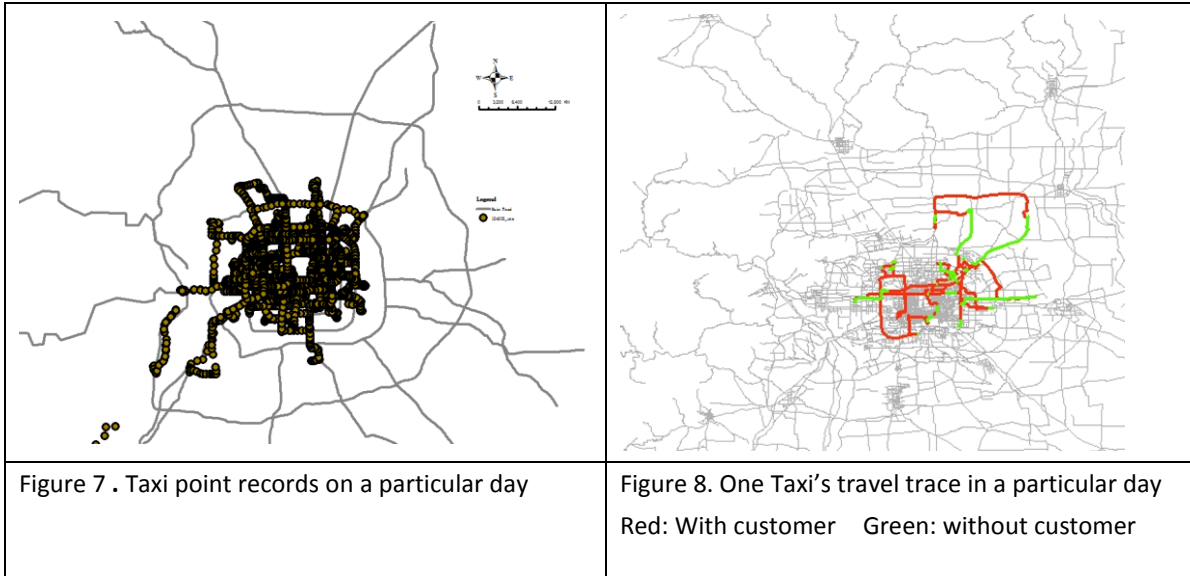
Previous research on taxis in Beijing mainly focused on regulation and monopolization of the market (Wang 2005; Guo & Mao 2007; Chen 2008). However, none of them used travel survey results or GPS data to delve the actual operation pattern of taxis. This thesis seeks to fill a gap using taxi GPS data for exploratory analysis in Beijing and establish a baseline for future studies. The analysis started with the spatio-temporal pattern of taxi service in Beijing in Section 5, followed by time and cost comparison of taxi and transit in Section 6.

Two different perspectives are included in the analysis. In Section 5, I evaluated the effectiveness of taxi operation based on taxi drivers' behavior. In Section 6, I measured the value of time from the perspective of passengers.

4.2 Methodology

For Sections 5.1 through 5.4, I extracted pick-up, drop-off, and trips with customer data on November 30, 2012, and converted them to GIS shapefiles. Point data with incorrect date, speed, or outside the boundary of Beijing were generated from GPS error and were removed from the shapefile. After the cleaning process, I used kernel density function in ARCGIS to create density maps for pick-up and drop-off locations.

For Section 5.3 through 5.7, the GPS point data were converted into actual trips (line feature) the taxis made in a day. The reason for converting point data to line data was to calculate the distance of each trip in ARCGIS, thus calculate the revenue and profit. I used a sample of 92 taxis operating on November 16, 2012 and converted them to 5637 traces using Arcpy programming. After identifying trips with customer and trips without a customer, drivers' revenues were calculated by distance per trip, following the 2012 Beijing taxi-fee standard below. Python scripts were developed for data cleaning and transforming, as well as adding fare information to attribute table. The left image below is a sample point shape file converted from the original text data. In addition, the right image demonstrated the line feature after being processed by python scripts. Due to GPS signal problems, errors existed in part of the converted traces. They were manually corrected in ARCGIS. The python script also added a field in the converted trace shapefile indicating the time of the trips. Based on the time information of the trace, fare revenue and empty cruise rate by hour were calculated accordingly.

Figure 7 . Taxi point records on a particular day	Figure 8. One Taxi's travel trace in a particular day
	Red: With customer Green: without customer

Beijing 2012 Taxi Fare

1.   The base fare of Beijing taxi in 2012 is 10 Yuan for the first 3 kms.

2.   For trips longer than 3 kms, fuel surcharge of 2 Yuan per trip is applicable.(Regulated by government in 2009 to ensure taxi driver's revenue while fuel price is rising)

3.   Mileage beyond 3 kms but shorter than 15 kms was charged at 2 Yuan per km.

4.   Mileage beyond 15 kms was charged at 3 Yuan per km.

5.   For late-night trips (23:00 to 5:00 the next day), the base fare is 11 Yuan for the first 3 kms. Beyond 3 kms, the price per km is 20% more than daytime.

Therefore, the fare-distance function can be expressed as:

Day Trip (From: 5:00-23:00)

When trip distance < or = 3km,

Fare = 10 Yuan

When 3km < trip distance < 10km,

Fare = 10 + 2 + (distance-3)*2=12+ (distance-3)*2 Yuan

When trip distance > 15 km,

Fare = 10 + 2+ 12*2+ (distance-15)*3=36+ (distance-15)*3 Yuan

Night Trip (From: 23:00-5:00 next day)

When trip distance < or = 3km,

Fare = 11 Yuan

When 3km < trip distance < 10km,

Fare = 11 + 2 + (distance-3)*2.4=13+ (distance-3)*2.4   Yuan

When trip distance>15 km,

Fare = 11 + 2 + 12*2.4 + (distance-15)*3 = 41.8 + (distance-15)*3.6 Yuan

Based on the fuel price in November 2012 and average fuel consumption for taxis provided by Sina News, I assume the average fuel cost for taxis as 0.8 Yuan per km.

Therefore, profit was calculated using the following formula:

Profit = Fare – Total mileage *(0.8 Yuan/km).

5. The Spatio-Temporal Pattern of Taxi Service in Beijing

The Spatio-Temporal Pattern of Taxi Service in BeijingAccording to Kaing (2012), in the United States, the majority of taxis today are pre-arranged by telephone, which by some estimate's accounts for 70–80% of overall demand (Darbera, 2007; Dempsey, 1996; Williams, 1980). However, in the core of New York City (i.e., Manhattan), 25% of all trips by public transit are made in a taxi, 90% of which are hailed on the street (Darbera, 2010; Schaller, 2006).

Similar to New York City, more than 90% of taxis in Beijing are hailed on a street. The telephone dispatch system was usually disfavored by users because of low success rate(e.g. no one is available to answer the phone, or no driver is willing to take the order). In San Francisco, 51% of the prearranged phones were unanswered or resulted in a no show (SFMTA, 2005).

In Beijing, hailing is still the most common method of calling a cab. People complained that the telephone-dispatch system was unreliable and waiting time was long(QianLong News, 2012).

The first question for taxis in Beijing is: Where are they operating? Alternatively, do taxis only serve dense urban environments in Beijing? Empirically in an on-demand market, taxis tended to cluster in densely populated areas for fares (Williams, 1980). Liu et al. (2012) also used GIS to confirm that the distribution of taxi pick-up and drop-off locations in Shanghai exhibited high positive correlations with population density. However, taxis are considered by regulators as "a supplementary mode serving special needs in urban transportation"(Xinhua News, 2013). Their potential for serving low-density areas in a prearranged mode might be overlooked.

For this study, I used the data generated by 12000 taxis on November 30, 2012, to examine whether this was the case in Beijing. The density of pick-up and drop-off locations are mapped by different periods. To determine their distribution of trips with customers, the density of points with 'status=1' were mapped at the neighborhood level.

5.1 The Distribution of Pick-Up and Drop-Off Points

The mapping results explicitly showed that both pick-up and drop-off locations of taxis clustered inside the fifth-ring road (the innermost ring on the map is the second-ring road), and especially inside the fourth-ring road. In morning and afternoon peak, the drop-off points were more diverse, probably accounting for some commuting trips to and from suburban areas. Late night (0–1am), densites were lower because fewer taxis are operating. According to the map, the late-night taxi market is concentrated in populated areas such as the CBD, Financial Street, Zhongguancun IT center, and the airport. An interesting finding is that drop-off points are much more dispersed than pick-up points. The asymmetry of pick-up and drop-off points, which was also verified by King et al. (2011) using New York data, might indicate that the needs for taxis in the suburban area are suppressed because an on-demand mode cannot survive. As a result, drivers returned to the inner city without a customer for another fare after a trip ending in the

suburban area.

Figure 9. Pick-up density of taxis in Beijing. Nov.30 2012   7:00-9:00 am
              Count per sq. / km.

Figure 10. Drop-off density of taxis in Beijing. Nov.30 2012   7:00-9:00 am
Count per sq. / km.

