

## Research on the Accessibility of Medical Facilities under the Hierarchical Medical System

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### Abstract

Establishing a rational Hierarchical Medical System is conducive to form scientific and ordered healthcare market, the system can improve the efficiency of medical resources' allocation and the ratio of the health insurance's utilization, and also reduce the burden of medical treatment on patients. This study improved the two-step's two-step floating catchment area method (two-step 2SFCA) by taking advantage of the distance decay model, and according to the relationship between spatial locations, the search radius of each points was determined, hence the disadvantage of the same accessibility in the same catchment area was compensated. By utilizing the huff model, the probability of hospital selection was calculated, and the spatial accessibility of medical facilities was more accurately evaluated. Comparing the accessibility between the General Medical System and the Hierarchical Medical System, results show that (1) Hierarchical Medical System can effectively improve the accessibility of medical facilities. (2) The referral process needs to be strictly controlled. (3) The improved method can describe the differences in the distribution of medical resources more objectively and detailed between regions, hence facilitating the analysis of allocation and optimization of medical resource.

### Keywords

**Hierarchical medical system; Resource Allocation; Accessibility; Referral Rate.**

### 1. Introduction

It is a long-time problem in Chinese healthcare industry that seeing doctor is difficult and expensive. About 80% of the high-quality medical resources in a city are concentrated on large comprehensive hospitals, and medical services failed to assign to the Primary Health Care [1], those reasons above lead to the difficulty of seeing doctors. Besides, lots of patients with common disease go to Tertiary Hospital, it is not only a wasting of high-quality medical resources, but also a difficulty for those patients with severe diseases to get treatment, hence finding a rational method to guide patients is one of the most important ways to mitigate the problem. Generally speaking, the establishment of clinics grading system is beneficial for constructing a scientific and ordered healthcare market, also improving the allocation of medical resources, so the Hierarchical Medical System is regarded as a crucial tool to facilitate the reformation of healthcare market and effective way to mitigate the "difficult and expensive to see doctors" problem. The instruction of the 13th Five-Year plan published by General Office of the State Council announced that the goal about constructing Hierarchical Medical System is "Gradually improving in the next two years, and becoming mature within five years" [2]. At the same time, all the major medical facilities should update their standard of assessment. By setting rational referral rate, strengthen relationship between referral and medical insurance, ultimately guide more patients with common diseases go to Primary Health Care, optimize allocation of medical resources. At present, Hierarchical Medical System has been implemented in many cities. The basic thought is "First visit at the Primary Health Care, then transfer to the Tertiary Hospital according to severity of diseases." Hierarchical Medical System regulates the first treatment must be done at the Primary Health Care, and then transfer to Tertiary Hospital, according to the strict procedure.

There are many researches about Hierarchical Medical System from theoretical analysis and technical support. The theoretical analysis includes two parts: qualitative analysis and quantitative analysis. The researches of qualitative analysis mainly focus on the mechanism of Hierarchical Medical System. The quantitative analysis focus on the factors of the referral behavior from views of the patient and the doctor [3][4][5], the construction of the evaluation system [6][7]. The technical support is the construction of electronic platform and informatization [8]. This study bases on the convenience of resources acquisition, evaluates accessibility of medical facilities under the Hierarchical Medical System. Through that, the supply and demand of medical resources can be objectively analyzed.

Accessibility to health care often refers to spatial accessibility and is concerned with the complex relationship between the spatial location of the population and the supply of health care facilities. Accessibility to medical facilities is recognized as an important facilitator of overall population health. From the perspective of space, accessibility evaluates whether the supply of medical resources is sufficient and rational. There are two focuses of accessibility researches: cost, supply and demand. Early research study, such as the nearest distance method, from the view of cost like travel time, distance, money and other costs. However, this method ignores the supply and service ability of medical facilities, can't reflect the scale and difference of medical service. Several studies since then have attempted to compensate the shortcomings. Some add the ratio of supply and demand to reflect the level of medical service. The common methods include ratio, gravity model[10] and two-step floating catchment area method [11,12]. The ratio method and gravity model focus on the resources-to-population ratio, ignore the competition for limited resources due to the sharing of the same medical service among the different residents, also the service radius isn't various. The early two-step floating catchment area method was proposed by Radke and Mu[14]. The method considers the potential interaction of supply and demand. In the first step, takes each medical facilities location as the research center, all population locations within a travel time or distance are searched for and the medical facilities-to-population ratio is calculated. In Second step, takes each population location as the research center, all medical facilities locations are searched for within the travel time or distance and their respective medical facilities-to-population ratios calculated in the first step are summed up. The shortcoming of competition for limited resources in gravity model is considered, but the same search domain still shares the same weight of distance decay[15]. Many recent 'improvements' to the original 2SFCA method have been developed, which generally either account for distance-decay within a catchment or enable the usage of variable catchment sizes[16][17].

