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Research Article

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The establishment of the assessment system of large-scale medical equipment allocation

Xiaoqing Lu[1], Ruyu Tian[1] and Ying Cui[2]

[1]*College of Science, Hebei United University, Tang Shan, China*
[2]*Nursing and Rehabilitation College, Hebei United University, Tang Shan, China*

ABSTRACT

Aim to design and establish large-scale medical equipment allocation assessment system, build the mathematical model of the allocation of large-scale medical equipment in the hospital, providing theoretical basis for the hospital medical equipment allocation. Methods Based on the Lorenz Curve and gini coefficient and the theory of queuing, make a comprehensive evaluation of large medical equipment allocation in medical institutions, to weight each index using the Delphi method and weight allocation method, and find out the main influencing factors, building a mathematical model in fairness, objectivity, equipment using efficiency as the planning objectives. Conclusion to make equipment allocation optimized, decision makers should refer to the output of the mathematical model and consider comprehensively combining with the experience of managing managers, then formulate scientific and rational decision scheme.

Keywords: Large-scale medical equipment; Allocation; assessment system; Mathematical model

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INTRODUCTION

To carry out the files 'The Application and Management of Large Medical Equipment Allo*cation'* [1] issued by Ministry of Health, the National Development and Reform Commission, and Ministry of Finance, '*Measures for the Use and Management of Large Medical Equipment Allocation in Hebei Province and Detailed Rules for the Implementation*' issued by Hebei Province [10], to strengthen and standardize the use and management of large medical equipment allocation in our province which requires that large medical equipment must meet the demands of the specific situations in provincial and national wide as well as the principle of regional health planning, take full account of the advanced technology, the suitability and accessibility, realize the regional health resources sharing, and improve equipment utilization. Therefore, the establishment of a universal, scientific, suitable assessment index system which can provide reliable data for the reference of government decision and health administration has important practical significance.

EXPERIMENTAL SECTION

Construction principles of comprehensive assessment system of large-scale medical equipment allocation

Principles of fairness

Equity of large-scale medical equipment allocation mainly includes two aspects: one is the fairness of regional distribution of equipment; the other is the fairness of hospital internal equipment allocation. In the fairness evaluation of equipment allocation, Lorenz Curve and gini coefficient can be used to estimate analysis method[2].

Lorentz Curve can be used to compare and analyze the population distribution of different years or area based on the same equipment application. Through complex Lenz Curve OBC (Chart 1), the equality or inequality of regional

large-scale medical equipment ownership could be shown easily and clearly. The area, represented as S, between OBC Lorentz Curve and the diagonal OCS can be used to describe the gap between the actual situation and the ideal situation: the bigger the area S and the greater the bending of Lorenz Curve are, the greater gap between configured and ideal realm is. Conversely, the smaller the area S, the flatter Lorenz Curve as well as the shorter distance between Lorenz Curve and the diagonal line are, the smaller gap between the actual situation and an ideal situation.

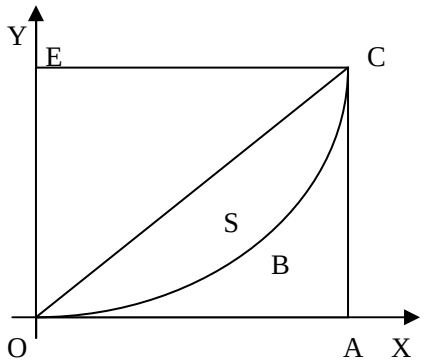

Figure 1: Lorentz Curve

The fitting curve can be used to get the gini coefficient. The procedures are demonstrated as follows：

(1) Set the Lorenz Curve equation $y = a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0$；

(2) Calculate parameters by regression method $a_n, a_{n-1}, \cdots, a_1, a_0$；

(3) Calculate definite integral $A = \int_0^1 \left(a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0 \right) dx$， Get the area of OACB；

(4) Calculate the gini coefficient $G = \frac{S}{A}$.