Figure 11. Pick-up density of taxis in Beijing. Nov.30 2012   10:00am-12:00 pm
Count per sq. / km.
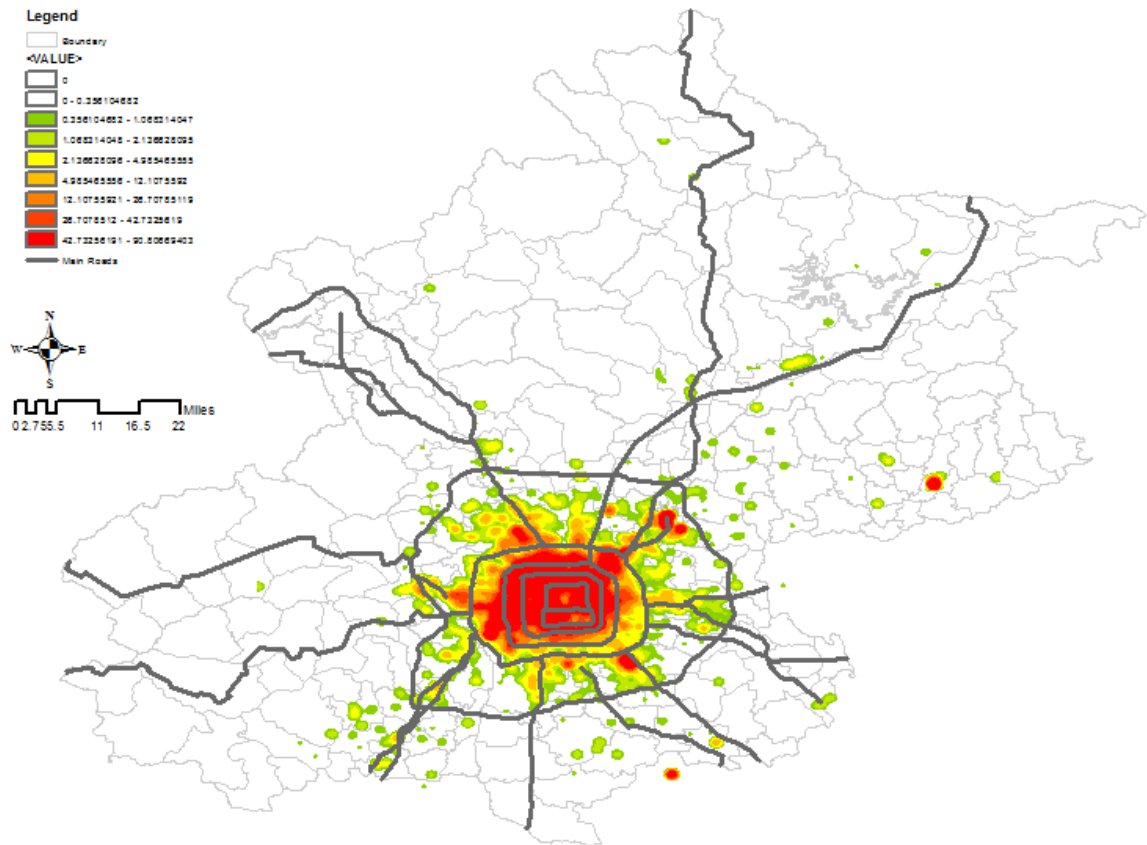
Figure 12. Drop-off density of taxis in Beijing. Nov.30 2012   10:00am -12:00 pm
Count per sq. / km.
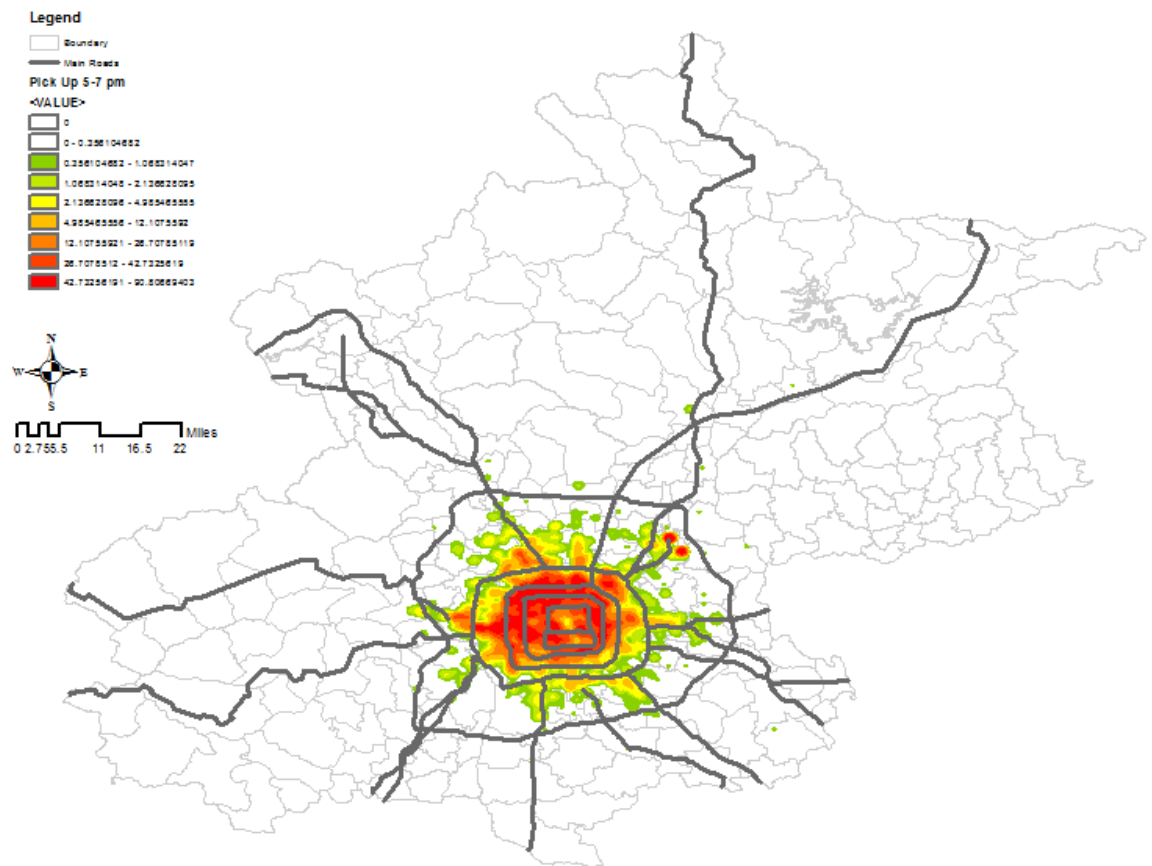
Figure 13. Pick-up density of taxis in Beijing. Nov.30 2012   5:00-7:00 pm
Count per sq. / km.
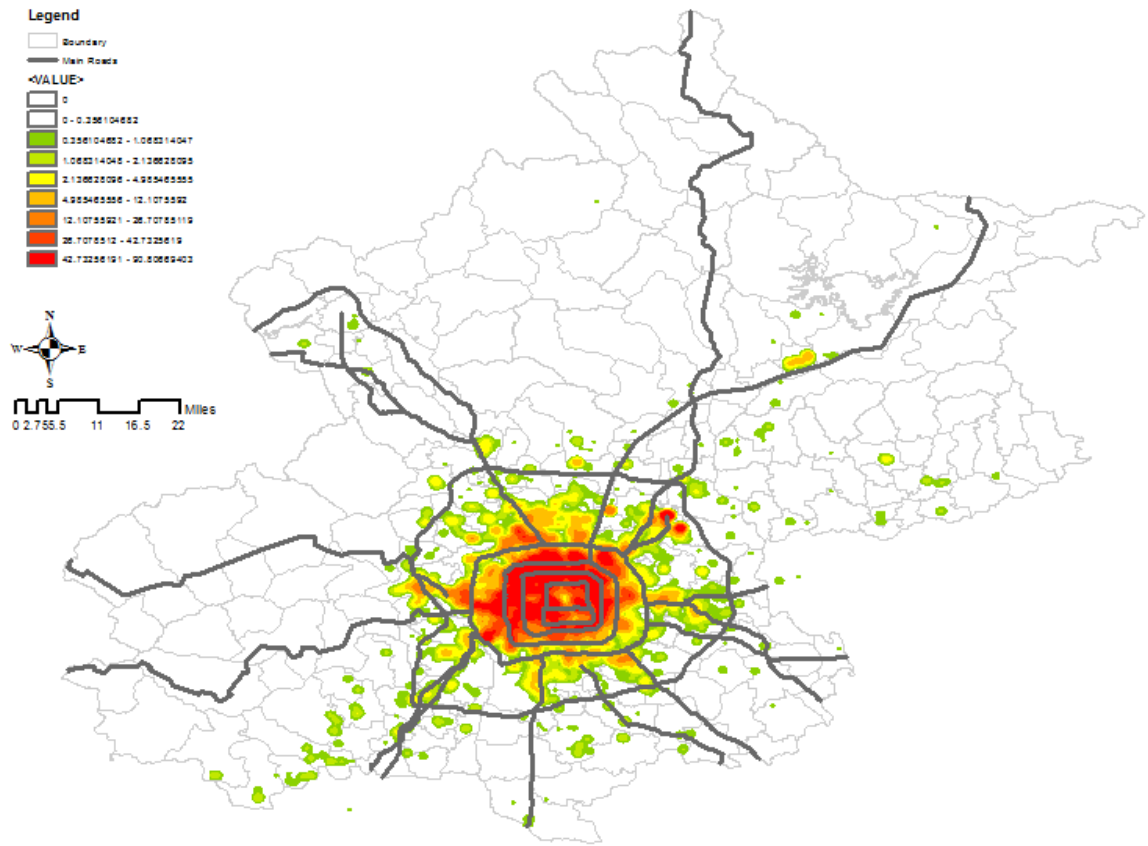
Figure 14. Drop-off density of taxis in Beijing. Nov.30 2012   5:00-7:00 pm
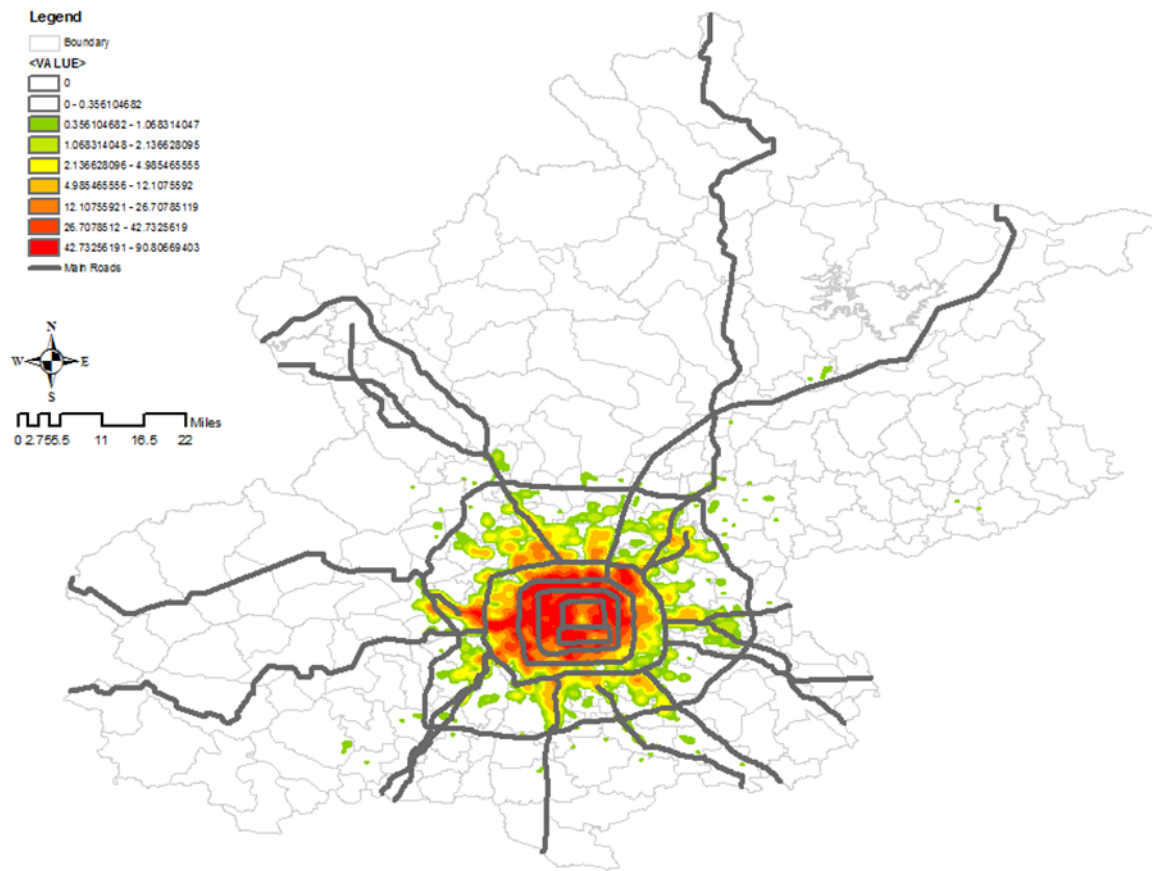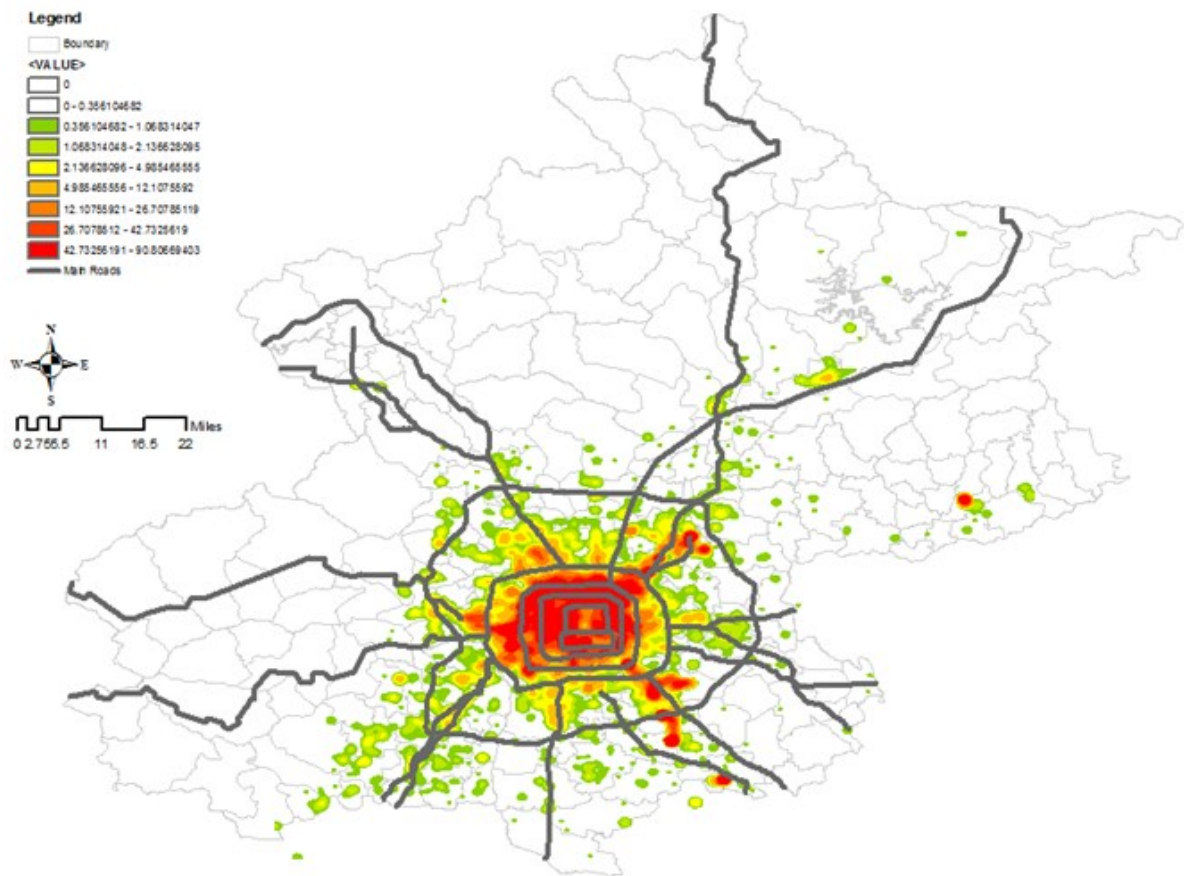Count per sq. / km.
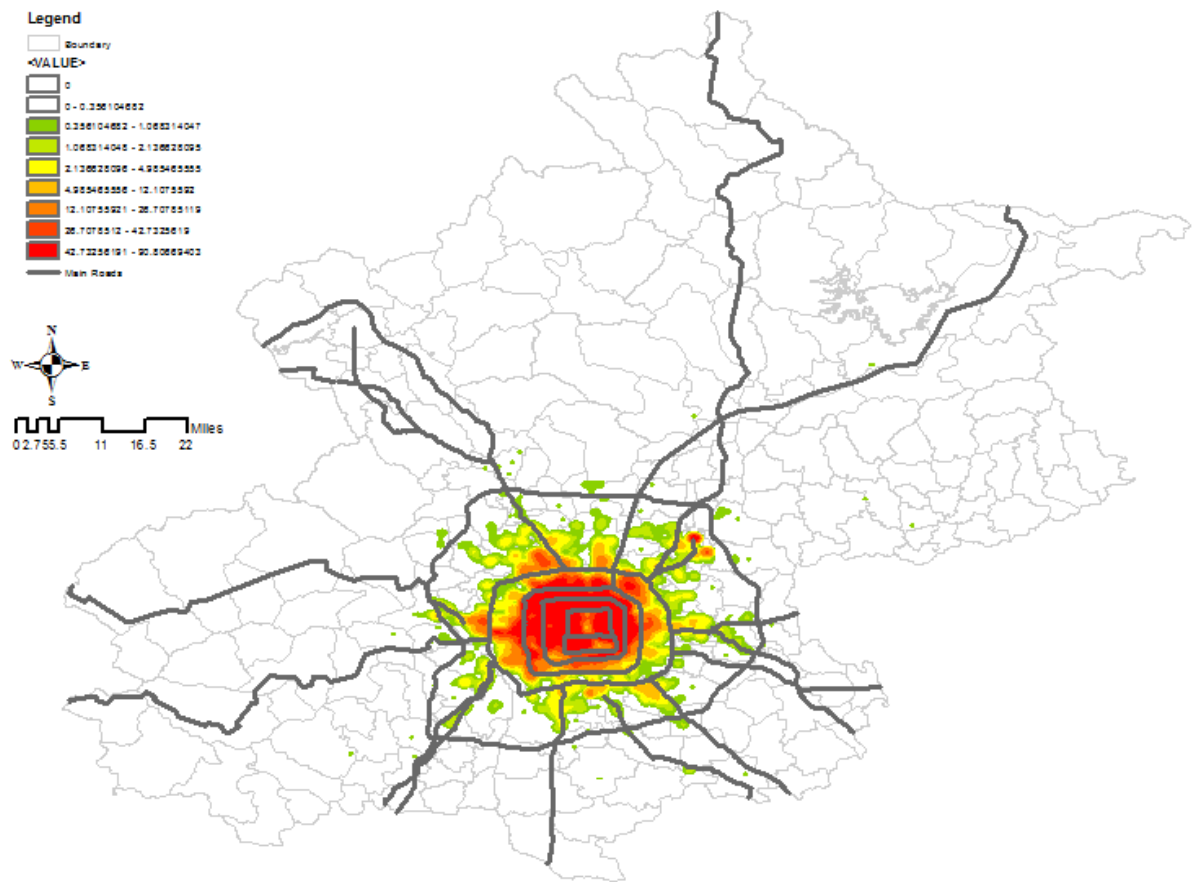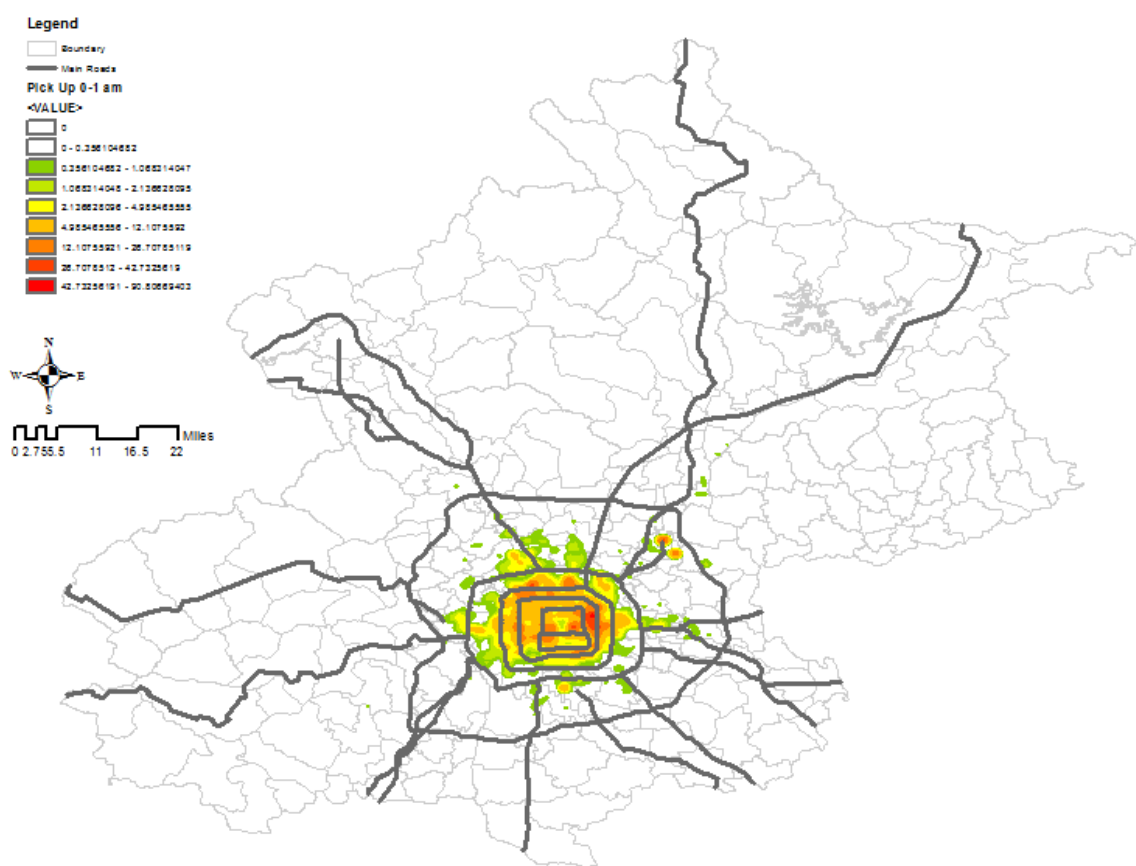
Figure 15. Pick-up density of taxis in Beijing. Nov.30 2012   0:00-1:00 am
Count per sq. / km.
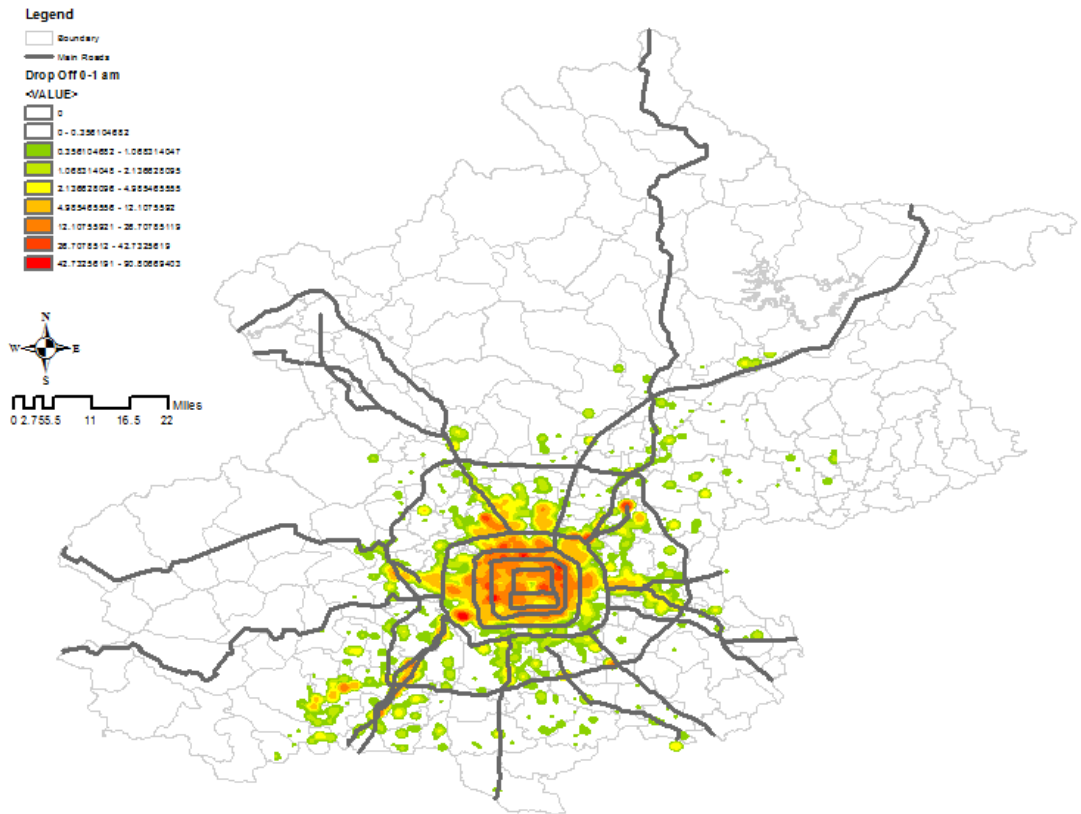
Figure 16. Drop-off density of taxis in Beijing. Nov.30 2012   0-1 am

Count per sq. / km.