Most studies of accessibility measure are once-visit from population locations to the medical facilities location. Few studies discuss the whole process including the referral process. The treatment under the Hierarchical Medical System is different from the existing medical system. According to the Hierarchical Medical System, patient's first treatment must be done at the Primary Health Care, and then transfer to Tertiary Hospital, according to referral procedures and the severity of patients' illness. Zhong[18] has proposed two-step 2SFCA method. Divided the treatment into two phases, and calculate the actual patients' number through different referral ratio, then sum up the accessibility of two phases. However, the study ignores the distance decay and patient preference. Zhang[19] measured the accessibility of medical treatment in Xi'an under the Hierarchical Medical System, provided theoretical support for the traffic construction under the new system. But the research lacks deeper discussion, only considers travel costs. Nowadays, Medical Reform pays more attention to patients, whose choice of hospitals or doctors directly affects the utilization of medical resource and further affect the balance of supply and demand. So it is important to consider patients' trait. Building on previous research, this paper presents an enhancement to the two-step 2SFCA method by applying distance decay, in both the first step and the second step, also accounting for and patients' preference.

## 2. Research Method.

The accessibility is measured under both General Medical System and Hierarchical Medical System by enhanced two-step 2SFCA. Under General Medical System, patients are easily attracted by

doctors' clinical experience and the abundant medicine hospitals provide. so we suppose that it is the first choice for patients to go to Tertiary Hospitals for treatment. Under the Hierarchical Medical System, It can be divided into two phases. Phase one: Finish treatment at Primary Health Care . Phase two: Refer to Tertiary Hospitals, receive treatment in both Primary Health Care and Tertiary Hospital.

**2.1 Under the General Medical System.**

Patients choose the Tertiary Hospital they preferred for treatment within the catchment area.  $P_{ip}$  represents the possibility of population (  $i$  ) choose Tertiary Hospital (  $P$  ) , can be calculated by Huff model:

$$P_{ip} = \frac{S_p(d_{ip})^{-\delta}}{\sum_{t \in (d_{it} \leq d_i)} S_t(d_{it})^{-\delta}} \tag{1}$$

Where  $d_{ip}$  is the distance between the population (  $i$  ) and the Tertiary Hospital (  $p$  ) ;  $d_{it}$  is the distance between the population (  $i$  ) and the  $t$ th Tertiary Hospital.  $d_i$  is the average value of the distance between population (  $i$  ) and all the hospital that can get, It shows the average travel capacity of population (  $i$  ) .  $S_p$  is the amount of medical resources in Tertiary Hospital (  $p$  ) ;  $S_t$  is the amount of medical resources in  $t$ th Tertiary Hospital, medical resources is described by the number of health bed.  $\delta$  is the friction-of-distance coefficient.

Firstly take Tertiary Hospital (  $p$  ) as the research center, Search all population (  $i$  ) that are within the catchment area from Tertiary Hospital (  $p$  ) , and calculate the weighted resource-to-population ratio (  $R_p$  ) within the catchment area.  $D_k$  is the  $k$  th population,  $\sum_{k \in (d_{kp} \leq d_i)} D_k$  is the number of patients in the catchment area, Gaussian function  $G(d_{ip}, d_i)$  [20] is used to differentiate the influence of distance within each catchment area.

$$G(d_{ip}, d_i) = \begin{cases} \frac{e^{-\frac{1}{2}(\frac{d_{ip}}{d_i})^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} & d_{ip} \leq d_i \\ 0 & d_{ip} \geq d_i \end{cases} \tag{2}$$