When the equipment allocation is perfectly reasonable, S = 0, and then G = 0; when the equipment allocation is totally unreasonable, S = A and G = 1. In actual situation, the gini coefficient is always between 0 and 1, that is, 0 < G < 1. The greater the gini coefficient is, the more unreasonable the equipment allocation is. The smaller the gini coefficient is, the more reasonable the equipment allocation is. Referring to the gini coefficient standard in economics, the gini coefficient less than 0.3 is the best state on average, between 0.3 and 0.4 is the normal state, more than 0.4 is alert, and above 0.6 belongs to the perilous state of the highly unfair [3].

The Principles of Objectivity

We tried to collect all the information and effective data as much as possible, fully considering various factors such as the source of funds, personnel resources, services, equipment utilization ability, and equipment efficiency in medical institutions and so on, in order to determine whether the medical institutions demand to equip or renew the large-scale medical equipment or not. The funding is related to the source of funds and the cost of the large-scale medical equipment occupied the proportion of the hospital total assets. Personnel resource should be given full consideration on the qualified personnel and doctors' recognition of large-scale medical equipments. The severing situation is mainly determined by the service quantity, service cost, service quality and service efficiency, etc.

Service quantity includes person-time of outpatient emergency check, amount of hospitalization and person-time of equipments' daily check. Service quality includes review rate, the statistics of the ratio between the actual test results and clinical first diagnosis rate. Service efficiency means the degree of equipments' full-load work, which is a sensitive index to evaluate the equipment potential work load. These indexes can be calculated as follows:

Annual boot utilization ratio = (annual person-time of equipment check * per capita time of using equipment) / (average daily boot time* the days of actual booting)

Annual utilization ratio = (annual person-time of equipment check * per capita time of using equipment) / booting days of per year

Capacity utilization ratio = annual person-time of equipment check/ (maximum workload per day *days of possible booting)

Annual effective utilization ratio = (using hours of the year*detected positive rate)/ annual hours of standard use

Average waiting time of patients: $W_q = \frac{L_q}{\lambda}$, The L_q is the average number of patients waiting for inspection, λ the average patients' arrival rate per unit time;

The intensity of the service: $\rho = \frac{\lambda}{C\mu}$, C is the number of equipments, μ is the number of equipment sets.

The Principle of Economy

At present, on the large-scale medical equipment allocation in the medical institutions the chief problem is that the quantity of equipments is inconsistent with the actual usage. Because the most advanced technology, equipments and talents are gathered in large hospital, making queuing phenomenon in these hospitals common. Longtime wait can reduce work efficiency, leading to the short of equipments and the waste of human resources. On the contrary, in remote hospitals the large-scale medical equipments are idle, checking level remaining low. Configuration of medical equipment should take economic law as an essential standard, considering the regional economy, population of service, hospital medical level, the financial conditions, together with the analysis of economic benefits after investments.

There are a lot of methods for medical equipment cost benefit analysis. We use the most common method-- the cost payback period method to calculate. It is the method to identify economic benefit according to the time recovered the medical equipment cost. Calculating formulas are listed as follows:

Static value investment recovery period = Total amount of medical equipment cost ÷ annual net income of the medical equipment

Annual net income of medical equipment = annual medical income of medical equipment—Relevant operating costs
Fixed costs = Equipment depreciation + fixing fund + medical staff's wages

Variable costs = Equipment maintenance cost + Cost of raw materials in equipment operation（Including electricity fee etc.）

Relevant operating cost mainly includes the equipment depreciation, maintenance cost, management cost, housing, utilities, personnel costs and capital-using opportunity cost, etc. In order to adapt to the medical service market demand and promote the development of medical technology, most scholars advocated that accelerated depreciation method should be applied into calculating equipment depreciation. Maintenance cost includes equipment fixing and maintenance labor cost; management cost includes office expenses and business expenses. Personnel cost includes personnel wages and expenses in training. The shorter the investment recovery period of the medical equipment is, the higher its economic benefits are. Therefore, the focus for the hospital to improve business efficiency is to reduce waste, improve work efficiency, and avoid old excessive members and equipment idling.