5.2 Distribution of Trips with Customer

Pick-up and drop-off points are the origins and destinations of taxi trips. Therefore, I mapped these taxi trip points by neighborhood. The density map of trips when taxis are carrying customers illustrated the areas that were most often visited by taxis passengers. Trips with customers almost barely exist outside the range of the sixth ring. By different periods, the area between the second and third ring road are always prone to taxi trips. In morning peak hours, the west side of the city had a higher trip density. In late night, the east side (mainly CBD area) were the most bustling areas.
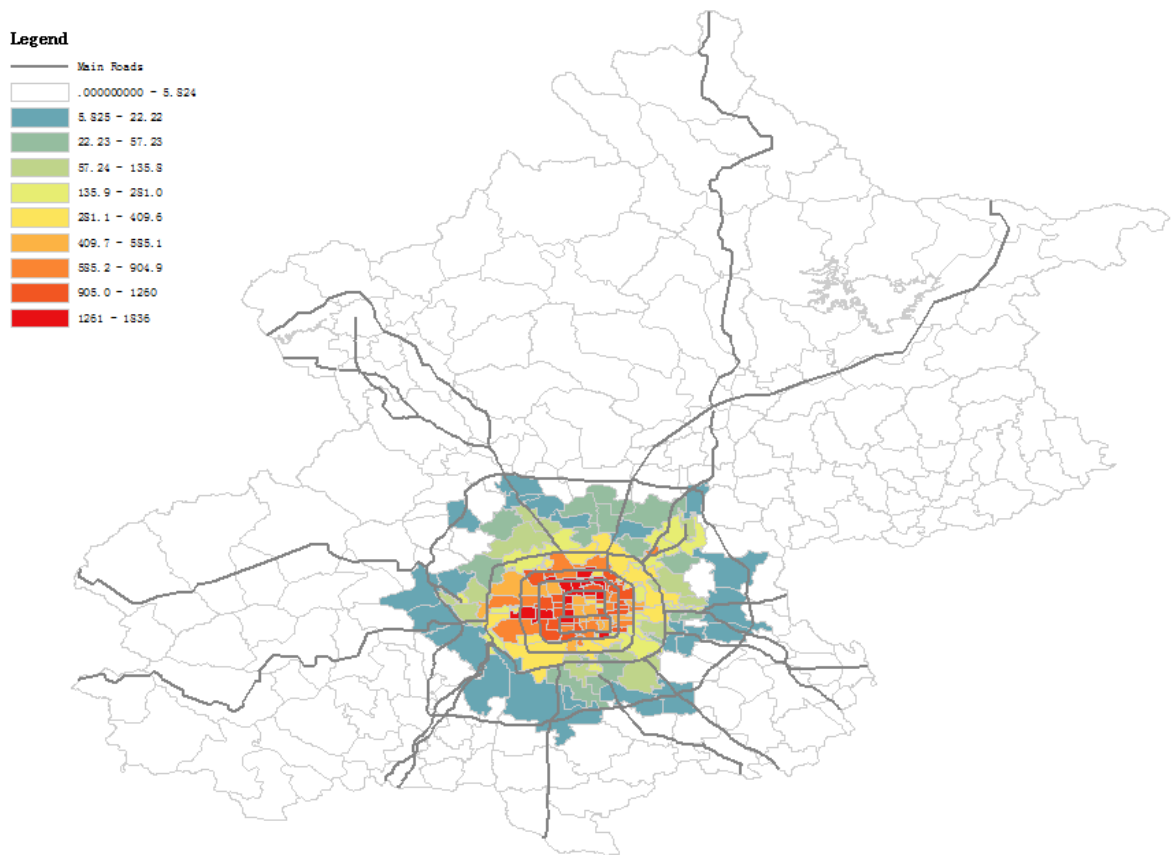
Figure 17. Density of taxi operating with customers   Nov.19 2012   7:30-8:30 am

(Point number with customer per sq. /km.   )

Legend

— Main Roads

	.000000000 - 5.824
■	5.825 - 22.22
■	22.23 - 57.23
■	57.24 - 135.9
■	135.9 - 281.0
■	281.1 - 409.6
■	409.7 - 585.1
■	585.2 - 904.9
■	905.0 - 1260
■	1261 - 2750
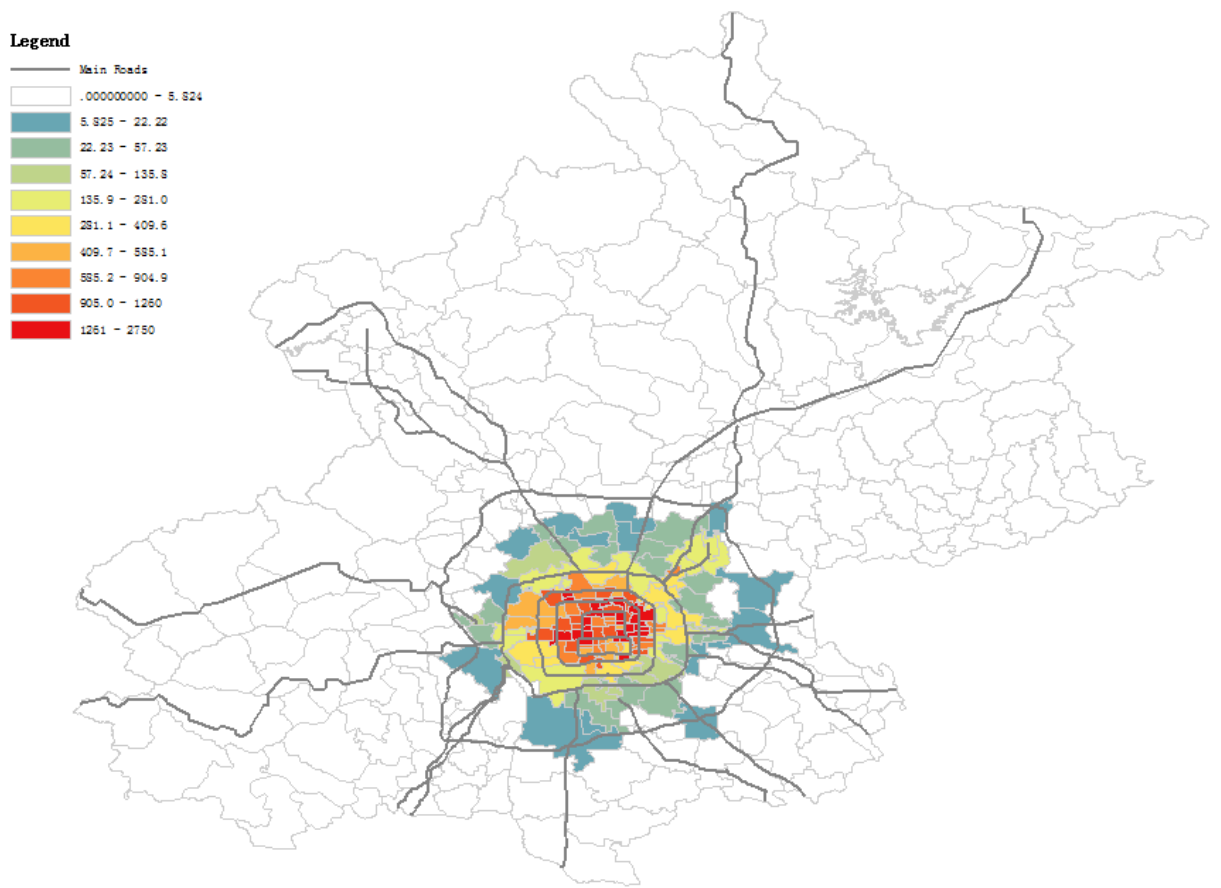
Figure 18. Density of taxi operating with customers   Nov.19 2012   10:00-11:00 am

(Point number with customer per sq. /km.   )

Legend

Main Roads

	.000000000 - 5.824
	5.825 - 22.22
	22.23 - 57.23
	57.24 - 135.8
	135.9 - 281.0
	281.1 - 409.6
	409.7 - 585.1
	585.2 - 904.9
	905.0 - 1260
	1261 - 2722
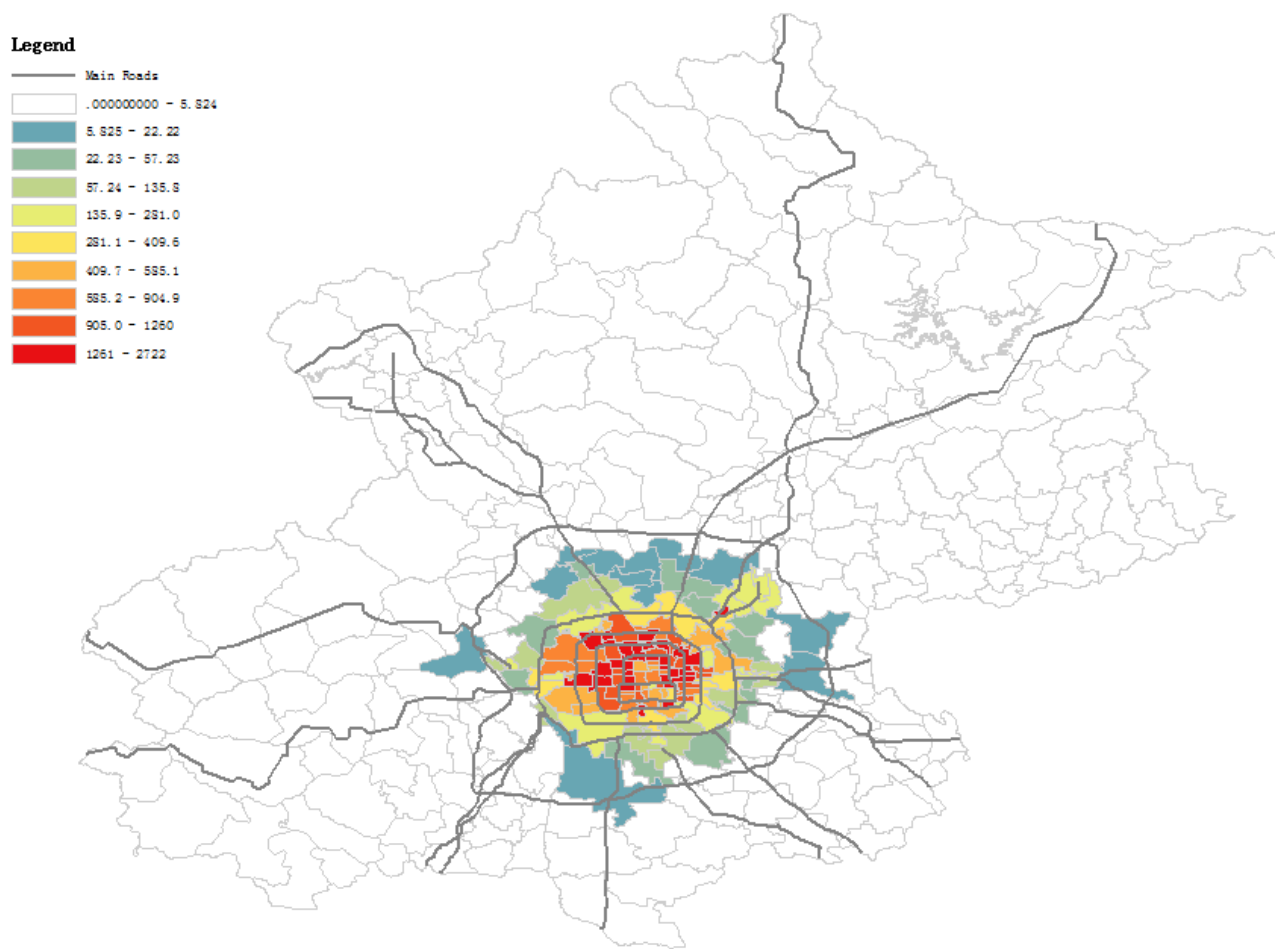
Figure 19. Density of taxi operating with customers   Nov.19 2012   17:30-18:30 pm

(Point number with customer per sq. /km.   )
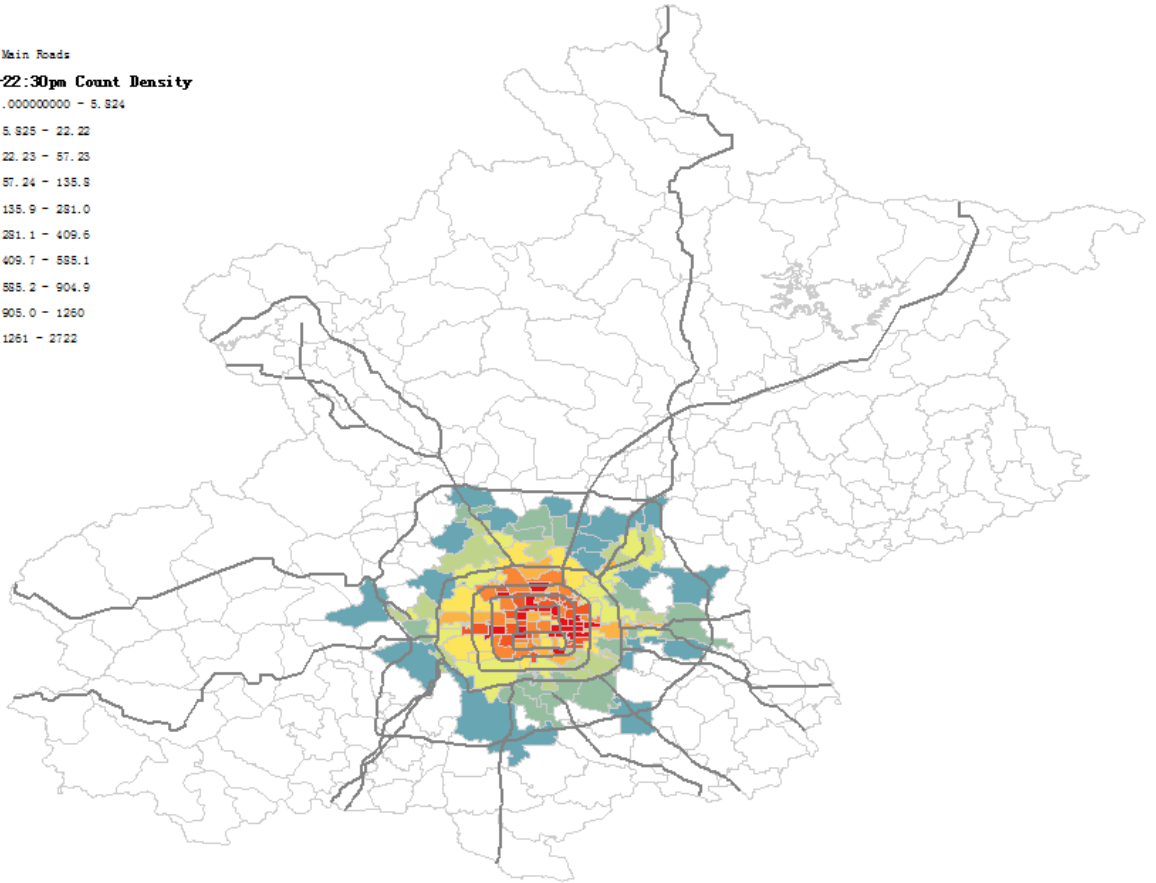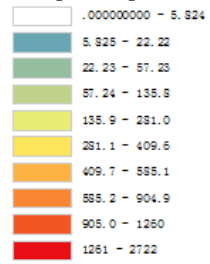
Figure 20. Density of taxi operating with customers　Nov.19 2012　21:30-22:30pm

(Point number with customer per sq. /km.　)
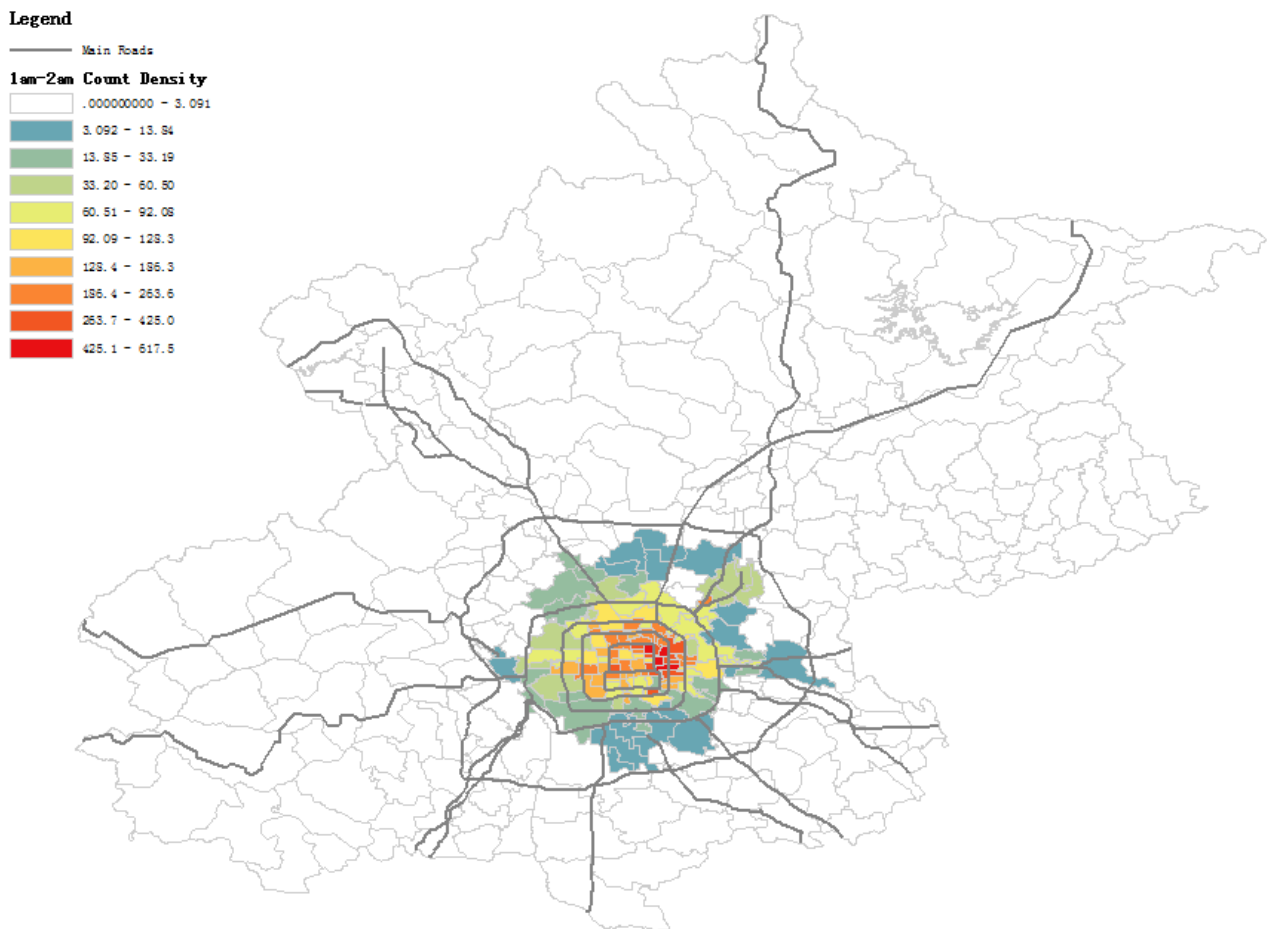
Figure 21. Density of taxi operating with customers   Nov.19 2012   1:00-2:00 am
(Point number with customer per sq. /km.   )

5.3 Empty Cruise Pattern Across Locations

The Kernel Density tool in ARCGIS calculates the density of features in a neighborhood around those features. Density can be calculated for both point and line features. 'Kernel density' function makes it possible to use point data that have only x and y coordinates and no other attributes (e.g. disease prevalence rates) required by more commonly used smoothing techniques, such as spline and kriging (Kloog, Haim & Portnov, 2009). Kernel density maps are visually smoother than point density or line density map.

The kernel density map of empty cruise trips and pick-up locations demonstrated slight differences between density distributions. Assuming a taxi market where demand and supply information is symmetrical, the density map of pick-up locations, which reflects demand, and empty cruising trips, which reflects supply, should be mostly similar. In Section 5.6, I analyzed the time series GPS data by individual drivers to see if they are using different spatial strategies when cruising in empty vehicles.

| Kernel Density: Pick-up locations | Kernel Density: Trips Without Customer |
| Count per sq./ km   Nov.19 2012 | Total length per sq./km   Nov.19 2012 |
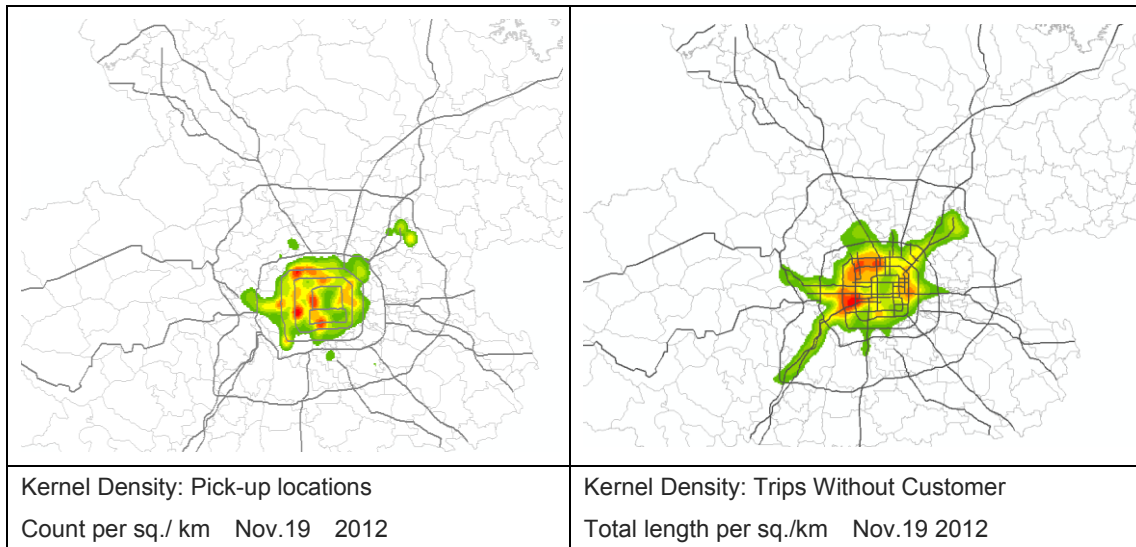
Figure 22. Density map of pickup location and trips without customer.

