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Evaluating the Influence of Taxi Subsidy Programs on Mitigating Difficulty Getting a Taxi in Basis of Taxi Empty-loaded Rate

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Abstract

With the advent of the "Internet plus" era, a number of companies have established the service platform of taxi-hailing apps relying on the mobile Internet, which builds up a communication bridge between passengers and taxi drivers. Besides, taxi companies have initiated many subsidy programs. Based on the prediction model of passenger waiting time built in this paper, it has been proved that there exists a negative correlation between passenger waiting time and taxi empty-loaded rate. This paper also analyzes the influencing factors of taxi empty-loaded rate. The results show that the higher the taxi sharing rate is, the lower the taxi empty-loaded rate is. And the longer the average operation time is, the higher the taxi empty-loaded rate is. By comparing various taxi subsidy programs, this paper finally draws a conclusion that it will be much more difficult to take a taxi if taxi companies provide subsidies for passengers. But the difficulty in taking a taxi can be alleviated if taxi companies provide subsidies for taxi drivers.

Keywords: prediction model of passenger waiting time, arrival time interval of empty taxis

1. Introduction

How to alleviate the difficulty in taking a taxi is an important issue facing urban traffic. Nowadays, most taxis can provide round-the-clock service. Although the number of taxis has been increasing, the difficulty in taking a taxi can not be resolved ultimately. Even worse, the operating efficiency of taxis has been declining. The increase of urban population and diversification of social activities make the demand for taxi rise. As the traffic jam becomes worse in cities, to guarantee personal income, many taxi drivers are unwilling to drive on busy roads and main urban zones, which makes it hard for many citizens to take a taxi near some transportation junctions, commercial centers and hospitals. City construction affects the efficiency of taxi. Not being standard in the taxi industry and taxi drivers' refusal to take passengers are the human factors that make it difficult to take a taxi. The most serious disadvantage of those factors is the extremely high empty-loaded rate---some taxi drivers drive aimlessly. And passengers are confused about the fact that it's impossible to take a taxi on rainy days or during rush hours even though they have been waiting for a long time.

With the development of "Internet plus" era, the taxi-hailing app Didi is becoming more and more popular among people. The unique ad-vantages of Didi have a profound effect on traditional taxi industry. The-se taxi-hailing apps always have their typical subsidy programs. The subsidy war between Didi and Kuaidi has drawn public attention. They have lost billions of dollars subsidizing riders and drivers in a bid for market share. This paper aims to discover what influence these subsidy programs have made on easing the difficulty in taking a taxi.

At present, Lu Shufang and other scholars have found that taxi-hailing apps like Didi can be great of great assistance for easing the difficulty in taking a taxi. Qi Guande and other scholars have predicted the passenger waiting time. Cao Yi and other scholars have searched for the influence of usage rate of taxi-hailing apps on urban taxi social welfare. Wang Guangtao and other scholars have made suggestions about integrating the management of taxi-hailing apps. Scholar Wu Yonghua has made the existing problem and countermeasure analysis of taxi-hailing apps. Zhang Zhenzhen has pointed out that the underlying cause of the difficulty in taking a taxi lies in the taxi company system, and high taxi rental fees lead to taxi drivers' unwillingness to take passengers during rush hours or shift time. AnYukang has researched on the difficulty in taking a taxi in Beijing area from the point of supply and demand. Sun Huitai has studied the strategies of alleviating the difficulty in taking a taxi, such as increasing effective supply of taxis and diverting the demand of taking a taxi. GengYonghao has expected to alleviate the difficulty in taking a taxi by presenting taxi drivers with gasoline cards if they can take passengers to the designed places. Jiang Yuan has made the conclusion that the extension of the city scale would increasingly deepen the difficulty in taking a taxi.

The difficulty in taking a taxi means that it's hard for passengers to take a taxi in the expected time or there is no taxi available. What's more, some taxi drivers are picky, meddlesome and even refuse to take passengers. The concentrated expression of the difficulty in taking a taxi is passenger's long waiting time. If the subsidy programs really decrease the passenger's waiting time to a certain extent, it can prove that subsidy programs can resolve the difficulty in taking a taxi.