The influencing factors of medical equipment allocation

Situation of the original equipment allocation in the area

Before setting an medical equipment allocation planning, we need to know the overall demand of medical equipment in the area, equipment distribution and usage, etc.. Combining with the Lorenz Curve and gini coefficient evaluation and analysis method, we should identify if medical equipment allocation is reasonable or not. For the area where the equipments are saturated and equipments' idling, the equipment should be audited strictly and relocated. For areas with low level of equipment allocation, appropriate policy should be carried out for them.

The quality and quantity of the medical staff

When designing different kinds of large-scale medical equipment allocation, relevant medical personnel qualifications must be considered. It directly affects the accuracy in diagnosis which is closely related to the patients' health, so this index needs to be focused on. On the other hand, the number of medical staff also reflects the scale of medical institutions, the bigger the number is, the larger the scale is, and the more corresponding number of visits is, the more demand on the equipments becomes.

Patients Demand

Population and household disposable income in the area are important indexes that affect demands for large-scale medical equipments. In the situations that prevalence and incidence are fixed, the more population means the greater

demands for the regional health service and the large-scale medical equipments. The higher household income is, the more obviously it influences the demand for large-scale medical equipments, such as medical magnetic resonance imaging (MRI) with features of high density resolution, which is without radiation, safe to human body, etc, widely used in early diagnosis of major diseases, like heart disease, head blood-vessel disease, cancer and so on. But purchasing MRI equipment need a large amount of funding, so the payment is much more expensive than X-ray computer tomography (CT) examination, therefore the affording of patients is one of the influential factors on allocation of medical equipments[4]. Thus, large-scale equipment allocation planning should be based on the regional patients' demand and assess the following components including the location, time, the quantity of check per unit time and household disposable income in the area, and then according to the maximum working capacity of equipments, determine the optimal large-scale equipments allocation.

The purchasing power of the medical institution

Due to insufficient funds and low maintenance capacity, the equipment ration index in some secondary hospitals often cannot meet the needs of actual medical service demand, and cause some equipments overload. Then the phenomena, that is, medical equipments' aging and low service efficiency are shown. Therefore, we should not only take hospital level as only standard to determine the large-scale medical equipment allocation, instead we should plan it from a universal perspective, taking various factors such as the area, population, hospital services, service ability and so on into consideration, adjusting measures to fit local conditions, making the equipment allocation and usage keep a balance.

Service cost

When purchasing the large-scale equipment, administrative staff ought to take patient's satisfaction, hospital efficiency and staff's priority as principles, through effective measures and flexible management, realizing the goals that improve the service quality and the efficiency. On conditional that do not reduce or increase the hospital run cost, make value which is represented the satisfied degree of patients and the degree of staff's priority reasonable.

Therefore, in order to make the large-scale medical equipment allocation optimized, if it is calculated from the aspect of the construction of service cost, there are two kinds of costs are meant to be contained, that is, one refers to the waiting cost for patient in unit; the other is the cost for equipment serving. Fomulas are listed as follows:

Total cost = service cost + waiting cost

When the total cost is minimum, the excellent service will be enjoyed by patients.

Suppose the time cost of every set of equipment was h and the waiting cost of each patient per unit in the system was b, then the service cost function f would be the sum of service cost per unit time and waiting cost, formula as follows:

$$f(C) = h \cdot C + b \cdot L(C)$$

L(C) is the quantity of patients when there are C sets of equipments.

The selection and the identification of the weight among the indexes of large-scale medical equipment assessment system

The Selection of the Indexes of Large-scale Medical Equipment Assessment System

Based on the literature review, referring to the relevant research fruits, combining with the actual situation of specific hospital, make a primary conclusion on the indexes of large-scale medical equipment assessment system, containing the indexes presenting the quantity and the quality, meanwhile identifying their standard values. The identification of the index could be processed from two aspects, namely, external indexes and the internal indexes. External indexes contains: the population scale of the served area, the structure of local population, the structure of local economy, the serving situation of the large-scale medical equipment (including annual boot utilization ratio, annual effective availability, serving intensity and so on) in the similar area, the fairness of equipment allocation. The internal indexes contains: the number of hospitalized patients, the person-time of emergency treatment, funding level, the medical level and condition of specific hospital and the profit created by the large-scale medical equipment.