5.4 Occupancy Rate By Time

The purpose of this section is to examine whether the spatio-temporal imbalance of empty cruise rates or taxi efficiency exists. The demand for taxis fluctuated throughout a day while supply remained approximately constant for most of the time except late at night. Accordingly, the empty cruise rate varied in different periods (Zhou, 2011; Guan et al., 2010). In Beijing, the typical workday is from 9:00 am to 6:00 pm. The morning peak hour is usually 7–9 am and the afternoon peak hour is 5–7 pm.

One hundred taxis running on November 16, 2012, were randomly selected as samples. Eight taxis among them were not taking customers on that day and were removed from the sample. Therefore, the sample of taxis was reduced to 92. After data cleaning, the point records of the 92 taxis were converted to traces. Trip distance and fare revenues were calculated accordingly using methods explained in 4.1.

Since each trip feature had time information, fare revenue, mileage with and without a customer was categorized by different time periods.

The results showed that occupancy rates started increasing from 4 to 5 am in the morning. In morning peak hours (7–9 am), percentage of mileage with customer reached its peak. Afternoon peak also demonstrated an increase in occupancy rates but was slightly lower. A possible explanation might be that congestion discouraged potential passengers from taking taxis. According to the data provided by Beijing Transportation Research Center, in the afternoon peak, the average vehicle travel speed was 23.5km/h, compared with 26.0 km/h in the morning peak.
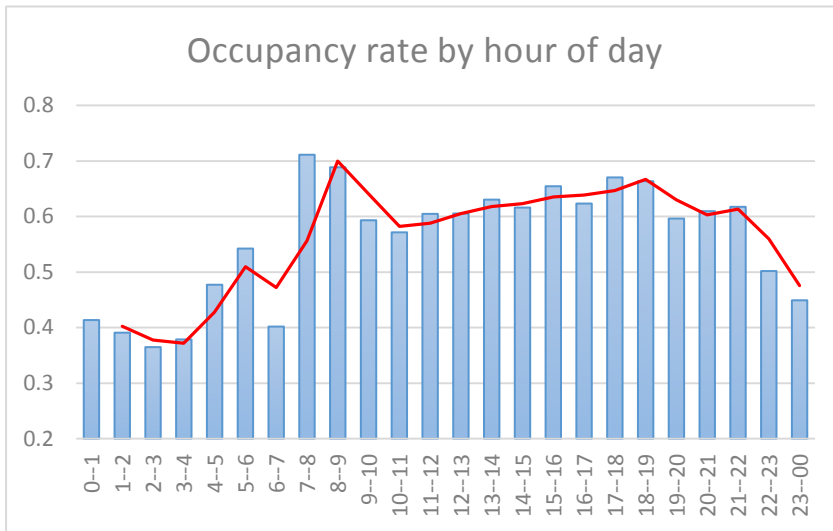
Figure 23. Occupancy rate by hour of day.

sample:92 taxis on   Nov. 16.

5.5 Pick-Up Number & Fare Revenue by Time

The pick-up variation trend by hour was mostly consistent with the result Veloso et al. (2011) found using taxi traces in Lisbon, Portugal. Unlike New York City data presented below, taxi pick-up numbers in Beijing reached their peak in afternoon hours between 1pm and 3pm and decreased after 8:00 pm. Taxi pick-up numbers in New York   peaked between 6 pm and 8 pm. Since 90.3% of NYC yellow taxis provide on-demand service, pick-ups occurred in Manhattan area, it is likely that tourists used taxis for night trips and constitute a large proportion of taxi riders in New York.
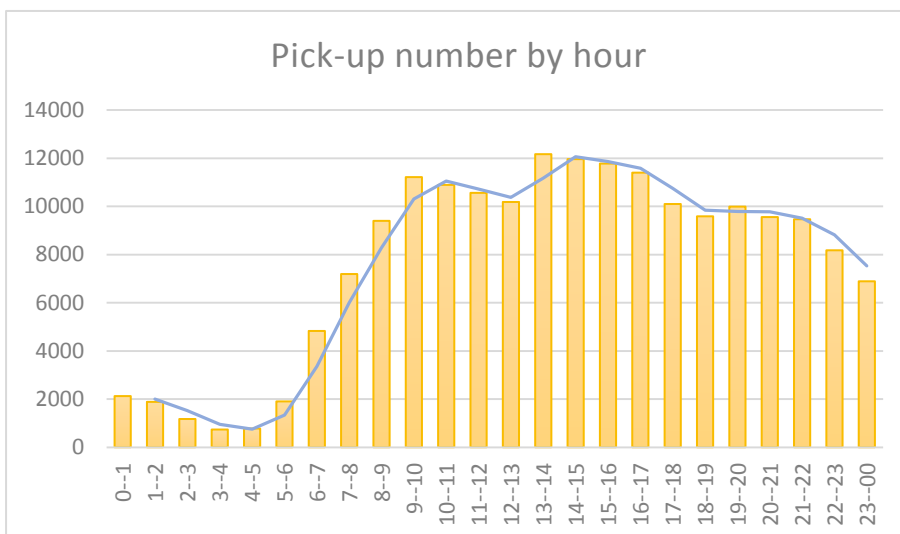
Figure 24. Pick-up number by hour.

Sample: 92 taxis in a day.
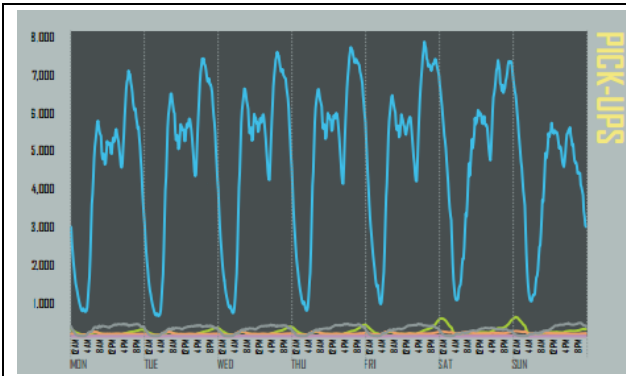
Figure 25.Number of pick-ups by hour in New York 1 week, Each interval is 4-hour period. (NYC Taxi Fact Book, 2014)	Figure 26.Number of taxi trips by hour in Lisbon Veloso et al., (2011)
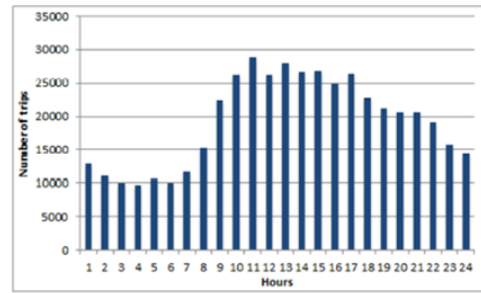
Morning peak and afternoon peak revenues were not significantly higher than other periods. This may indicate although occupancy rates were higher, congestion in peak hours reduced the number of trips in a certain period.
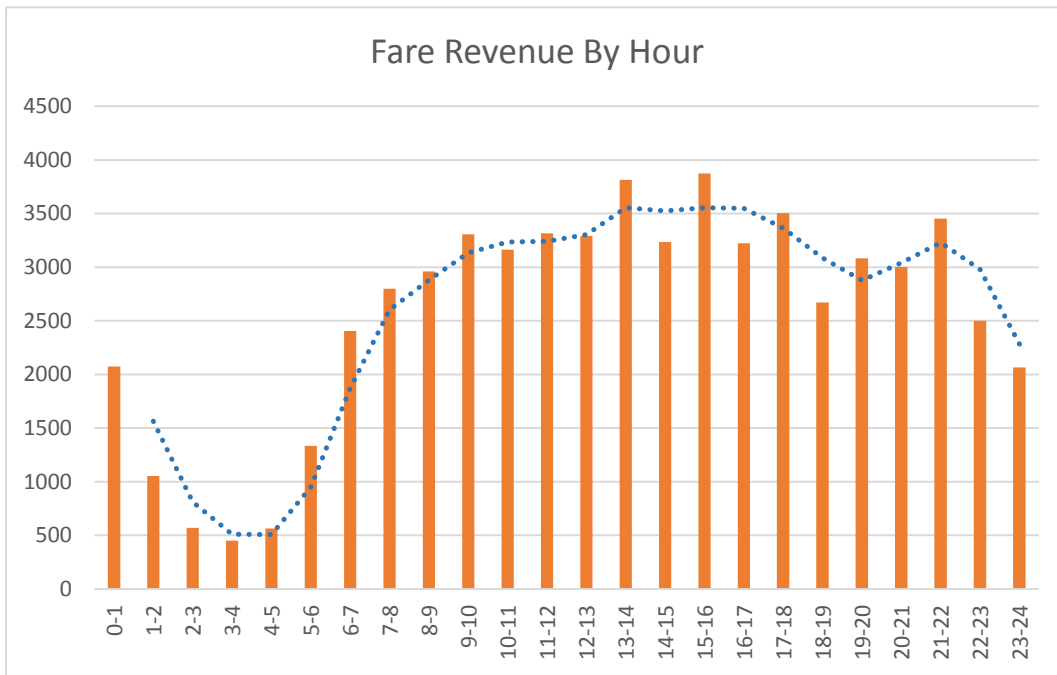
Figure 27. Fare revenue by hour.

Sample: 92 taxis in a day.

5.6 Do Drivers Strategically Cruise for Customers?

Is there a way to reduce the percentage of empty driving mileage and increase the efficiency

of taxis? When we looked at empty cruise mileage, they were mostly the distance the driver traveled to find the next customer after a customer exited from the cab. Although drivers could not foresee their customer's destination, they could decide their own cruise route of finding customers. If they had expectations for customers in a typical location, they were likely to stay in such area.

The maps below exhibit taxi 45393's travel trace from November 19 to November 23, 2012.The red lines are trips with customers and the green lines are empty cruise trips. We can see that although trips with customers end in different areas of the city, the driver always returned to the eastern part of the city for the next customer.

The density map better demonstrated that the driver tended to cruise for fares in the eastern part of Beijing, mainly the CBD area and airport.

Monday. November 19　Taxi 45593
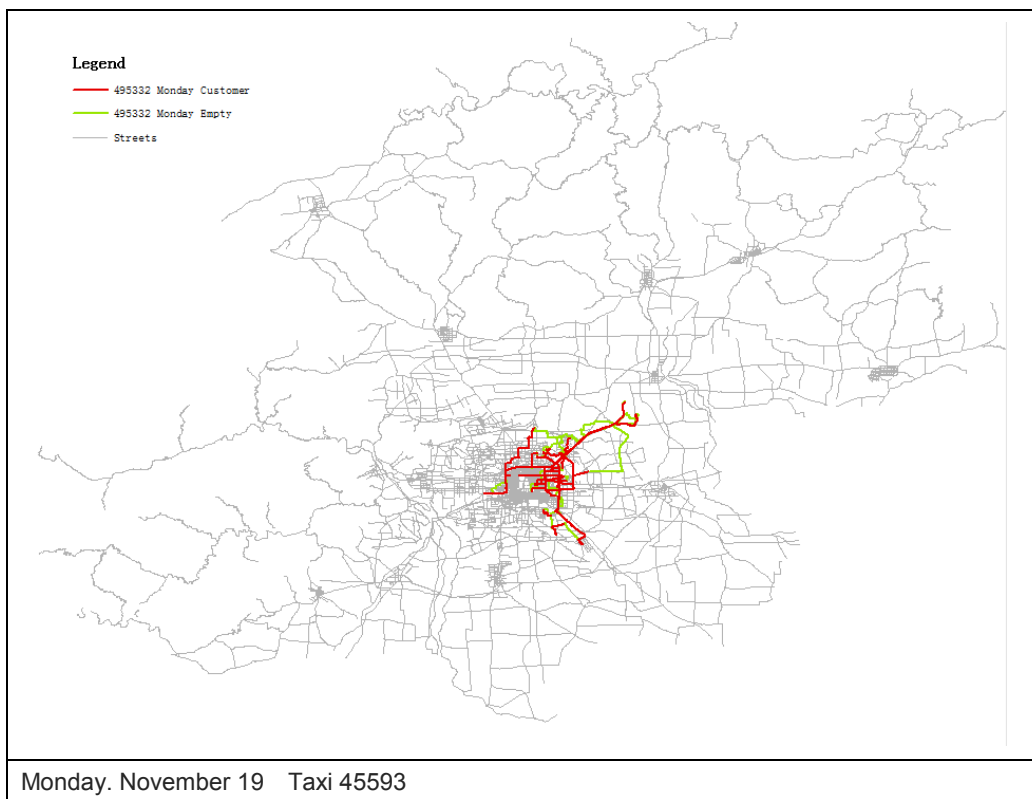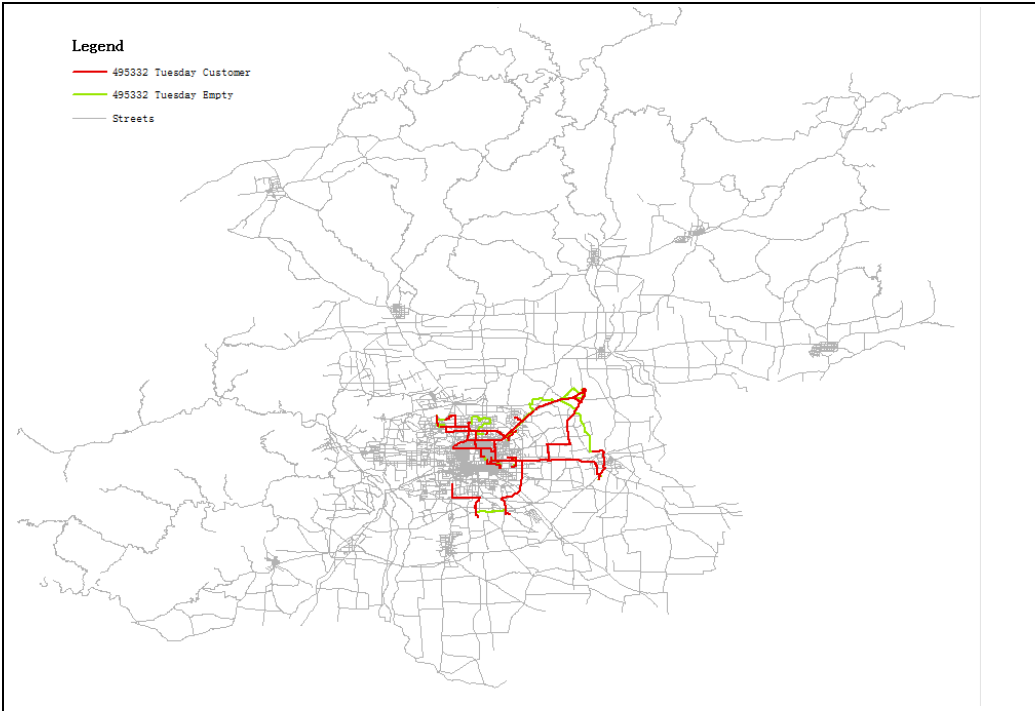
Tuesday, November 20   Taxi 45593
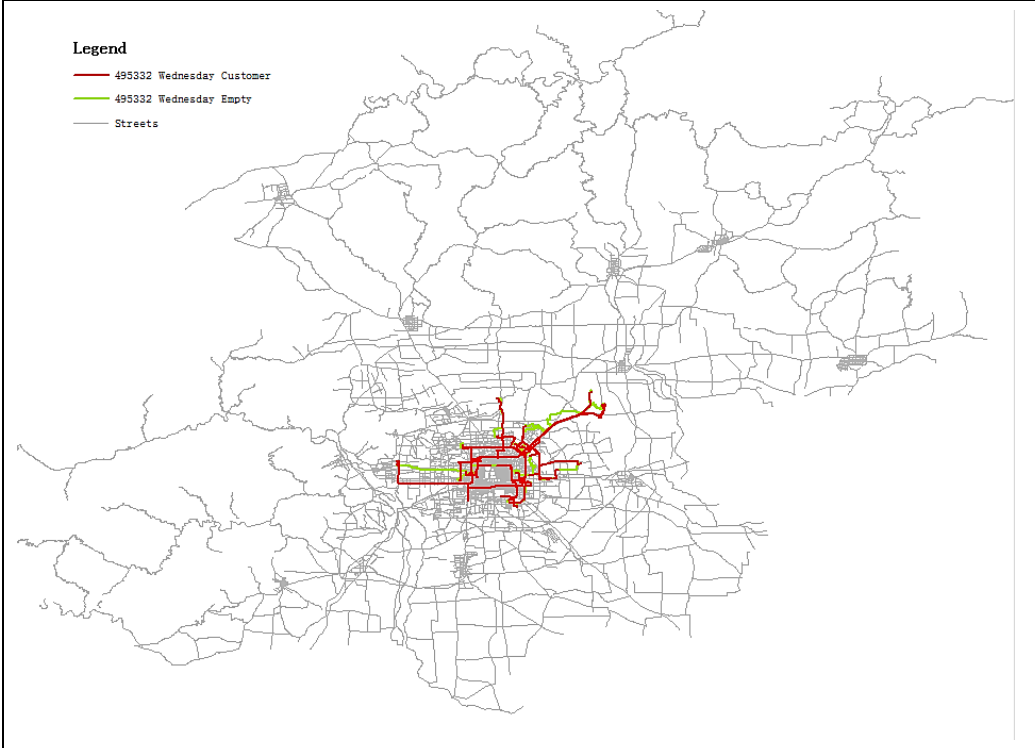
Wednesday, November 21   Taxi 45593