$A_i^F$  represents accessibility as follows:

$$R_p = \frac{S_p}{\sum_{k \in (d_{kp} \leq d_i)} D_k G(d_{kp}, d_i)} P_{ip} \tag{3}$$

$$A_i^F = \sum_{p \in (d_{ip} \leq d_i)} G(d_{ip}, d_i) P_{ip} R_p \tag{4}$$

**2.2 Under the Hierarchical Medical System.**

Phase one: follow the rule of Hierarchical Medical System, Patients go to the Primary Health Care (  $j$  ) they liked within catchment area.  $\beta$  % of them are transferred to the Tertiary Hospital for further treatment, because the severity of the disease.  $(1-\beta) \sum_{k \in (d_{kj} \leq d_i)} D_k$  is the number of patients treated at Primary Health Care.

The accessibility of the first phase as follow:

$$A_i^F = \sum_{j \in (d_{ij} \leq d)} G(d_{ij}, d_i) P_j \left[ \frac{S_j}{(1-\beta) \sum_{k \in (d_{kj} \leq d)} D_k P_{kj}} \right]^+ \tag{5}$$

Phase two: Primary Health Care (  $j$  ) becomes the demand point. The new supply point is Tertiary Hospital (  $p$  ) .  $d_{pj}$  is the distance between Primary Health Care (  $j$  ) and the Tertiary

Hospital (  $p$  ),  $d_j$  represents the average value of the distance between Primary Health Care (  $j$  ) and all the Tertiary Hospital (  $p$  ) that it can get,  $\beta \sum_{k \in (d_{kj} \leq d_i)} D_k$  is the number of patients who transfer from Primary Health Care,  $S_j$  is the amount of medical resources in catchment area,  $G(d_{pj}, d_j)$  is Gaussian function considering distance decay. This phase describe the situation that patients transfer from Primary Health Care to the Tertiary Hospital. Generally, the probability of transference to which Tertiary Hospital is similar, so  $P_{ij}$  is not considered.

$A_j^p$  is the spatial accessibility from Primary Health Care (  $j$  ) to Tertiary Hospital (  $p$  ) :

$$A_j^p = \sum_{j \in (d_{pj} \leq d_j)} G(d_{pj}, d_j) \left[ \frac{S_p}{\sum_{j \in (d_{pj} \leq d_j)} (\beta \sum_{k \in (d_{kj} \leq d_i)} D_k) G(d_{pj}, d_j)} \right] \tag{6}$$

In order to get the service from Tertiary Hospital they want, patients would like to go to the designated Primary Health Care which can transfer to the Tertiary Hospital, so  $P_{ij}$  should be considered. The accessibility of population location to the Primary Health Care should be considered:

$$A_i^p = \sum_{k \in (d_{kj} \leq d_i)} A_j^p P_{ij} \tag{7}$$

The accessibility of population (  $i$  ) :

$$A_i^M = A_i^F + A_i^p \tag{8}$$

The accessibility of whole population:

$$A = \frac{A_i^M \times D_i}{\sum D_i} \tag{9}$$

### 3. Research Data.

To illustrate the advantages of the enhanced two-step 2SFCA method, we apply in to examine the accessibility to hospital facilities in a group of three districts in Xi'an, and compare the results under different systems. The three districts are XinCheng District, BeiLin District and LianHu District. Chooses street as the smallest research unit. The three urban districts include 26 streets. Each street is a demand point, and the geometric center of the street is recognized as the center of population distribution. The population data comes from the report of The Sixth National Census of Xi'an. According to the list of medical insurance designated hospitals in Xi'an, Primary Health Care and Tertiary Hospital are identified. The spatial coordinates of medical facilities are obtained from google map. The number of health bed and other information are obtained through the official website of hospitals. The road network dataset in the main city of Xi'an is digitized by ArcGIS, based on the "Xi'an city traffic map" from Xi'an Municipal Transportation Bureau.