Passenger waiting time is closely related to empty-loaded rate, so this paper attempts to find out the relationship between passenger waiting time and empty-loaded rate. Many factors contribute to the empty-loaded rate. By way of the study on the major factors influencing the empty-loaded rate, the researcher is able to get the interaction between taxi subsidy programs and empty-loaded rate. And then the researcher deduces the relationship of passenger waiting time and taxi subsidy programs. Namely, the relationship between the degree of difficulty in taking a taxi and taxi subsidy programs can be obtained. Finally, this paper examines whether the implementation of subsidy programs is helpful to alleviate the difficulty in taking a taxi.

2. Evaluation of the Model

The difficulty in taking a taxi means that it's hard for passengers to take a taxi in the expected time or there is no taxi available. What's more, some taxi drivers are picky, meddlesome and even refuse to take passengers. The concentrated expression of the difficulty in taking a taxi is passenger's long waiting time. If the subsidy programs really decrease the passenger's waiting time to a certain extent, it can prove that subsidy programs can resolve the difficulty in taking a taxi. Next this paper will discuss the relationship between subsidy programs and passenger waiting time.

2.1 The Prediction Model of Passenger Waiting Time

The high-pressured water jet cutting is a special way of removal. The water jet could reach the pressure up from 10MPa to 400MPa or even higher with the help of superchargers. The water gains pressure energy and squirts out of tiny injectors, then the pressure energy transforms into kinetic energy therefore forms a high speed jet-flow. The water jet removal reaches its goal of removing the debris by using this kinetic energy of the high speed jet-flow to shock and do damage to the workpieces.

2.1.1 Modelling of the Arrival Time Intervals of Empty-loaded Car

This paper uses the exponential distribution method to model the arrival time intervals of empty-loaded car. With the course of time, the arrival quantity of the empty-loaded car in a certain place is a classic Poisson process. In time divisions, the arrival quantity of the empty-loaded car in a certain place obeys Poisson distribution, namely the arrival time intervals should obey exponential distribution. As the increasing rate of the arrival quantity of the empty-loaded car in a certain place varies in real life, so does the arrival time interval, the paper works on the assumption that the arrival time interval of empty-loaded car in a specified time period of obeys the time-sharing exponential distribution. In this situation, the rate of empty-loaded car is inversely proportional to the arrival time interval. Figure 1 and Figure 2 visualize the relation between the arrival quantity of the empty-loaded car in a certain place and exponential distribution in a period of time.

Since the quantity of empty taxis is nearly not affected by the surrounding environment, this paper holds that the event of the taxi driver arriving at some place is ran-dom. Then the probability distribution table is built based on Poisson distribution.

Table 1. The Probability Distribution Table Based on Poisson Distribution

$P_1(t)$	$P_2(t)$	$P_3(t)$	$P_4(t)$	$P_5(t)$	$P_6(t)$	$P_7(t)$	$P_8(t)$	$P_9(t)$	$P_{10}(t)$	$P_{11}(t)$	$P_{12}(t)$	$P_{13}(t)$	$P_{14}(t)$
0.015	0.034	0.061	0.091	0.117	0.132	0.132	0.119	0.093	0.071	0.047	0.030	0.007	0.004

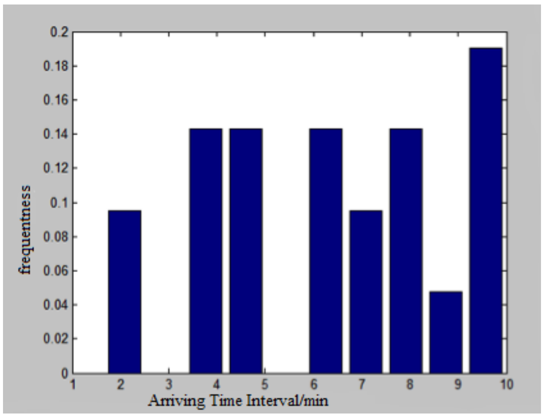

Figure 1. The Distribution of Arriving Time Interval between 12:00-13:00 in Guangzhou