Legend

─── 495332 Thursday Customer
─── 495332 Thursday Empty
─── Streets
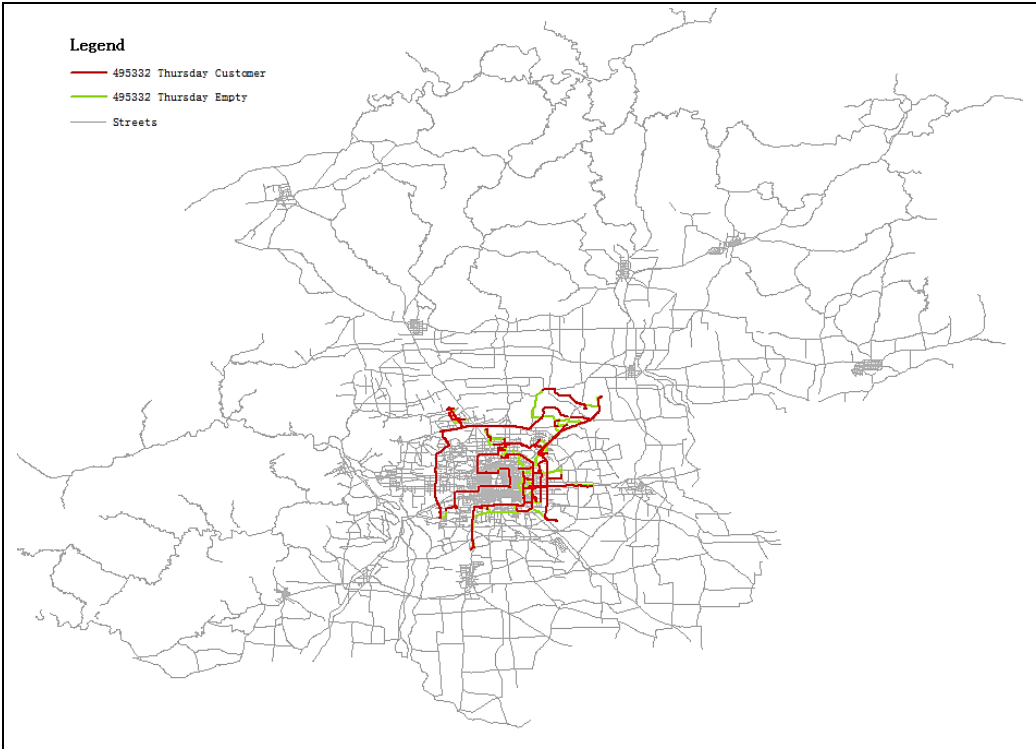
Thursday, November 22   Taxi 45593

Legend

─── 495332 Friday Customer
─── 495332 Friday Empty
─── Streets
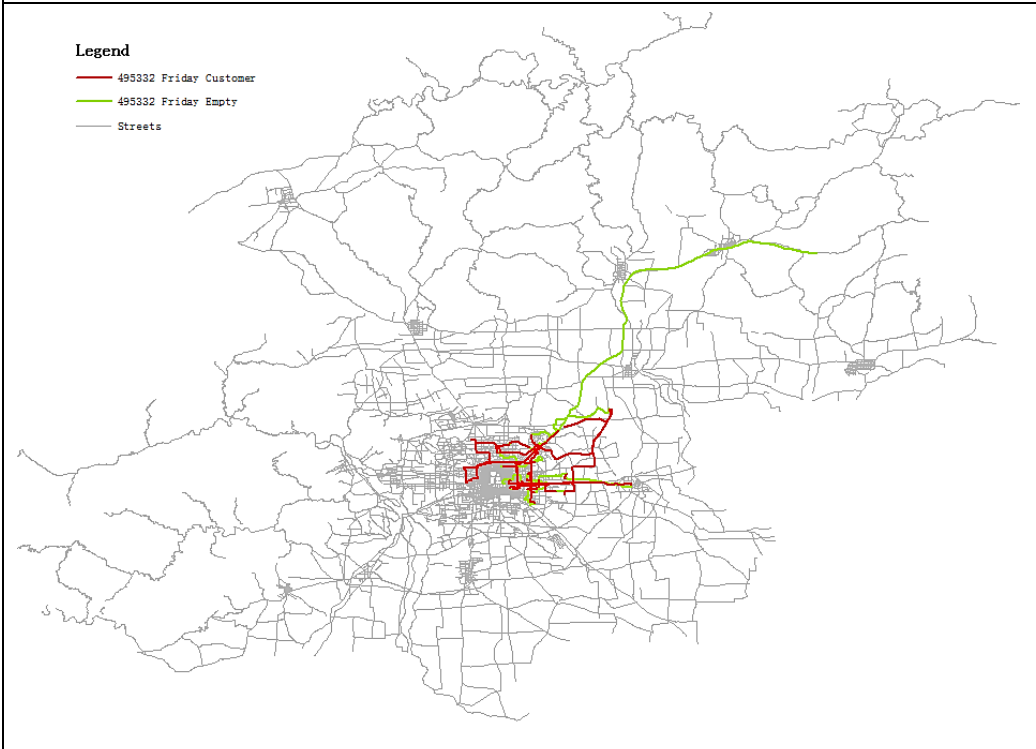
Friday,   November 23   Taxi 45593

34

Total Cruise Trip   (November19–November21)
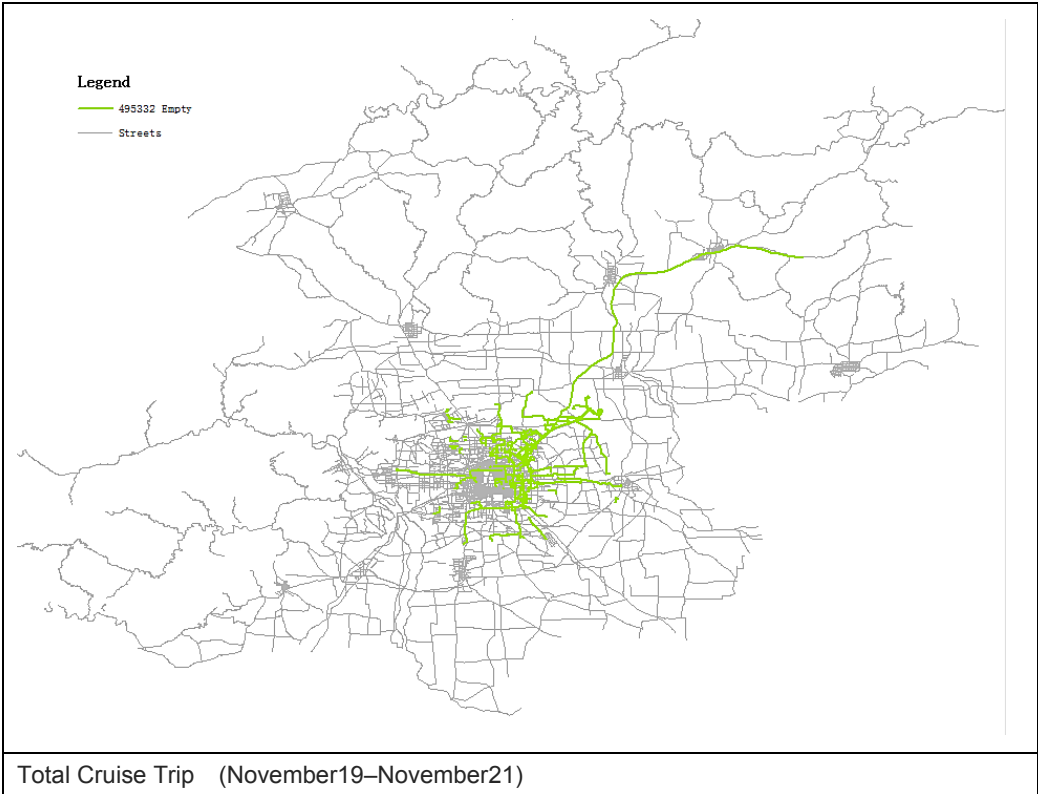
Figure 28. Five-day travel route of taxi 45593.

Red: With customer   Green: Empty Cruise

Cruise Trip Kernel Density   (November19–November23)

Unit: Sum of trips length per sq./km.
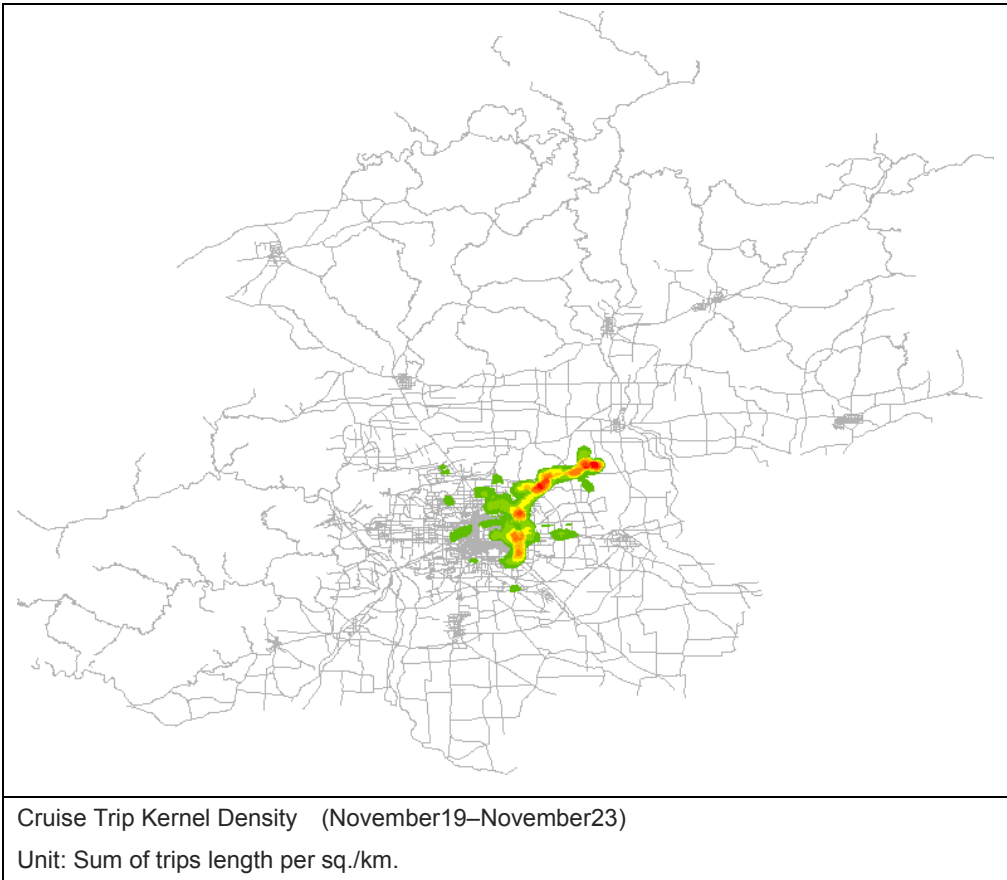
Figure 29. Cruise trip density of taxi 45593

Similarly, I tracked 12 other taxis' travel patterns from November19 to November 23. They were randomly picked from the sample of 92 and divided into two groups according to averaged daily fare revenue during November 19–November 23, 2012. In group1, the revenue ranged between 600–800 Yuan per day. In group 2, the fare revenue was greater than 1000 Yuan per day. Almost all the drivers demonstrated spatial preferences to some extent. Most of the group 1 drivers tended to cruise in the western side of the city, while the group 2 cruise pattern seemed to be more dispersed. Liu et al. (2010) concluded that top earning drivers had a special strategy to maximize profit. For example, they avoided high-density areas in typical morning and afternoon peak hours and traveled at higherspeed compared with ordinary drivers when they were taking a customer. In an on-demand mode where demand and supply information is not symmetrical, drivers looked for customers based on experience and luck. Sometimes, experience might even act as inherent bias(Guan & Zhu, 2010).

Group1:

ID: 126407 684 Yuan	ID:154805 603 Yuan
ID:154862 681 Yuan	ID:164524 827 Yuan

| ID:164898   715 Yuan | ID:174663   639 Yuan |
| ID:184626   790 Yuan | ID:194183   839 Yuan |
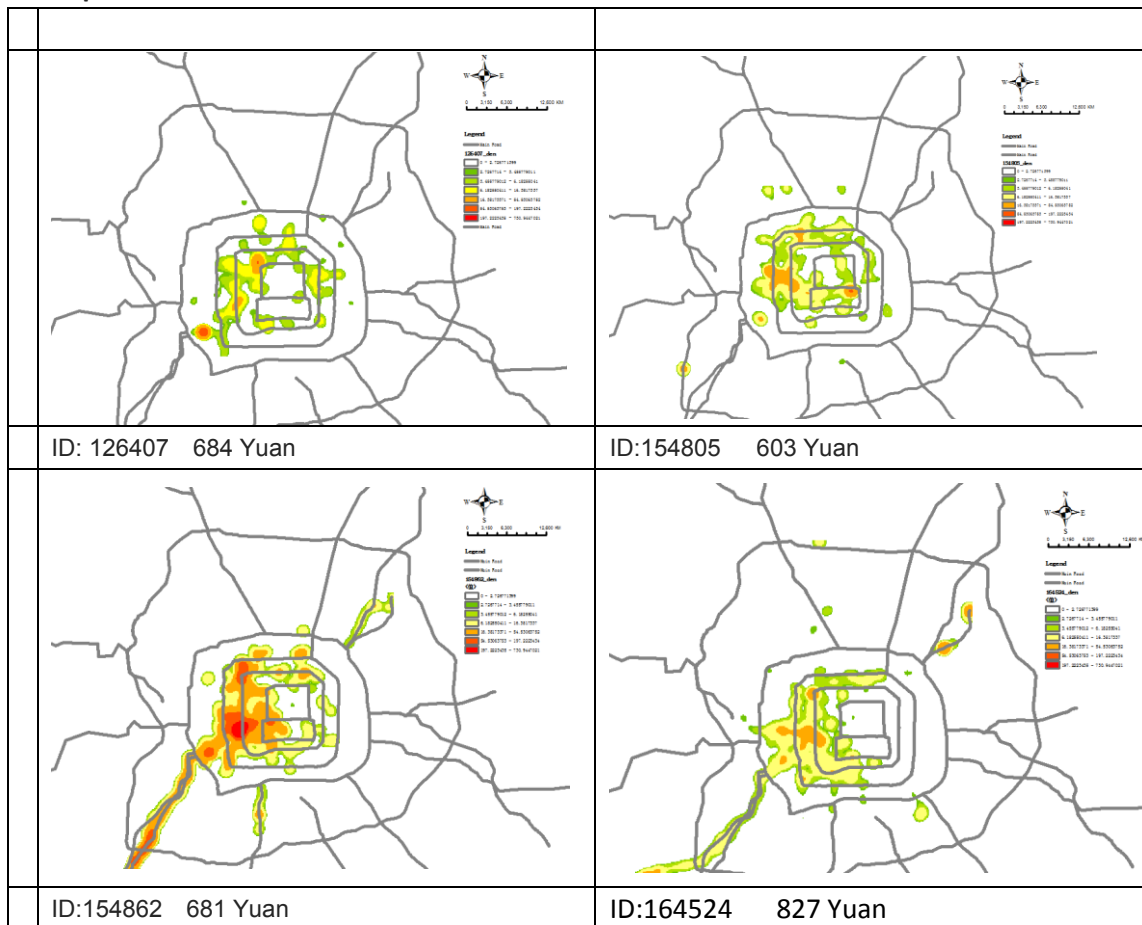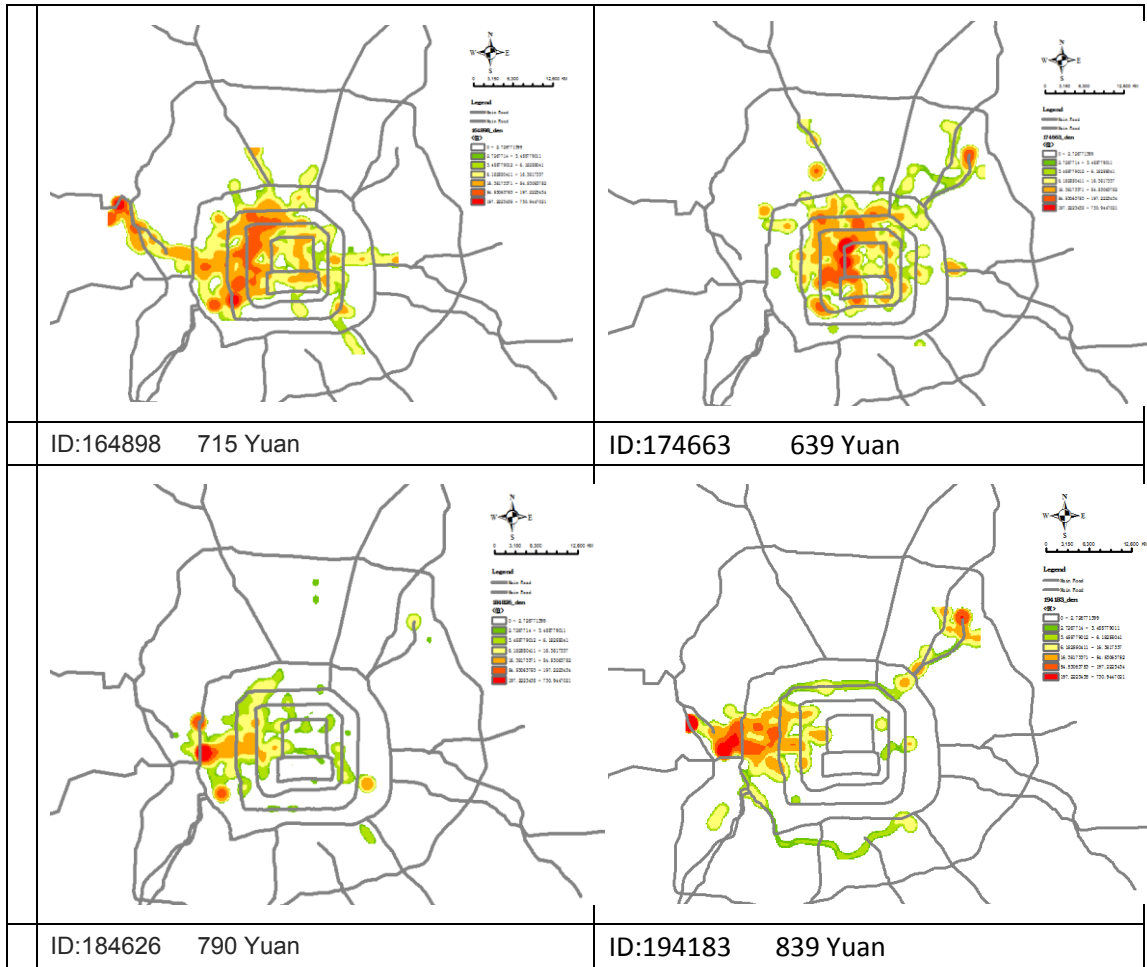
Figure 30. Group 1 cruise patterns.