### 4. Measurement of Accessibility.

Accessibility under the General Medical System

The result of applying the enhanced two-step 2SFCA method under the General Medical System to the study area is shown in Fig. 1. Under the General Medical System, Tertiary Hospitals are still the first choice for most patients. After calculation, the accessibility of medical facilities in the whole urban area is 0.0054. The majority of the high accessibility are in the east and it decreases from the east to the West. The accessibility of XinCheng District is 0.0061; The accessibility of BeiLin District is 0.0057; LianHu District's accessibility is 0.0031. The XinCheng District has the largest quantity of Tertiary Hospitals, the health bed it owned is 2.95 times that of LianHu District, 1.89 times that of

BeiLin District. Under the general medical system, accessibility is positively correlated with the density of distribution of medical facilities, which means the streets with denser distribution of hospitals get higher accessibility. For example: TaiYi Street, which is surrounded by intensive traffic road, is in the BeiLin District, and there are 3 Tertiary Hospitals within the scope of 1000 meters from this street, hence it is easy to access the medical resources. The accessibility of TaiYi Street is 0.0053. However as for the ZaoYuan Street, which locates in the LianHu District, and there is no Tertiary Hospital within 1000 meters. Besides, the road network is poor here(the value of Gauss distance decay is only 0.16), hence the medical resources is relatively difficult to access. ZaoYuan Street's accessibility is only 0.0021.

Accessibility of Xian's Main Districts under the General Medical System

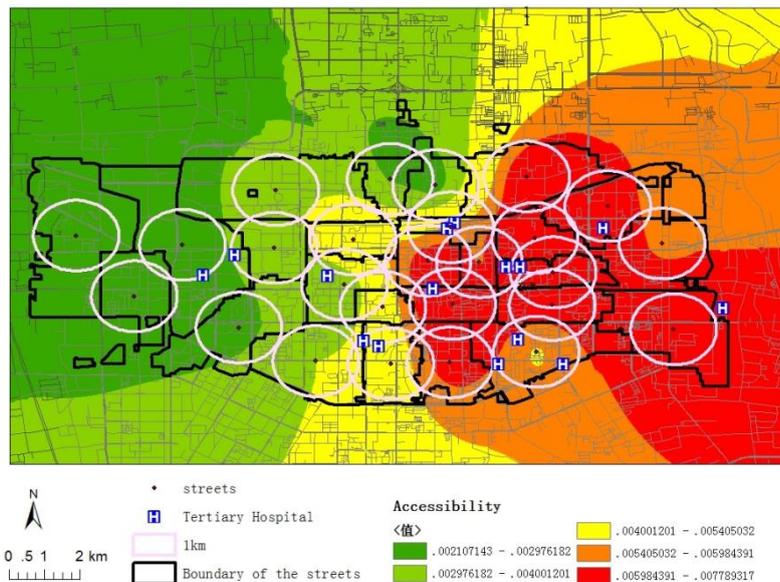


Fig.1. Accessibility of Xian's Main Districts under the General Medical System

Accessibility under the Hierarchical Medical System.

In order to provide reference for the construction of the Hierarchical Medical System, this study calculates accessibility of medical facilities with 6 different referral rates.