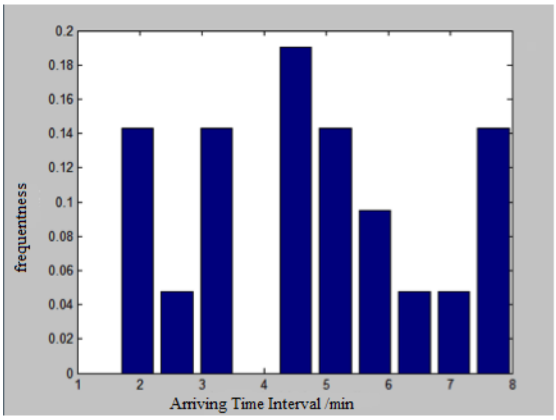

Figure 2.The Actual Distribution of Waiting Time between 12:00-13:00 in Guangzhou

2.1.2 Passenger Waiting Time Modelling

This paper calculates the passenger waiting time distribution by estimating the worst case. Firstly, this paper assumes that passengers arrive and wait for taxis uniformly, randomly and equiprobably within a specified time period of *t*. As a result, it is suggested that the probability density where passengers are in the time period of *t* is proportionate to the product $p(t)t$ of the probability density of time interval itself and the length of the time interval. Next, a passenger needs to wait for a period of *t* to get on a taxi at most in the worst case when he is in the time interval of *t*. Thus in the worst case, the probability density $f(\Delta t)$ of waiting time $WT=t$ is in proportion to $p(t)t$, normalized to the formula:

$$f(WT=t)=\frac{P(t)t}{\int_0^{\infty}P(t)tdt}=\frac{\lambda e^{-\lambda t}t}{\int_0^{\infty}\lambda e^{-\lambda t}tdt}=\lambda^2e^{-\lambda t}t \tag{1}$$

In this formula, $p(t)t$ stands for the product of the probability density of time interval itself and the length of the time interval. $p(t)$ stands for the probability density of time interval itself, λ stands for simple variable relating waiting time and probability of getting on the taxi.

Base on the the waiting time distribution(formula(1)), the cumulative probability of getting on the taxi $F(T)=P(WT\le T)$ is calculated by the distribution of cumulative probability.

$$F(T)=\int_0^T f(t)dt=\int_0^T\lambda^2e^{-\lambda t}d=1-\lambda Te^{-\lambda T}-e^{-\lambda T} \tag{2}$$

λ refers to a single variable of passenger waiting time and the probability of taking taxis, $WT=t$ refers to the passenger waiting time, $WT=t$ refers to the cumulative probability of taking taxis when passengers have waited for some time.

2.1.3 The Model Parameters

The parameter λ As for a period of time, the passenger waiting time is a random variable. Its probability density and cumulative distribution can be calculated by parameter estimation by historical data. According to formula 2, the relationship between the passenger waiting time and the probability of taking taxis is only associated with the single variable λ. So this paper adopts maximum likelihood estimation.

$$\bar{\lambda} = \arg\max \bar{l}(\lambda \mid t_1, \ldots, t_n) = \arg\max_{\lambda} \lambda^n e^{-\lambda \sum t_i} = \sum t_i / n = \frac{1}{\mu} \tag{3}$$

$t_1 \ldots t_n$ is the time interval of the empty-loaded cars' arriving time, μ is the sample mean of arrival time interval.

The length of time: The length of time has an influence on the actual time interval for arriving of empty taxi and exponential distribution fitting. The best fitting effect is the length of one hour. As shown in figure 3, when the length of time is too short, the quantity of empty arriving taxis will be small, and the distribution of time interval for arriving of empty taxi will be more easily affected by the environment, and the fitting effect will become worse. When the length of time is too long, time interval for arriving of empty taxi may be variant in this period, and the fitting effect will become worse, too. Therefore, this paper assign one hour as time length's value.