Group2:

| ID:164337   1319 Yuan | Id:194136   1073 Yuan |

| ID:174939   1135 Yuan | ID:188741   1311 Yuan |
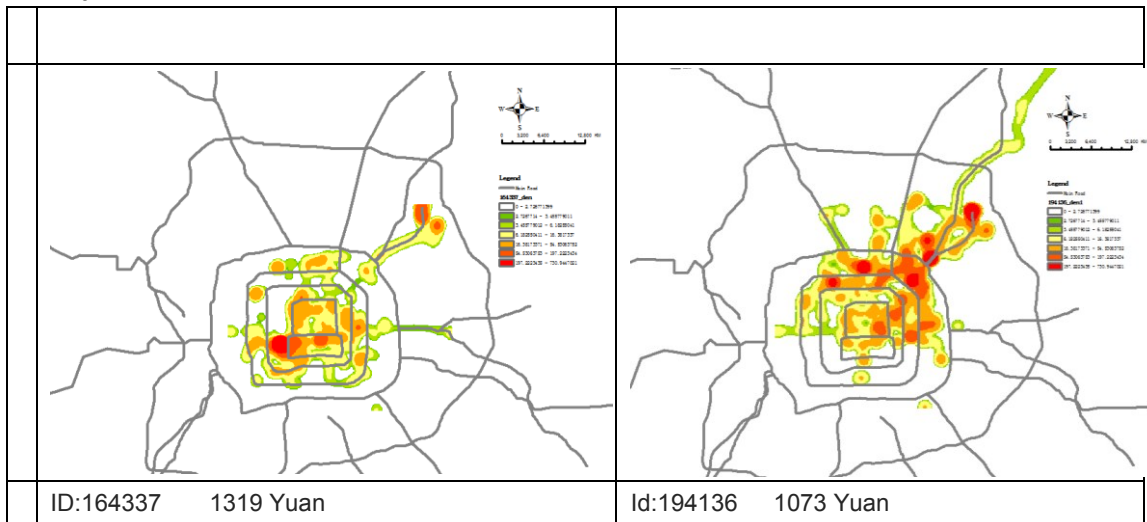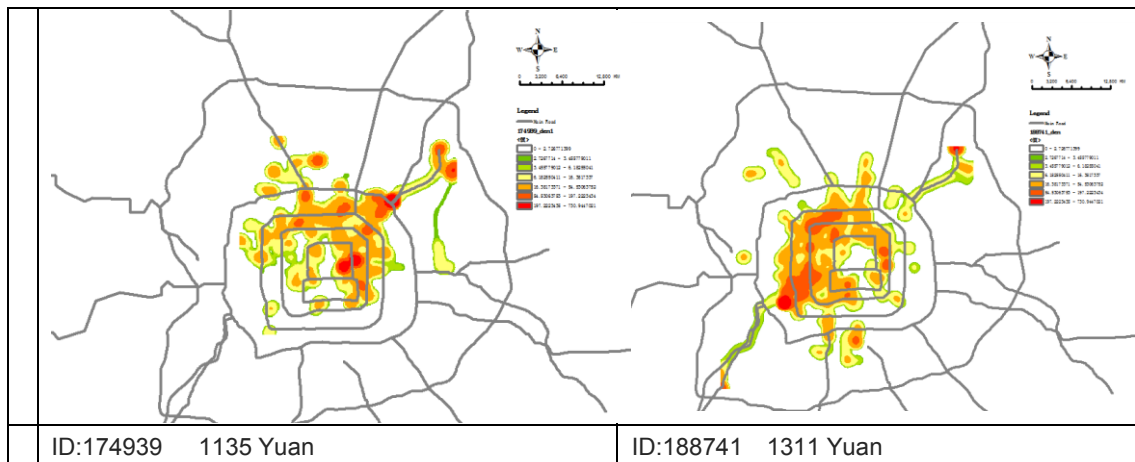
Figure 31. Group 2 cruise patterns

5.7 Is Staying In Inner City A Good Strategy For Profit?

Drivers might think that clustering in the inner city is profitable (Guan & Zhu., 2010). However, taxi demand is always dynamic. If the majority of taxi drivers held the same perception, the inner city might be over supplied while suburban areas would be underserved. Taxi drivers' spatial strategies will affect their profit (Li et al., 2011; Liu et al., 2012; Gao et al., 2012). If a driver choses to stay in a high-density area, demand will be high but travel speed is more likely to be low, thus opportunity cost might increase. Moreover, competition might be more intense. In low-density areas, however, travel speed is high but demand might be less fewer clients are waiting there. Trips from the inner city to suburban areas, such as airport trips, are usually higher in fare but very likely lead to empty return trips. In an on-demand context, trade-offs always exist between time and distance. Liu et al. (2010) explored the spatial strategy of taxi drivers in Shenzhen and concluded that top drivers who made 50% more than ordinary drivers per day chose to cruise in low-density areas at typical times, while ordinary drivers tended to cluster in the CBD area of the city. Gao et al. (2012) also found that high income taxi drivers had multiple favored operating regions, while low income driver concentrated in a small number of regions. High income drivers seem to be more aggressive and actively search for customers rather than waiting (Li et al., 2011; Gao et al., 2012)

The purpose of this section is to categorize the different kinds of trips a taxi made and how they contributed to profit. Trips were classified by spatial characteristics and length. Since taxi services primarily cluster inside the fifth ring of Beijing, I used the fifth ring to delimit inner city and suburban area. Trips could be classified into three categories: inner-city trips, suburban trips, and cross trips.

Definition:

1.Inner-city trips: Taxi trips inside the fifth ring.

2.Suburban trips: Taxi trips outside the fifth ring.

3.Cross trips: Taxi trips that travel cross the fifth ring, from the inner city to suburb or conversely(from suburban area to inner city).

GIS is used to classify trips by location from the original shape file. Among the overall 2749 trips with customers, inner-city trips counted for 80.1% of total trip numbers. Suburban trips counted for 6% and cross trips counted for 13% of all the trips generated by 90 sample taxis in a day.

A more detailed classification considers trip length. Each trip category could be divided into three sub-categories based on length. As mentioned in section 4, trips less than 3km were charged at flat rate, and trips greater than 15 km were charged extra rates. Based on how the taxi fare is calculated, I determined the threshold of length as 3 kms for short trips and 15 kms for long trips. The average length of inner-city trips was 5.8 km per trip, compared with an average of 16.2 km per trip for cross trips and 5.9 km per trip for suburban trips.

Table 2. Average length of different trips by category

	1km < Trips < 3km	3km<Trips<15km	Trips > 15 km
Inner-city trips	2 km	6.9 km	19km
Suburban Trips	1.7 km	7.3 km	18.5 km
Cross trips	2.3 km	9.4 km	24.8 km
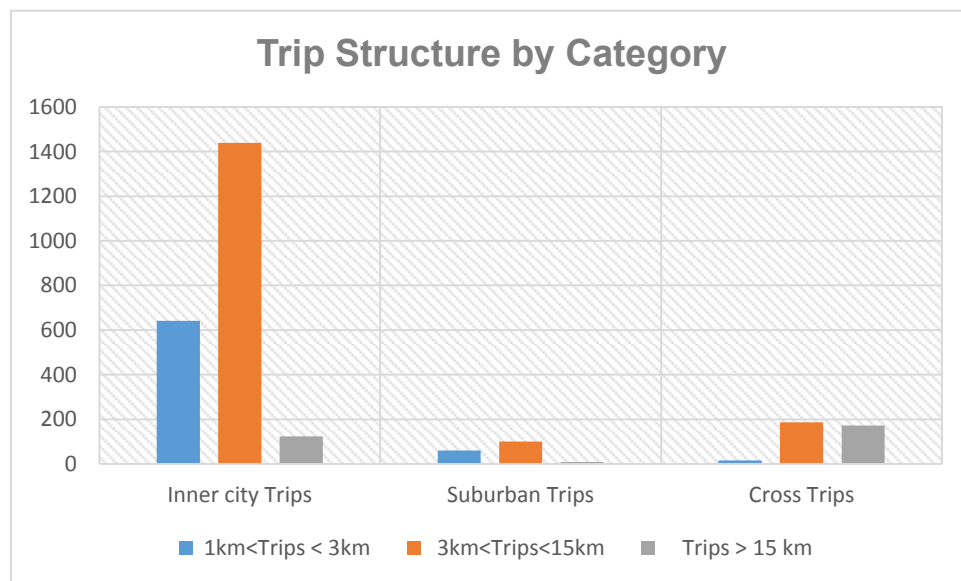
Figure 32. Trip structure by category

Since the distribution of profit is approximately normal, a linear regression model was used to explore how different trips affected profit. Linear regression is widely used to model the relationship between dependent variable and one or more independent variables.

In matrix form, linear regression model could be expressed as

$$Y = X\beta + \varepsilon \hspace{4cm} (1)$$

Where Y is the n-dimensional vector of dependent variable,

X is a matrix for independent variables,

β is a matrix of coefficients for X, and

ε is the error vector.

P =α1 C+ α2 E+α3 P +Constant+ε   **(2)**

Where α 1, α 2 and α 3 are coefficients

  C denotes "count of trips,"

  E denotes "empty cruise rate,"

  P denotes "percentage of mileage of a certain kind of trip," and

  ε is the error term.
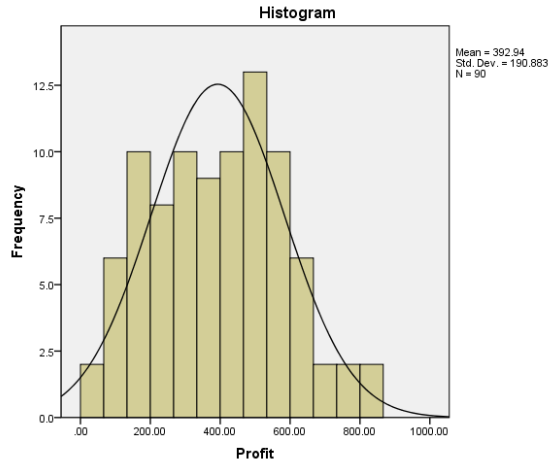
Figure 33. Density distribution of profit.

Table 3. Regression variables.

Count of Trips	Denote	Description	Source
Empty Cruise Rate	C	Number of trips with fare of a single taxi in a day	Calculated from GPS data
Percentage of:	E	The ratio of mileage without customer and total mileage of a single taxi in a day	
a. Inner city trips **b. Suburban Trips** **c. Cross trips** **d. 1km<Trips < 3km** **e. 3km<Trips<15km** **f. Trips > 15 km**	P	The ratio of particular trip type mileage and total mileage with fare of a single taxi in a day	

Dependent variable is profit; independent variables are the number of trips, empty cruise rates, and the ratio of a particular trip.

Table 4. Regression Results

Profit	Model A	Model B	Model C	Model D	Model E	Model F
Count of trips	10.939 ***	10.308 ***	11.152***	10.978 ***	11.232 ***	11.627***
	(0.818)	(0.771)	(0.838)	(0.825)	(0.840)	(0.870)
Empty cruise rate	-519.614***	- 567.602 ***	-502.667***	-462.929***	-479.759***	-434.014***
	(-0.290)	(-0.318)	(-0.281)	(-0.258)	(-0.268)	(-0.243)
Percentage of trip (A through F)	-146.987***	195.694 *	186.102***	-557.441**	-237.581***	249.795***
	(-0.166)	(0.061)	(0.175)	(-0.102)	(-0.196)	(0.220)
N	90					
Adjusted R-square	0.927	0.904	0.932	0.908	0.936	0.942
* p<0.1, ** p<0.05, *** p<0.01						

Model A: Regression result of inner city trips

Model B. Regression result of suburban trips

Model C. Regression result of cross trips

Model D. Regression result of 1km < Trips < 3km

Model E. Regression result of 3km < Trips < 15km

Model F. Regression result of Trips >15 km

Table 5. Trip influence on Profit by Location and Length

	1km<Trips < 3km	3km<Trips<15km	Trips > 15 km
Inner city trips	- **	- ***	+
Suburban Trips	+	+**	+
Cross trips	-	+	+***

* p<0.1, ** p<0.05, *** p<0.01

The result showed that the number of trips is the dominant factor for profit. The percentage of inner-city trips had a negative effect on the net profit of a driver, while the percentage of suburban trips and cross trips had a positive effect on profit. In other words, clustering in the inner city might not be a good strategy for drivers. Finding a customer in the suburban area might lead to higher profits as long as the trip is not too short. Long trips are lucrative despite the risk of empty return. The most profitable pattern is to ensure the total number of trips and make longer trips at the same time. Speed is a hidden factor here. For suburban trips and cross trips, the travel speed might be higher, thus the taxi could make more trips in a fixed period.

6. The Money Value of Travel Time - Comparing Taxi with Transit

Another question for taxis: are they threatening or complementing public transit? Long, Han and Yu (2012) used smart card data to analyze the commuting pattern by bus in Beijing. They extracted 221,773 cardholders' commuting trips from 80 million records generated by 8.5 million cards/persons in April 2008; 32,419 trips were identified as inter-TAZ trips. The results below showed that long-time commuting (greater than 90 minutes, one way) prevailed in suburban areas of Beijing.
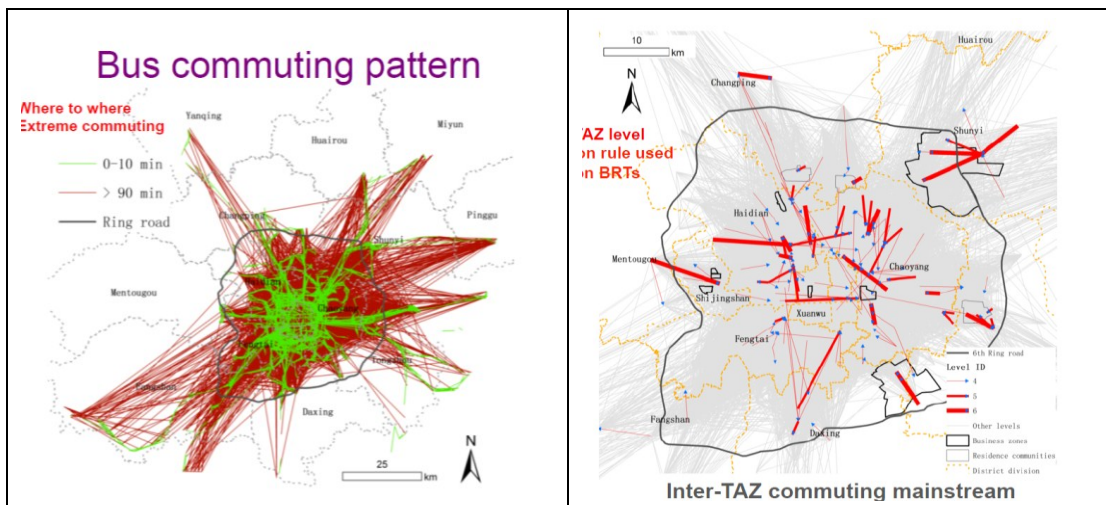
Figure 34. Bus commuting pattern in Beijing (Long et al. 2012)

Sample: 221,773 cardholders identified with commuting trips in Beijing

34219 inter-TAZ links

The bus-line density map in Beijing displayed below showed that bus lines covered a larger area than taxis, while most bus lines and metro stops also clustered inside the fifth ring. In suburban areas and satellite towns in the Beijing metropolitan area, bus service was rarer than in the inner city, and urban rail was unavailable in many places. Although taxi pick-up points mainly clustered inside the fifth ring, the drop-off pattern below indicated the demand for taxis in suburban areas. While the transit system in Beijing is almost free, why are taxis used by passengers?

Bus Line Density and Metro stations in Beijing Data Source: Beijing City Lab, extracted from open street map.	
Taxi drop-off density	
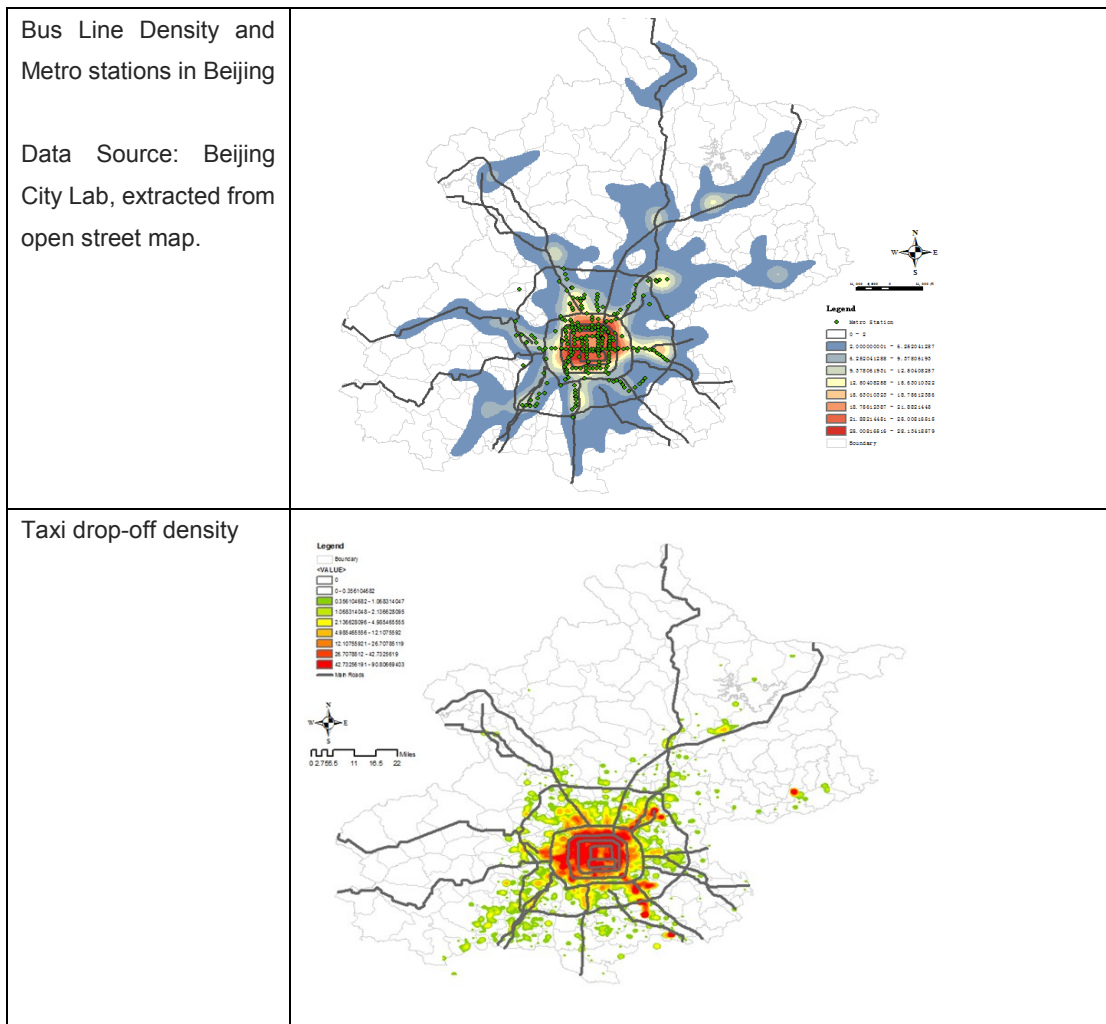
Figure 35. Bus line density and taxi deop-off density

Although time saving is not the sole reason for people taking taxis, it is proved the most important one (Darbera, 2010). The transit system in Beijing offered extremely low prices to residents (2 Yuan for metro and 0.4 Yuan for buses). However, it was hard for the transit system to cover travel demands in a complicated metropolitan area such as Beijing perfectly, at least for now. Besides, travelling by auto or taxis is more comfortable compared with transit, which is more likely to be crowded in Beijing.Paratransit like taxis might still be necessary if the passenger wishes to shorten his or her travel time at a higher cost than regular bus or metro system fares. If travel time by transit is long and the option of paratransit system does not exist, passengers who have higher value of their time are more likely to turn into potential auto-owners. For tourists and visitors who are not familiar with the city, taxis save them the trouble of finding routes to their destinations as well.