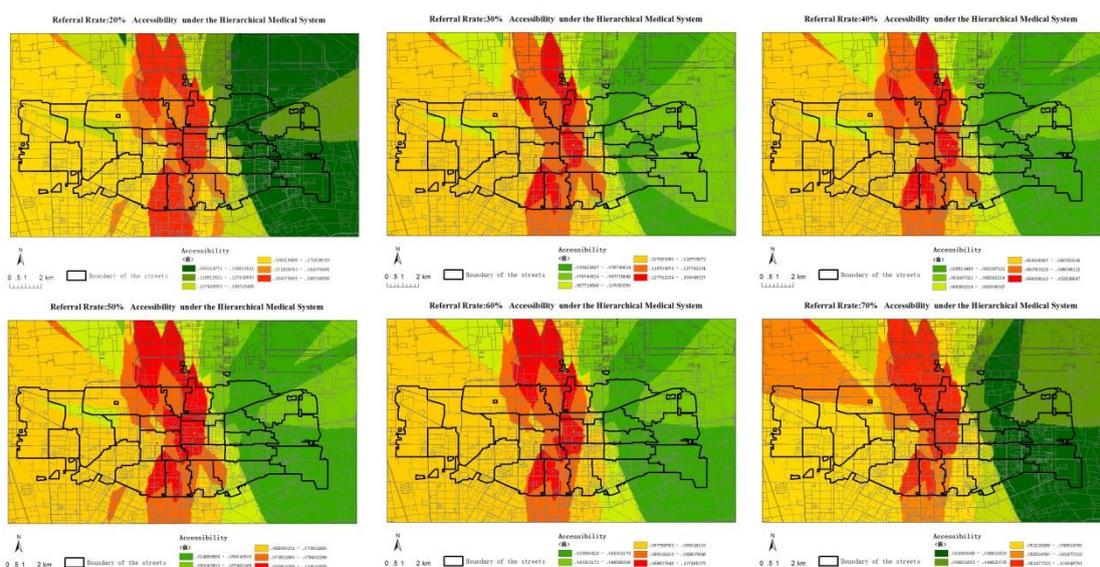


Fig.2. Accessibility of medical facilities under different referral rates

The accessibility of medical facilities under Hierarchical Medical System is higher in center region and lower in the East and the West. This is due to the referral mode enlarges the potential range of the patient's movement, and multiple potential service areas are overlaid in the middle. Such as ZiQiang

Street, under the General Medical System, patients can go to 7 Primary Health Care hospitals, potential service radius is about 7 km. under the Hierarchical Medical System, through referral, patients can reach the medical resources from 10 Tertiary Hospital, the potential service radius increased to 14 km. The focus of potential service area moves to the center, also the scope of potential medical service is enlarged because of the convenient transportation in the central city, and potential medical services in the central area is repeatedly covered, so the accessibility increases significantly. But there is less coverage in the East and the west, hence accessibility of those two regions is relatively low.

In addition, the accessibility of medical facilities is related to the patient's choice of medical treatment. Patient will go to a hospital that they preferred to. Taking HongMiaoPo Street for example, the number of Primary Health Care that patients can get is 11. Its' location is close to the Xi'an Hospital of China Aviation Industry and the Second Hospital of Xi'an, the number of medical resources that two hospital can provide is similar, but the accessibilities are quite different. As for HongMiaoPo street, the accessibility of the Second hospital of Xi'an is 0.0114, the accessibility of Xi'an Hospital of China Aviation Industry is 0.0067, nearly two times. According to the huff mode, residents in HongMiaoPo Street prefer the Second Hospital of Xi'an than Xi'an Hospital of China Aviation Industry; the probability of seeking doctors in Second Hospital of Xi'an is higher. So it gets higher accessibility.

Using SPSS to fit function of accessibility and referral rate, the result is shown in Figure 3. As for Xi'an three districts, when the referral rate is low, most of the patients see doctors at the Primary Health Care, a few patients go to Tertiary Hospital. The pressures in the Tertiary Hospital are relieved, and also patients are distributed, so it shows higher accessibility. when the referral rate rises to 40% or more, accessibility begins to decrease obviously. Because more patients are transferred to Tertiary Hospital, a large number of patients concentrated in Tertiary Hospital. The resources of Primary Health Care are not fully utilized, so the accessibility showed a trend of down. It is obvious that the control of referral rate is very important to build the Hierarchical Medical System.

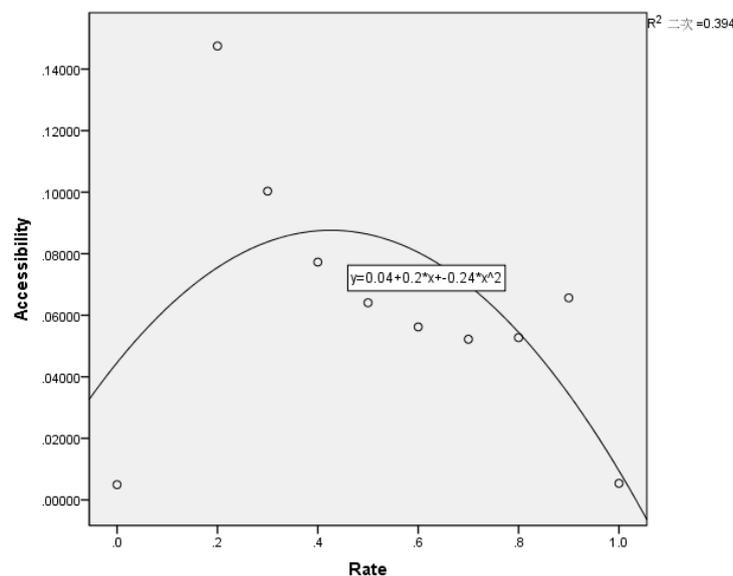


Fig.3. Fitting of accessibility function

a) Comparison and analysis of accessibility under the General Medical System and Hierarchical Medical System.