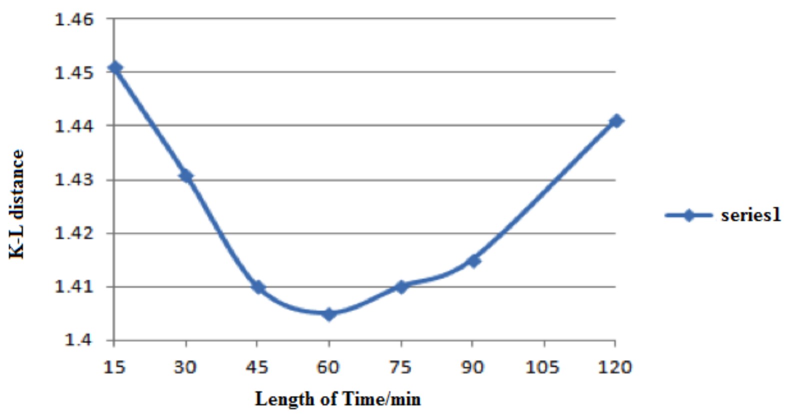

Figure 3. The Effect of Length of Time on the Result of Exponential Distribution Fitting

On the premise that an hour is assigned as the value of time length, the value distribution of λ is shown in table 2.

Table 2. The Value of λ when the Length of Time is an Hour

the Length of Time	$\lambda_i (i=1,2...14)$
7:00~8:00	0.15
8:00~9:00	0.12
9:00~10:00	0.14
10:00~11:00	0.18
11:00~12:00	0.16
12:00~13:00	0.15
13:00~14:00	0.14
14:00~15:00	0.13
15:00~16:00	0.17
16:00~17:00	0.21
17:00~18:00	0.15
18:00~19:00	0.14
19:00~20:00	0.2
20:00~21:00	0.19

When normalized value λ is put into the model of empty intervals and passenger waiting time, two functions of time t can be obtained.And because empty intervals negatively related to empty-loading ratio, passenger waiting time and taxi empty-loading ratio are fitted with matlab. Then the figure of some function of passenger waiting time and empty-loading ratio can be obtained.

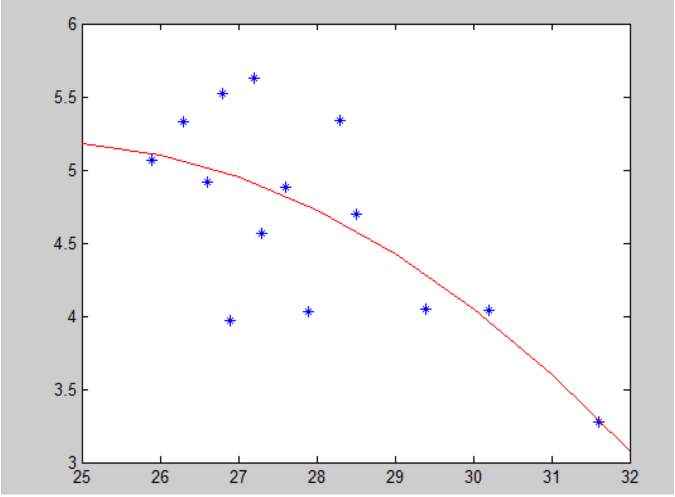

Figure 4. Passenger Waiting time and Empty-loading Ratio

As the figure shows, the horizontal axis demonstrates the taxi empty-loaded rate and the vertical axis demonstrates the passenger waiting time.

Judging from the figure, it is not difficult to draw the conclusion that the higher the taxi empty-loaded rate is, the shorter the passenger waiting time is. This conclusion is in conformity with the assumption which was made according to the modelling study. Thus, it is reasonable to deduce the passenger waiting time from empty-loaded rate. In other words, the taxi empty-loaded rate is inversely proportional to the passenger waiting time.

2.2 Analysis on Major Influencing Factors of the Empty-loaded Rate

Urban resident trip survey plays a central role in urban traffic planning. On the basis of urban taxi traffic mode survey and taxi operating status survey, this paper analyzes empty-loaded rate of urban taxi.