After calculating the value of time of people who took taxi trips, I compared the time and money cost of the same trips made in transit mode and taxi mode. Trip classification was defined the same as in section 5.7. Samples of trips by different category were randomly selected from the processed data in section 5.7 and shown in Figure 25. For each category, I selected 20–25 trips for analysis. Suburban trips greater than 15 kms and cross trips shorter than 3 kms were rare; therefore, the sample size was smaller than other categories. After acquiring coordinates of

the start and ends of trips from ArcMap, I used Google Maps to calculate the time and cost of each trip in both modes.

According to ex-Google engineer Richard Russell's answer in Quora[1], Google Maps calculated estimated travel time using the data available in a particular area. Data ranged from official speed limits and recommended speeds, likely speeds derived from road types, historical average speed data over certain periods (sometimes just averages, sometimes at particular times of the day), actual travel times from previous users, and real-time traffic information. According to Russell, the Google engineers mix data from whichever sources they have, and come up with the best prediction they can make. Google Maps provided theoretical travel time when traffic is smooth, as well as actual travel time based on real-time traffic information for driving option. For transit, it only provided theoretical time estimation.

In this section, I used estimated travel time of taxi and transit for comparison. Extra time caused by congestion was not calculated here since it was unpredictable, such as waiting time generated by a delayed bus. The 2012 Beijing transportation annual report divided congestion into five levels: seriously congested, congested, slightly congested, smooth, very smooth. According to the report, the average time duration of "seriously congested" and "congested" in Beijing was 1 hour and 30 minutes. Since the sample was distributed all over the city in a whole day, it was not likely that serious congestion would affect a majority of them. However, according to Beijing Transportation Research Center, congestion has been much worse in Beijing during the past decade. Therefore, the travel time by taxi might be estimated as shorter than the actual situation.

a.Inner-city Trips
1km<Trips < 3km

---
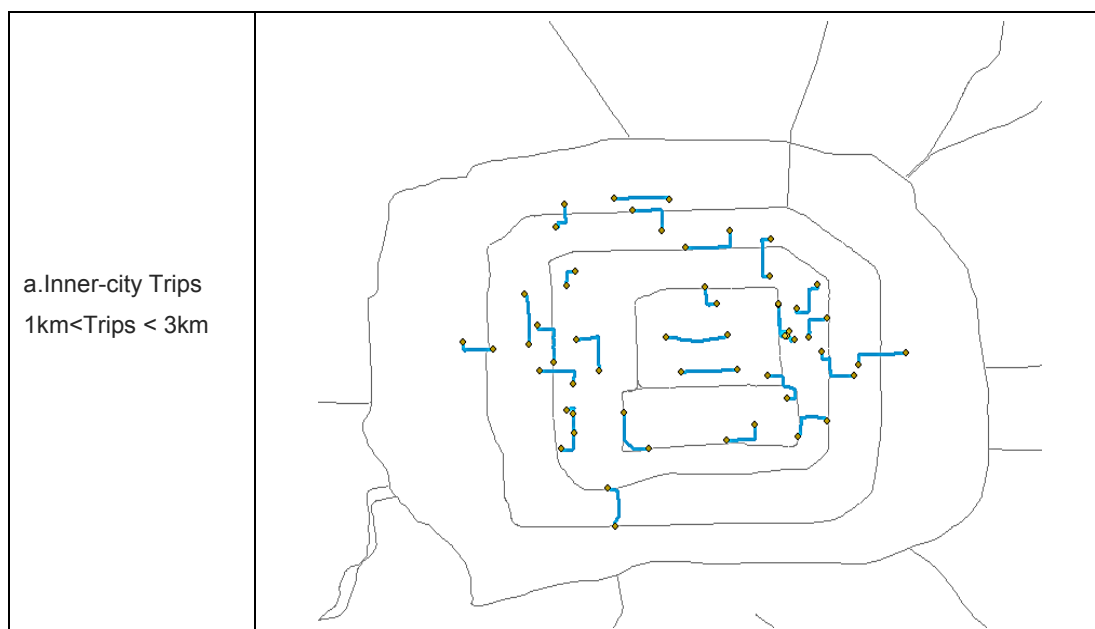
[1] http://www.quora.com/   Quora is a question-and-answer website where questions are created, answered, edited and organized by its community of users. Quora requires users to register with their real names rather than a screen name.

b.Suburban Trips 1km<Trips < 3km	
c.Cross Trips 1km<Trips < 3km	
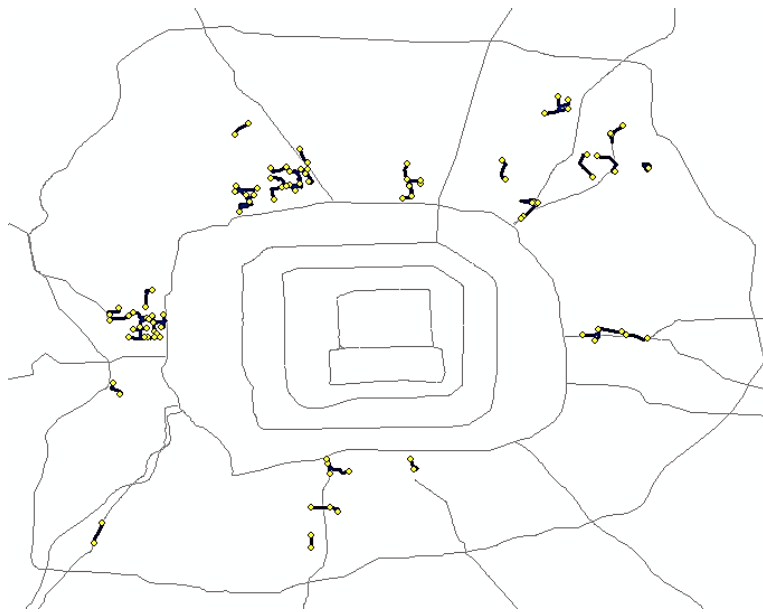
d.Inner-city Trips 3km<Trips<15km	
e.Suburban Trips 3km<Trips<15km	
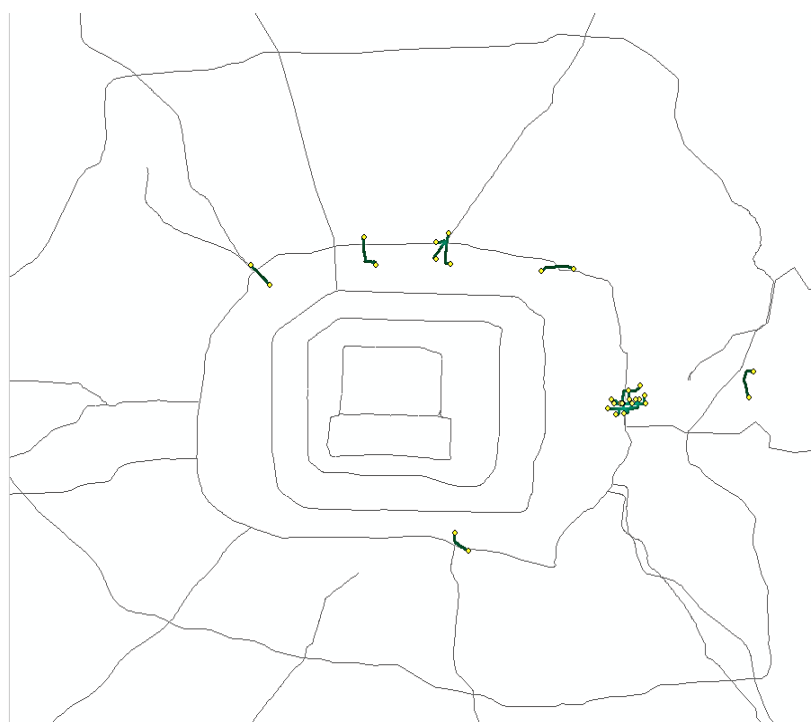
f.Cross Trips 3km<Trips<15km	
g.Inner-city Trips Trips> 15 km	
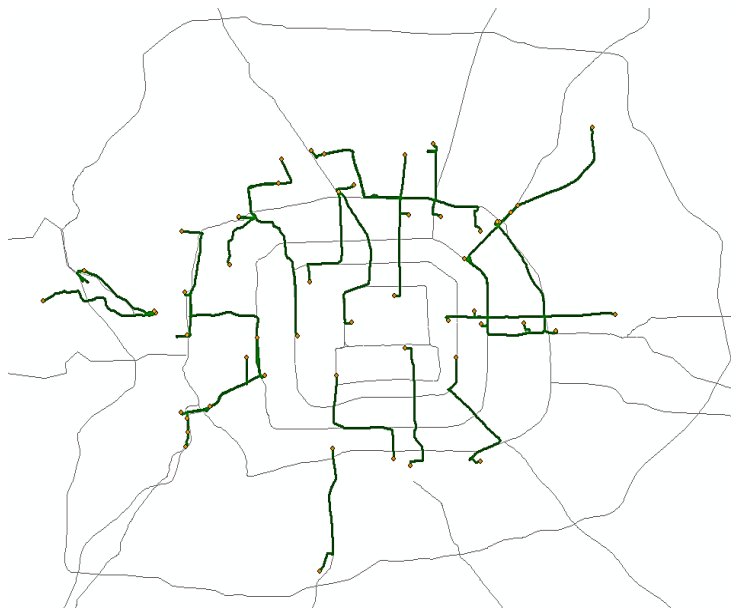
h.Suburban Trips Trips > 15 km	
i.Cross Trips Trips > 15 km	
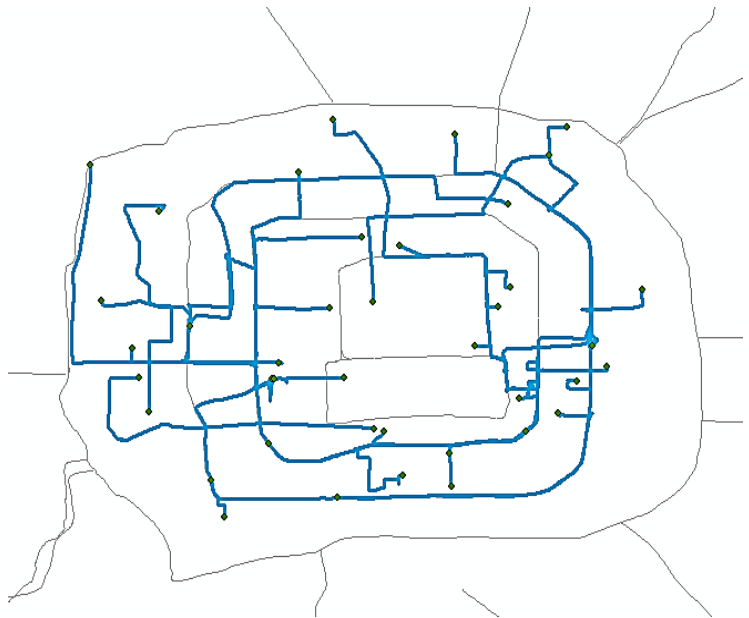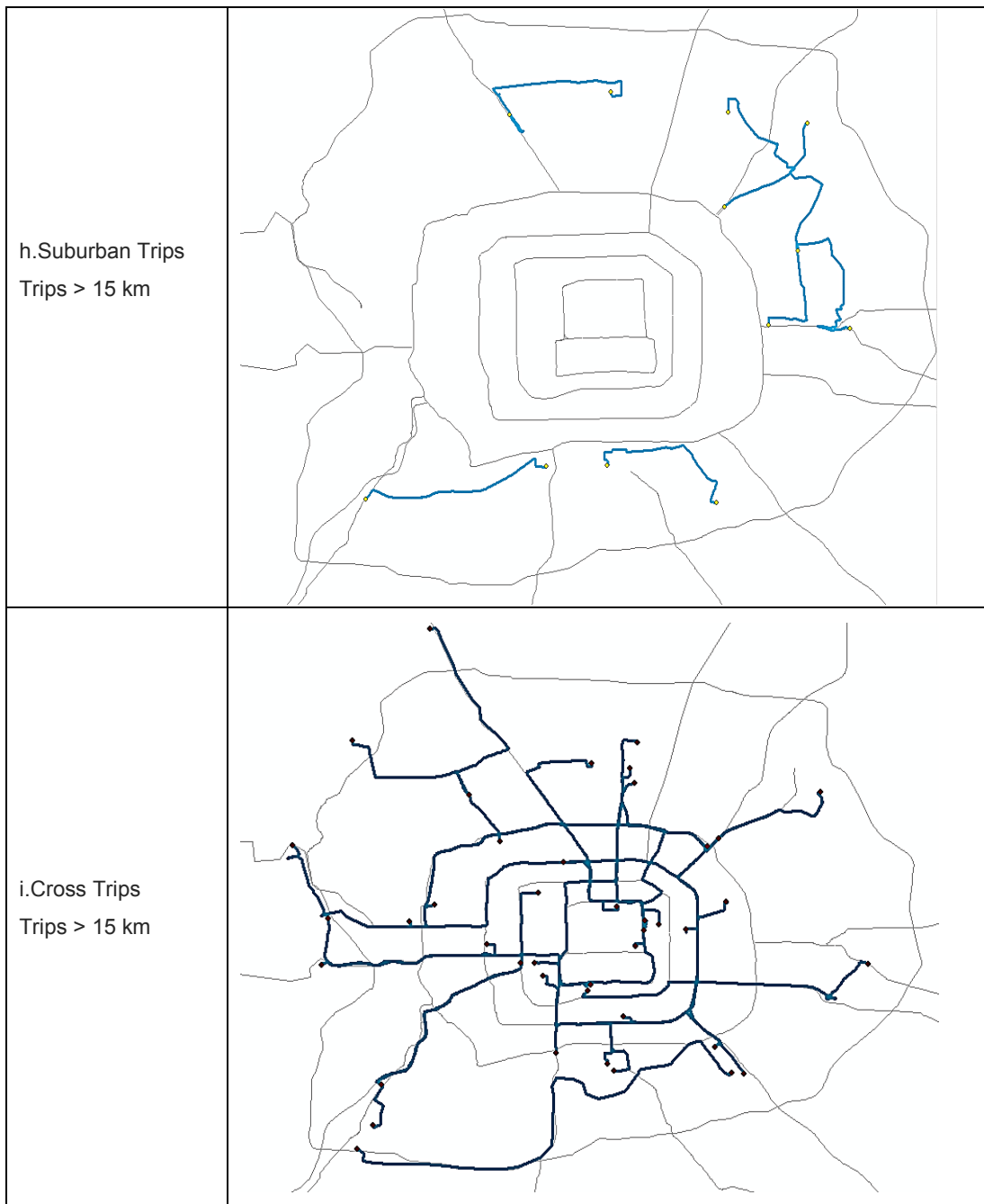
Figure 36. Sample of different trips

For each trip in the sample, time by taxi was always less than time by transit. As a result, time saving and taxi rider's money value of time are calculated in the formulas below. Traveler's value of time here is the minimum value since in reality their value of time may be greater.

Time saved = (Time in transit – Time in taxi) / Time in transit
Lower-bound time value = (Cost of taxi – Cost of transit) / (Time in transit – Time in taxi)

The result showed that theoretically taxis saved an average of 75% of time per trip compared with the same trip made by transit. In suburban areas, the average time saving was 78% per trip, slightly higher than the number of 73% of inner-city trips and 74% of cross trips. For

inner-city trips and cross trips greater than 15 kms, time saved by taxis is slightly lower than trips shorter than 15 kms. In the outskirts of the city, taxis saved more time for trips greater than 15 kms. The rail system in the inner city is likely to contribute to reduce the travel time for long trips by transit.

Time Saving per trip by Trip Catergory
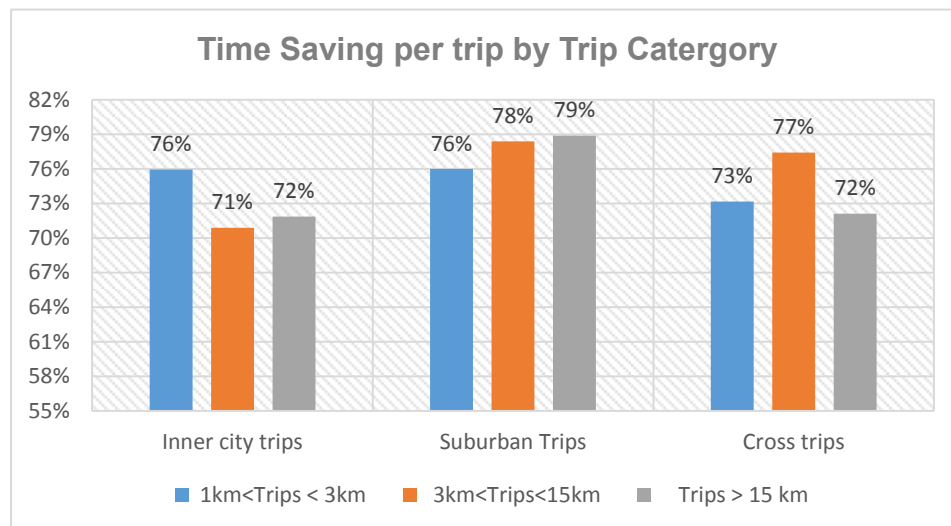
Figure 37. Time saved per trip by category

Assuming a single-rider situation, the average time value of taxi riders saved is calculated as 33 Yuan per hour. According to the annual report released by Beijing Transportation Research Center, taxis in Beijing transport 1,990,000 passengers per day. According to the GPS data, each taxi took an average of 32 trips per day. Assuming that 85% of all the 66,000 taxis were in operation each day, the number of riders per trip could be estimated as 1.1 passenger per vehicle trip. In New York, the number is 1.23 passenger per vehicle for yellow taxis. (New Yowk Taxi fact book, 485,000 trips and 600,000 passengers per day). Thus, the average money value of taxi passengers saved is approximately 30 Yuan for an hour, slightly lower than the 2012 average income of 32.6 Yuan per hour in Beijing (Government Statistics). The result only explained theoretical situations when traffic is extremely smooth. If congestion is taken into account, the value might be higher since rail transit would be much less affected by heavy traffic. For inner-city trips, trips less than 3 kms are most cost effective. The time value of long trip riders is significantly higher than taxi riders traveling less than 15 kms per trip. Suburban riders have the lower time value of 27.3 Yuan per hour compared with inner city and cross trip taxi riders. According to Figure 27, suburban taxi trips between 3 and 15 kms seemed to be the most cost-effective for the travelers. A possible explanation is transit are rarer in suburban area, thus passengers could save more time using taxis. Thus, taxis might actually be able to play a better role in the peripheral area of the city. Although an on-demand mode is hardly feasible, prearranged taxis could be a viable choice. In areas where rail option does not exist, taxis could also be used to connect urban rail instead of park+ride.