The comparative calculation results show that the accessibility of medical facilities under the Hierarchical Medical System is significantly higher than that under the General Medical System. so Hierarchical Medical System can significantly improve the accessibility of medical facilities. Taking referral rate is 0.4 for example, accessibility of XinCheng District is 0.1384, Lianhu District's is 0.0729, BeiLin District's is 0.0565. Under the Hierarchical Medical System, three main urban

districts all achieve the goal: One hundred people own 0.433 health bed in hospital, which is stipulated in the regional health plan of Xi'an (2006 to 2015). Compared with the General Medical System, the utilization rate of medical resources increases nearly 20%. It is visible that the Hierarchical Medical System expands the scope of access to medical resources.

From the perspective of supply and demand, a large number of patients are effectively distributed in the Tertiary Hospital. Patients with common diseases accept treatment at the Primary Health Care. Others with serious illness or emergency condition are assigned to the Tertiary Hospital. Medical resources are rationally used. Under the General Medical System, TuMen District's spatial accessibility of health facilities is 0.0028. they can get resources from 6 Tertiary Hospitals. But through the referral, the number of that increased to 11, accessibility increases nearly 20 times, reach 0.0431. It is obvious that the Hierarchical Medical System has a positive impact on the accessibility of medical facilities.

From the perspective of patients, Hierarchical Medical System schedules most patients to receive treatment at the nearby Primary Health Care, only seriously ill patients need to go to the Tertiary Hospital. Patient's waiting time decreases; the quality of medical service is improved.

From the perspective of hospitals. with implementation of Hierarchical Medical System, The workload of the doctors is reduced, which is conducive to the sinking of high-quality medical resources to Primary Health Care, more doctors can provide better quality medical services for ordinary patients. There are lots of Primary Health Care located about the 4000 meters far from densely populated area, so patients can see doctors at the Primary Health Care, which save time and money, also increase patients' satisfaction with public services. In a comprehensive view, the implementation of the Hierarchical Medical System can effectively alleviate the "Difficulty and Expensive Problem in Health Care".

## 5. Conclusion

In this paper, based on two-step 2SFCA, distance decay is used to enhance the two-step floating catchment area method, and the search radius is determined according to the location of each street. The revision of the superposition part of the two phases is calculated. At the same time, combined with the idea of patient centered, the huff model is used to calculate patients' preference. Accessibility is described more realistically. The result shows:

(1) Under the General Medical System, the spatial accessibility of medical facilities in the east is higher than that in the west, and decrease from the east to the southwest. Accessibility is related to the density of traffic network and the distribution of hospitals. The denser the traffic network and the distribution of hospitals is, the higher the accessibility gets. Accessibility is related to the patient's behavior of choosing doctors and hospitals. Patients would like to go to the hospital they preferred when they need health service.

(2) Under the Hierarchical Medical System, when the referral rate reach 40% or higher, the accessibility begins to decline, the referral rate needs to be strictly controlled.

(3) Compare accessibility under the General Medical System and Hierarchical Medical System. Hierarchical Medical System can effectively improve the accessibility of medical facilities, because of two-step movement, possibility of obtaining medical resources is increased, effectively alleviate hospital's pressure. Provide theoretical support for the implementation and promotion of grading treatment.

(4) The enhanced two-step 2SFCA objectively and accurately describe the accessibility, reflect differences in accessibility of various demand points, provides a reference for the analysis and optimization of the allocation of medical resources.