2.2.1 The Turnover Volume of Urban Resident Travel By Taxi

The turnover volume of urban resident travel by taxi are products of the passenger capacity and the distance traveled by the taxi.

$$Z = P \cdot Q \cdot R \cdot D = P \cdot Q \cdot R \cdot (S + \frac{C - m_0}{m}) \tag{4}$$

In the formula (4), *Z*refers to the turnover volume of urban resident travel by taxi.*P*refers to the total number of urban citizens. *Q* refers to the rate of urban resident trip (time/day). *R* refers to the sharing rate of urban taxi traffic mode. *D* refers to the average trip distance(km). *C* refers to the average cost of residents in taking a taxi (yuan). m_0 refers to the flag-down fare(yuan). *S* refers to the starting mileage (km). *m* refers to the charging fee per kilometer (yuan/km).

2.2.2 Total Mileage of Occupied Taxi Every Day

The number of the passengers is variable each time when the taxi is in service. Thus average number of the passengers each time is used to calculate the total mileage of occupied taxi every day, the formula is:

$$L = \frac{Z}{A} \tag{5}$$

In the formula (5), *L* refers to the total mileage per day (km). *A* refers to the average number of passengers taking taxis (ten thousand people/a taxi).

2.2.3 Calculation of the Taxi Empty-loaded Rate

The Formula of the Taxi Empty-loaded Rate is as follows.

$$K = 1 - \frac{L}{T\overline{V}n} \tag{6}$$

In formula (6), *K* refers to the taxi empty-loaded rate(%). $\overline{V}$ refers to the average service time per day (km/h), n refers to the taxi quantity.

In the formula (6), the taxi quantity can be obtained by calculating the taxi quantity. Considering the temporal distribution of passenger source has obvious difference, the taxi quantity calculated by the rate of resident trip per day may exceed the demand of resident night trip because the demand of resident day trip is ignored. So it’s needed to correct the formula (6).

$$K = 1 - \frac{xL}{yT\overline{V}n} \tag{7}$$

In the formula (7), x, y stands for the quantity travel by taxi by percentage of x in a period of yT. Substitute formula (5) and (6) in formula (4).

$$K = 1 - \frac{xPQ}{AfyT\overline{V}} \cdot (S + \frac{c - m_0}{m}) \cdot \frac{R}{N} \tag{8}$$

2.2.4 Analysis on the Major Influencing Factors of the Taxi Empty-loaded Rate

In order to analyze the influencing factors of taxi quantity,

$$\frac{xPQ}{AfyT\overline{V}} \cdot (S + \frac{c - m_0}{m}) = g \tag{9}$$

The relational model among taxi quantity, empty-loaded rate and sharing rate is established.

$$K = 1 - \frac{gR}{N} \tag{10}$$

The scale coefficient g is determined by the parameter of resident trip, taxi service, etc. It reflects the sensitivity level of the taxi empty-loaded rate to the sharing rate and taxi quantity. The bigger the value of g is, the higher the sensitivity level of the taxi empty-loaded rate to the sharing rate and taxi quantity is. When the city develops into a certain stage, both of the economic level of residents and urban traffic structure tend to be stable and change a little in short time. Hence The scale coefficient g may be considered as constant.

According to the formula (10), the empty-loaded rate of taxi is negatively related to sharing rate but positively related to taxi quantity.

3. Analysis on Various Subsidy Programs

3.1 The Influence of Subsidy Programs on Alleviating the Difficulty in Taking a Taxi throughout the City

The taxi subsidy programs of Kuaidi and Didi are shown in table 3 and table 4 respectively.

As can be seen from the table above, the subsidy programs of Didi and Kuaidi are mainly reflected in two aspects: subsidy on passengers and subsidy on taxi drivers. Meanwhile, subsidy programs directly affect the passenger's total fare of taxi and taxi driver's profitability.

With this subsidy, passengers can spend less money on taking taxis and they are more willing to taking taxis. Then the sharing rate of taxi will be increased. According to the formula $K=1-\frac{gR}{N}$, the decrease of the empty-loaded rate can lead to the increase of passenger waiting time.