Time value per hour by Trip Catergory

	Inner city trips	Suburban Trips	Cross trips
1km<Trips < 3km	28.14	33.23	33.72
3km<Trips<15km	32.38	20.46	27.17
Trips > 15 km	42.63	31.06	49.55
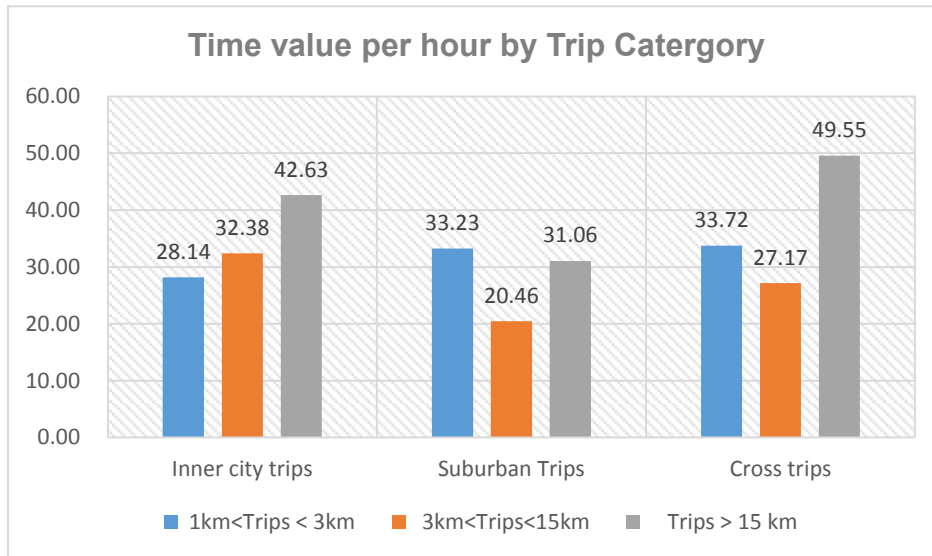
Figure 38. Time value per hour

7.   Conclusion

7.1 Taxi Operating Patterns in Beijing

The result of the study confirmed the geographical imbalance phenomenon found in previous studies. Taxis in Beijing, searching for customers in the context of a robust street hail market, clustered inside the inner city where density is high. Consistent with the findings of King et al. (2011) for New York City, the drop-off locations of taxis are much more dispersed than pick-up points, which might indicate that an on-demand mode cannot survive in suburban areas, thus the needs for taxis in suburban areas are suppressed.

Compared with ordinary drivers who always chose to stay in high-density areas for business, drivers of higher daily incomes seemed to have a different strategy by cruising in larger territories for profit. The occupancy rates of taxis fluctuated around 60% over time and reached 70% in morning peak, which suggests the existence of information asymmetry in taxi demand and supply. Although searching for customers seemed to be a random process in the past, information asymmetry could be largely reduced using location-based taxi apps, GPS dispatching system, or prearranged taxi services.

The analysis of time time partially explains why taxis or other vehicles-for-hire services exist despite the relatively high cost compared with the current transit system. When people chose to use taxis instead of transit for their trips, they saved an average of 75% of time per trip compared with the same trip made by transit. This suggests that in Beijing, when people considered their time worth more than 30 Yuan an hour, they were likely to use taxis instead of transit.

Due to file size and computing speed limitation of ARCGIS, I used one-day trace data and five-day point data to reduce calculation time, which limited the explanatory power of the analysis. In future studies, data of longer time series should be analyzed. Data cleaning should also be improved as manually correcting trace error generated from unordered GPS signal is not only time consuming but also prone to errors.

7.2   Non-Traditional Roles of Taxi Service?

Commonly, but not exclusively in developing countries, taxis are providing services away from the traditional definition of the industry. 'Parataxis,' including shared taxis and taxi bus services, could be an option for areas where demand is too dispersed to support an effective conventional public transportation system (Cooper et al., 2007).

Organized collective taxi services are common in Europe, especially for trips to and from the airport. The 1985 Transport Act of United Kingdom legitimized shared taxi service on either an immediate hiring basis (Section 10), where sharing schemes are identified by special signs at

ranks, or on vehicles that one might classify as informal sharing; or in a more formal prearranged way (Cooper et al., 2010). Gholami and Mohaymany (2012) evaluated the cost-effectiveness of taxi khattee, a fixed-route, unregulated, and shared taxi commonly used in Iran. They compared the jitney-like service with traditional bus service and argued that such service was cost effective in areas where population density and labor cost were low and people's value of time was high. Factor and Miller (2006) explored the concept of transit-taxi as a means to fill the need for improvement in off-peak public transport service.

Beijing has a population of over 20 million as well as an urban road area ratio of 5.8 percent. Road resources are limited compared with most cities in the United States (e.g. Los Angeles has an urban road area ratio of around 30 percent). In areas where people share origins, destinations and routes, shared rides in larger vehicles may help reduce vehicle number and alleviate congestion compared with more single rides in smaller vehicles. Taxi GPS data could be used to aggregate the individual travel pattern and to determine the routes where demands are high. For the high-demand routes, shared rides in larger vehicles could be used. Smaller vehicles provide flexibility where demand is weaker but still exists.

At the end of 2013, Beijing started a pilot program of employing customized bus service in its transportation system. The customized bus was more like a prearranged transportation to employment (T2E) service. Riders used prepaid monthly passes and were guaranteed seats on the non-stop shuttle to downtown CBD area or other job concentraters. The price is 15 Yuan (about $2) per trip, significantly higher compared with regular bus price (0.4 Yuan with IC card) or metro (2 Yuan per trip). The customized buses, although was regarded as "Buses for the Beverly Hillbillies" at first, actually attracted a large number of riders who would otherwise be auto-users.
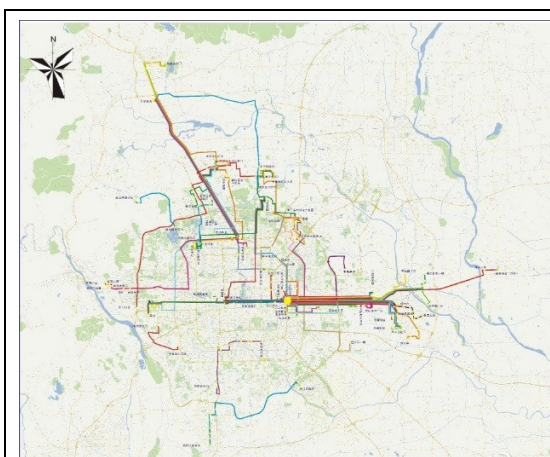
Figure 39. Route map of current customized bus service. Source: KangMing Xu, Weibo.com, 2014	Figure 40. Density map of taxi trips between inner city and suburban area.
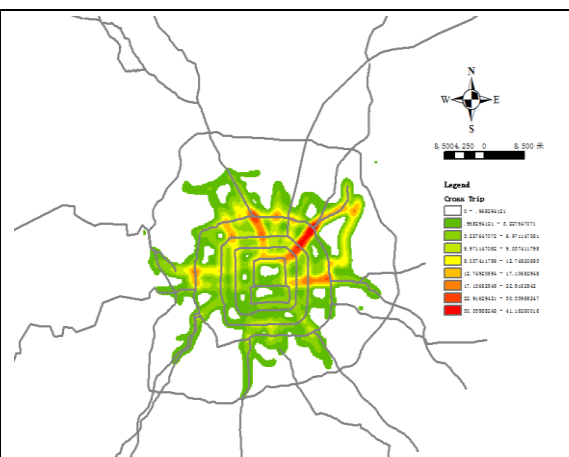
Comparing the customized bus service route map with the density map of taxi cross trips in Beijing (cross trips are defined in Section 5 as trips between inner city and suburban areas), we can see a similarity between the busiest corridors of taxi trips and customized bus routes. (Note: The northeast corner corridor is the airport highway. Therefore, it is frequently visited by taxis

but not by customized buses.) For corridors where demands are not high enough to support shared buses, shared taxis could also play a supplementing role in commuting. Taxis would be more affordable assuming that each customer pays 60–70% of the original fare. Moreover, drivers could have a higher profit as an incentive to serve suburban areas.

Appendix

Step1 Script: Identify different trips

```
############################################################
# Basic Settings
############################################################

import arcpy
import math
import os
from arcpy.sa import*
folder_path= os.getcwd()

#      Define workspace as your folder path
arcpy.env.workspace=folder_path
#      Overwriting output files
arcpy.env.overwriteOutput=True



############################################################
# Module0: Preparation
############################################################

fc3=arcpy.GetParameterAsText(0)

idlist=[]

arcpy.AddField_management(fc3,"trip_num","Double")
#Add field 'trip type'    1=With customer, 0=Empty Cruise
arcpy.AddField_management(fc3,"trip_type","Double")

# Get an array of id list
ID=arcpy.SearchCursor(fc3)
for row in ID:
      idlist.append(row.id)
# Clear redundunt element in the list
idlist=list(set(idlist))
idlist=sorted(idlist)
del row
del ID
```

```python
timelist=[]
startlist=[]
endlist=[]
trip_num_list=[]
trip_type_list=[]


trip_num=0
initial_status=0
current_status=0
time=0


for id in idlist:#for id in idlist[0:10]:
        trips=arcpy.UpdateCursor(fc3,'"id"='+str(id))
        i=1                 # first element controller

        trip_num=trip_num+1

        for row in trips:
            if i==1:     # first element
                initial_status=row.status
                current_status=int(initial_status)
                row.trip_type=current_status
                row.trip_num=trip_num
                trip_num_list.append(trip_num)
                trip_type_list.append(current_status)
                i=i+1
            else:           #other element
                if row.status==current_status:      #same trip
                    row.trip_num=trip_num
                    row.trip_type=current_status
                    trip_num_list.append(trip_num)
                    trip_type_list.append(current_status)

                else:
                    trip_num=trip_num+1
                    row.trip_num=trip_num
                    current_status=abs(current_status-1)
                    row.trip_type=current_status
                    trip_num_list.append(trip_num)
```

```
                    trip_type_list.append(current_status)
            del row
            del trips
            print time
            time=time+1


#print trip_num_list
#print trip_type_list

# variable j is defined to control the time information list
j=0
#Update the trip_num and trip_type information

times=arcpy.UpdateCursor(fc3)
for row in times:
        row.trip_num=trip_num_list[j]
        row.trip_type=trip_type_list[j]
        times.updateRow(row)
        j=j+1
        if j>(len(trip_num_list)-1):
                break

del row
del times



print "End of Point to Line Step1"
```

Step2 Script : Convert point to line and calculate fare information

```
################################################################
# Basic Settings
################################################################

import arcpy
import math
import os
from arcpy.sa import*
folder_path=r"F:\\thesis script"
line_folder_path="F:\\thesis script\\IDsep"
line_folder_content=os.listdir("F:\\thesis script\\IDsep")
```

```python
#      Define workspace as your folder path
arcpy.env.workspace=folder_path
#      Overwriting output files
arcpy.env.overwriteOutput=True




for file in line_folder_content:
 print file
 if file.split('.')[-1]=="shp":
     filename=file
     print filename
     fc3=str(line_folder_path)+"\\"+str(filename)
     print fc3
     #fc3=arcpy.GetParameterAsText(0)
     arcpy.MakeFeatureLayer_management(fc3, "lyr")

     fc5=folder_path+"\\Output\\"+"Line\\out_lines.shp"



     # Get an array of ID list
     Idlist=[]
     ID=arcpy.SearchCursor(fc3)
     for row in ID:
          Idlist.append(int(row.Id))
     # Clear redundunt element in the list
     Idlist=list(set(Idlist))
     Idlist=sorted(Idlist)
     del row
     del ID

     Id=Idlist[0]

     fc4=folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".shp"

     # Get an array of trip_num list
     idlist=[]
     ID=arcpy.SearchCursor(fc3)
     for row in ID:
          idlist.append(row.trip_num)
     # Clear redundunt element in the list
     idlist=list(set(idlist))
     idlist=sorted(idlist)
```

```python
        del row
        del ID
        print idlist


timelapselist=[]
timelist=[]
startlist=[]
endlist=[]



#   Variable i is defined to control the time of loop,
#   I set i<10 here simply for efficiency.
#   It takes too long to convert all the points to tracks



i=0
for id in idlist:    #id is trip num here

        # First created shape file linemerge.shp is used for later files to append
        if i==0:
                arcpy.SelectLayerByAttribute_management("lyr",          "NEW_SELECTION",
'"trip_num"='+str(id))
                arcpy.CopyFeatures_management("lyr",
folder_path+"\\Output\\templine.shp")

                #   For taxi GPS points with the same ID, Get the minimum and maximum
time in timelist
                #   Due to the format of the original data,the minimum time is starttime and
maximum time is end time
                trips=arcpy.SearchCursor(fc3,'"trip_num"='+str(id))
                for trip in trips:
                        taxiid=trip.id# the id of taxi that make this trip
                        timelist.append(trip.time)
                starttime = int(min(timelist))
                startlist.append(starttime)
                endtime  =  int(max(timelist))
                endlist.append(endtime)
                timelist=[]
                Idlist.append(int(taxiid))

                del trip
                del trips
```

```python
            inFeatures = folder_path+"\\Output\\templine.shp"
            outFeatures                                              =
folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".shp"
            lineField = ""
            sortField = "TIME"
            #   Execute PointsToLine
            arcpy.PointsToLine_management(inFeatures, outFeatures, lineField, sortField)
            #   Add field 'start'

#arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+"linemerge.shp","START",
"DOUBLE")
            # Add field 'end'

#arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+"linemerge.shp","END","
DOUBLE")

            i=i+1
            #print "1st round finished"

        # while loop>1,append out_line.shp to the linemerge.shp in each loop
        elif i<len(idlist):
            arcpy.SelectLayerByAttribute_management("lyr",          "NEW_SELECTION",
'"trip_num"='+str(id))
            arcpy.CopyFeatures_management("lyr",
folder_path+"\\Output\\templine.shp")

        #   For taxi GPS points with the same ID, Get the minimum and maximum time in
timelist
        #   Due to the format of the original data,the minimum time is starttime and
maximum time is end time
            trips=arcpy.SearchCursor(fc3,'"trip_num"='+str(id))
            for trip in trips:
                taxiid=trip.id# the id of taxi that make this trip
                timelist.append(trip.time)
            starttime = int(min(timelist))
            startlist.append(starttime)
            endtime   =   int(max(timelist))
            endlist.append(endtime)
            Idlist.append(int(taxiid))

            timelist=[]

            del trip
```

```
            del trips


            inFeatures = folder_path+"\\Output\\templine.shp"
            outFeatures = folder_path+"\\Output\\"+"Line\\"+"out_lines.shp"
            lineField = ""
            sortField = "time"
            # Execute PointsToLine
            arcpy.PointsToLine_management(inFeatures, outFeatures, lineField, sortField)
            # Add field 'start'

#arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+"out_lines.shp","START",
"DOUBLE")
            # Add field 'end'

#arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+"out_lines.shp","END","D
OUBLE")

            #Merge the individual tracks to one shapefile using the append function

arcpy.Append_management([folder_path+"\\Output\\"+"Line\\"+"out_lines.shp"],
folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".shp" ,"TEST","","")
            i=i+1
            #print str(i)+"st round finished"

    #   Add field 'start'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","START","DOUBLE")
    # Add field 'end'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","END","DOUBLE")
    #Add field 'length'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","length","DOUBLE")
    #Add field 'starthour'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","starthour","DOUBLE")
    #Add field 'timelapse'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
```

```python
p","timelapse","DOUBLE")
    #Add field 'speed'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","speed","DOUBLE")
    #Add field 'fare'

arcpy.AddField_management(folder_path+"\\Output\\"+"Line\\"+str(Id)+"_linemerge"+".sh
p","fare","DOUBLE")
    # variable j is defined to control the time information list
    length=0
    j=0

    desc = arcpy.Describe(fc4)
    shapeName = desc.ShapeFieldName
    #Update the start and end time information
    time=arcpy.UpdateCursor(fc4)
    for row in time:
        row.START=startlist[j]
        row.END = endlist[j]
        row.starthour=int(str(startlist[j])[4:6])
        deltaday=float(str(endlist[j])[2:4])-float(str(startlist[j])[2:4])
        deltahour=float(str(endlist[j])[4:6])-float(str(startlist[j])[4:6])
        deltamin=float(str(endlist[j])[6:8])-float(str(startlist[j])[6:8])
        deltasec=float(str(endlist[j])[8:10])-float(str(startlist[j])[8:10])
        row.timelapse=
float(deltaday*24*3600)+float(deltahour*3600)+float(60*deltamin)+float(deltasec)
        row.Id=Idlist[j]
        feat = row.getValue(shapeName)
        row.length= feat.length
        #row.speed=(row.length/1000)/row.timelapse

        if row.starthour>5 and row.starthour<23:    #day trip
            if row.length <=500:
                fare=0
            elif row.length <= 3000:
                fare=10+1
            elif row.length <15000:
                fare=10+1+((row.length-3000)/1000)*2
            else:
                fare=11+12*2+((row.length-15000)/1000)*3
        else:                                            #night trip
            if row.length <=500:
                fare=0
```

```python
        elif row.length <= 3000:
                fare=10+1+1
        elif row.length <15000:
                fare=10+1+1+((row.length-3000)/1000)*2.4
        else:
                fare=11+1+12*2.4+((row.length-15000)/1000)*3.6
    row.fare=fare
    time.updateRow(row)
    j=j+1
del row
del time


print "End of Point to Line Step2"
```

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