## References

- [1] Y.M. Dong, X. P.Du,J.Q.]Dong .Feasibility of Implementation System of First-treatment by Family Doctors in Yuetan District of Beijing, Chinese General Practice,vol.12 (2009) No.9,P.763-764. (In Chinese)
- [2] Information on [http://news.china.com.cn/txt/2015-10/30/content\\_36935881.htm](http://news.china.com.cn/txt/2015-10/30/content_36935881.htm).
- [3] L.Liu,G.W.Liu,X.P.Zhang,et al. Analysis on Factors of Outpatient Referral,Chinese Health Service Management,vol.25(2008)No.6,p.400-402. (In Chinese)
- [4] K.Gao,X.Q.Gan. Behavioral Decision in Two-way Referral and Its Influencing Factors in China, Chinese General Practice, vol.28(2015),p.3393-3395. (In Chinese)
- [5] X.X.Zou,Y.Yao,W.Li,et al. Cognitive Appraisal on Hierarchical Medical Service System in China on the Side of the Referral Patients,Chinese Hospital Management, vol.35(2015)No.7,p.18-21. (In Chinese)
- [6] Y.Zhou,Z.M.Zhou,X.P.Zhang. Research on Evaluation System on Bilateral Referral,Medicine and Society, vol.23(2010)No.4,p.46-48. (In Chinese)
- [7] X.F.Sun ,Y.Liu,Y.W.Zhu,et al. Establishment of Performance Evaluation System for Two-way Referral,Hospital Administration Journal of Chinese People's Liberation Army, vol.5(2015),412-414.(In Chinese)
- [8] G.P.Yang,H.F.Xu,X.Gu,et al. Exploration on the Mechanism of Regional Classification Diagnosis and Treatment Based on the "Dual Referral" Electronization,Chinese Health Quality Management,vol.22(2015)No.5,p.4-7. (In Chinese)
- [9] J.M.Yang. The research on the information system of hospital and community two-way referral monitoring system(Huazhong University of Science and Technology ,Wuhan2010). (In Chinese)
- [10]J.J.Wu,Y.F.Kong,B.Li. Spatial accessibility analysis of rural medical facilities base on GIS: A Case Study of Lankao County in Henan,Human Geography,Vol.5(2008),37-42. (In Chinese)
- [11]Z.Liu,S.Q.Guo,H.H.Jin,et al. Application of the GIS-based two-step floating catchment area method in measurement of spatial accessibility to hospitals in Beijing,Science of Surveying and mapping,vol.32(2007)No.1,p.61-63. (In Chinese)
- [12]R.S.Hu,S.C.Dong,H.Hu. A two-step Floating Catchment Area (2SFCA) Method for Measuring Spatial Accessibility to Primary Healthcare Searvice in China:A Case Study of Donghai County in Jiangsu Province,Progress in Geography, vol.12(2012)No.31,p.1600-1607. (In Chinese)
- [13]X.Xu, Y.Liu.Spatial Distribution Pattern and Accessibility Assessment of Pension Service Facilities in Nanjing: Two-step Floating Catchment Area Method Based on Time Cost,Modern Urban Research,vol.2(2017),1-11. (In Chinese)
- [14]Radke John, Mu Lan. Spatial Decom positions, Modeling and Mapping Service Regions to Predict Access to Social Programs ,Geographic Information Sciences, vol.6(2000) No.2,p. 105-112.
- [15]MR Mcgrail, Humphreys J S. Measuring spatial accessibility to primary care in rural areas: Improving the effectivenessof the two- step floating catchment area method,Applied Geography,29(2009)No.4,p.533-541.
- [16]N.Wan,B.Zou,Troy Sternberg.A three-step floating catchment area method for analyzing spatial access to health services,International Journal of Geographical Information Science,vol.26 (2012)No.6, p.1073-1089.

- [17]W. Luo ,Y. Qi.An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians,Health &Place,15(2009)No.4,p.1100-1107.
- [18]S.Y.Zhong,X.Yang,R.Chen. The accessibility measurement of hierarchy public service facilities based on multi-mode network dataset and the two-step 2SFCA:A case study of Beijing's medical facilities,Geographical Research,vol. 35(2016)No.4,p.731-744. (In Chinese)
- [19]Q.Zhang, T.S.Li, X.Y.Ren. Study on the accessibility of urban community health institutions under grading treatment system: a case study of Xi'an downtown ,Journal of Shaanxi Normal University(Natural Science Edition) ,44(2016)No.4,p.87-93. (In Chinese)
- [20]D.Dai.Black residential segregation,disparities in spatial access to health care facilities,and late-stage breast cancer diagnosis in metropolit Detroit,Health&Place,vol.16(2010),1038-1052.