In addition, taxi drivers can gain more profits with this subsidy. And they are more willing to picking up passengers. Thus the business hours of taxis are increased. Based on the formula $K=1-\frac{L}{TVn}$, the increase of the empty-loaded rate can lead to the decrease of passenger waiting time.

From the perspective of whole city, it can be concluded that subsidy programs really decrease passenger waiting time, and then the difficulty in taking a taxi will be alleviated.

Table 3. The Changes of Subsidy Program of Kuaidi

Date	The Change of Subsidy Program
2014.1.20	Total fee is reduced by 10 yuan,
	Driver gets a reward of 10 yuan.
2014.2.17	Total fee is reduced by 10 yuan,
	Driver gets a reward of 5-11 yuan.
2014.2.18	Passenger gets 13 yuan as subsidy.
2014.3.4	Passenger gets 10 yuan as subsidy,
	Drivers' subsidy remains unchanged.
2014.3.5	Passenger gets 5 yuan as subsidy.
2014.3.22	Passenger gets 3-5 yuan as subsidy.
2014.5.17	Passenger gets no subsidy.
2014.7.9	Driver gets 2 yuan as subsidy.
2014.8.9	Driver gets no subsidy.

Table 4. The Changes of Subsidy Program of Didi

Date	The Change of Subsidy Program
2014.1.10	Total fee is reduced by 10 yuan,
	Driver gets a reward of 10 yuan.
2014.2.17	Total fee is reduced by 10-15 yuan,
	Driver gets a reward of 50 yuan for the first business.
2014.2.18	Passenger gets 12-20 yuan as subsidy.
2014.3.7	Passenger gets 6-15 yuan as subsidy at random.
2014.3.23	Passenger gets 3-5 yuan as subsidy.
2014.5.17	Passenger gets no subsidy.
2014.7.9	Driver gets 2 yuan as subsidy.
2014.8.12	Driver gets no regular subsidy.

3.2 The Influence of Subsidy Programs on Alleviating the Difficulty in Taking a Taxi during Rush Hours

With this subsidy, taxi drivers can gain more profits and more incentives to work. Then the daily operating time of taxis will be increased because taxi drivers are more willing to work during rush hours. According to the formula $K=1-\frac{L}{T\bar{V}n}$, the increase of empty-loaded rate can lead to the decrease of passenger waiting time. Thus the difficulty in taking taxi during rush hours will be alleviated.

3.3 The Influence of Subsidy Programs on Alleviating the Difficulty in Taking a Taxi in Congested Areas

Subsidizing on passengers may deepen the difficulty in taking a taxi in congested areas. To some degree, such subsidy programs increase the number of passengers, and also increase the sharing rate of taxis. Then the rate of empty taxis will be lower and passenger waiting time will be longer. That is, this kind of subsidy programs can not alleviating the difficulty in taking a taxi in congested areas.

The increase of the taxi driver's operating time contributes to the empty-loaded rate, then the passenger waiting time will be decreased. Therefore, difficulty in taking a taxi in congested areas can be alleviated.

4. Conclusion

The number of empty taxis arriving at some area can be regarded as a classical Poisson process. Based on the prediction model of passenger waiting time built in this paper, it has been proved that there exists a positive correlation of passenger waiting time with empty taxi arrival time interval. And because taxi empty-loaded rate is negatively related to empty taxi arrival time interval, there exists a negative correlation between passenger waiting time and taxi empty-loaded rate.

This paper also analyzes the influencing factors of taxi empty-loaded rate. The results show that the higher the taxi sharing rate is, the lower the taxi empty-loaded rate is. And the longer the average operation time is, the higher the taxi empty-loaded rate is.

By comparing various taxi subsidy programs, this paper finally draws a conclusion that it will be much more difficult to take a taxi if taxi companies provide subsidies for passengers. But the difficulty in taking a taxi can be alleviated if taxi companies provide subsidies for taxi drivers.

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Appendixes

Table 1. Distribution of Taxis in Beijing From DidiCangqiong Intelligent Platform

Longitude	Latitude	Numbers of Taxis
121.4788	31.2143	555
121.5136	31.1883	179
114.324	30.5454	128
121.6109	38.9121	98
116.4581	39.9692	87
121.5518	38.9612	85
116.4581	39.9603	80
116.4953	39.9892	78
116.5139	40.0137	75
116.4983	39.9133	73
116.4758	39.9187	71
116.5195	40.0207	70
118.1808	39.63	70
116.5039	40.0064	70
116.4678	39.8938	68
116.4952	39.9941	68
118.3014	35.1099	67
116.4713	39.9772	67
116.3834	39.988	66
116.4791	39.9916	65

116.4944	39.9916	65
116.4824	39.982	64
116.466	39.9553	64
116.3783	39.9712	63
116.5263	40.0188	62
114.4792	38.0154	62
130.2768	47.3452	62
116.4697	39.9551	62
116.454	39.9954	62
116.473	39.9373	61
116.3145	39.8997	61
116.4774	39.9065	61
116.4813	39.9816	60
116.3829	39.95	59
116.3263	39.9026	59
116.4988	40.0009	59
125.9585	41.7474	59
116.4755	39.9186	58
116.3621	39.9875	58
116.5083	40.0128	58
116.4771	39.8857	58
116.4663	39.8902	57
122.9956	41.1145	57
116.4766	39.917	56
116.2847	39.9037	56
116.4732	39.9064	56
116.4255	39.9897	55
116.5319	40.0228	55
116.4434	39.9475	54
116.4411	39.9211	54
116.422	39.9753	54
116.3498	39.9064	53
124.3983	43.1727	53
116.4539	39.9657	53
116.576	40.0463	53
116.3624	39.9727	53
116.4506	39.9377	52
116.3032	39.9919	52
116.4714	39.9541	52
116.4717	39.9233	52
116.2839	39.9274	52
116.4358	39.9076	52
116.5557	40.0358	52

125.979	41.7459	52
116.4243	39.9501	52
116.4354	39.9342	51
116.4773	39.9731	51
116.3647	39.9022	51
116.5386	40.0303	51
116.5614	40.0355	51
116.5671	40.0345	51
130.2822	47.3069	51
116.5448	40.0331	51
116.5018	39.9195	51
116.4712	39.8774	50
116.4164	39.9588	50
116.4898	39.9182	50
116.3666	39.9542	50
116.3273	39.974	50
116.3231	39.9335	49
116.3733	39.9941	49
116.4384	39.9713	49
116.3763	40.0101	48
116.4468	39.8666	48
116.4968	39.9147	47
116.4406	39.997	47
116.46	39.9428	47
130.2748	47.2994	47
116.3613	39.9447	47
116.591	40.092	47
116.356	40.034	47
116.3384	40.0535	47
115.686	37.7388	47
116.3122	39.9699	46
116.459	39.9831	46
116.4604	39.8735	46
116.418	39.9739	46
116.322	39.8976	46
116.4037	39.9771	46
116.3602	40.0176	46
116.4085	39.9515	46
116.3972	39.9535	46
116.3151	39.9487	46
116.3441	39.9058	45
116.3663	40.0268	45
130.272	47.2883	45

120.3032	30.4392	45
116.5904	40.079	45
116.4724	39.9333	45
129.6056	44.5991	45
116.4423	39.9592	44
116.3284	40.0702	44
116.3623	39.9349	44
116.4393	39.9335	44
116.3448	39.9661	44
116.33	40.0689	44
116.4199	39.9949	44
116.5145	39.9115	44
116.3569	39.9064	43
116.446	39.8975	43
116.3918	39.9795	43
116.3372	39.994	43
116.5927	40.0608	43
116.2686	39.9312	43
116.3559	39.9296	43
116.6251	40.0529	42
116.2815	39.9222	42
116.3447	39.9877	42
116.5972	40.0565	42
116.443	39.942	42
116.2858	39.9173	42
116.3655	39.9238	42
116.3013	39.9109	42
116.355	39.8583	42
116.4936	39.9213	42
116.469	39.8738	42
116.3556	40.0373	42
116.3147	39.9905	42
116.6282	40.0506	42