Utilizing Questionnaire Survey on expert[5], designing the questionnaire, giving each quantitative or qualitative index their own value, from 4 to 1, finally calculate the value of each index based on the survey, formula listed as follows:

$$w_n = \frac{\sum_{i=1}^{4} A_i B_i}{\sum_{i=1}^{4} B_i}$$

w_n is the weight coefficient of the nth index; A_i is the value of the nth index; B_i is the number of people when the value of the nth index is A_i.

The Identification of Weight Coefficient of Assessment Indexes

After identifying the quantity of the indexes of large-scale medical equipment allocation assessment system, Delphi [6]and FUNNY weight allocation method can be used to identify the weight coefficient of the each index, formula listed as follows:

$$y = \sum_{i=1}^{m} w_i x_i \qquad \sum_{i=1}^{m} w_i = 1$$

y is the integrated assessment value in the system; w_i is the corresponding weight coefficient to assessment index x_i, $x_i = [x_{i1}, x_{i2}, ..., x_{im}]^T$ (i=1,2,…,m).

RESULTS AND DISCUSSION

Establish an optimized model of the quantity of large-scale medical equipment allocation

The Condition of Model Assumption

To reduce the complexity, identify the weight coefficient of each index based on Delphi method and FUNNY weight allocation method, finding out chiefly influential factors, making assumptions in order to conveniently obtain the solution based on the model.

Assumption is as following:

(1) There is a upper limit for hospital medical equipment purchase;

(2) In using period of the large-scale medical equipment, the increase of the patients is limited. If patients' increase goes beyond hospital equipment inspection capacity, extra equipment should be purchased before it happened, and each hospital only can add one set of equipment each time.

Establishment of Mathematical Model

To realize the scientization and rationalization of mathematical model, on one aspect, the prospective profit earned by the large-scale medical equipment should be considered; on the other hand, based on the patients' satisfaction and the rationality of equipment application, taking the profit maximization of medical institution as the goal, regarding fairness, objectivity and service efficiency as constraint condition[7,8], establish the mathematical model. It is as following:

The objective function:

$$\min \ \cos t = \sum_{j=1}^{n} \left(C_{gj} + C_{bj} \right)$$

$$\max Z = \frac{\sum_{t=1}^{s} Q_t}{N \cdot s}$$

Constraints:

$$0.2 \le \frac{\sum_{j=1}^{n} \left(1 + \sum_{i=1}^{m} Y_{ij} P_{ij} - 2 \sum_{i=1}^{m-1} V_{ij} Y_{ij} \right)}{n} \le 0.3$$

$$\sum_{i=1}^{m} x_{ijk} \le p$$

$$\sum_{k=1}^{p}\sum_{i=1}^{m} x_{ijk} \ge \sum_{i=1}^{m} A_{ij}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{s} B \cdot x_{ijk} \le A$$

$$x_{ijk} = 0,1$$

Instructions：

(1) Establishing mathematical model, on one hand, the prospective profit earned by the large-scale medical equipment should be considered, on the other hand, a fair checking chance for patients and avoiding equipment idling should be considered. Now to establish mathematical model, we take the profit maximization of medical institution as the goal, and take the gini coefficient of population distribution of patients' reasonable using medical equipments as constraint condition.

(2) The objective function: the cost means total cost of equipment operation，C_{gj} is fixed cost of equipment operation in the jth year; C_{bj} is variable cost of equipment operation in the j th year； Z is medical equipment capacity utilization per year，Q_t is annual inspection person-time of the t th equipment；N is the equipment's annual average workload； s is the region's total amount of equipments.

(3) The constraint：Y_{ij} is the percentage of the population occupying the region's total population in the i th region in the j th year; P_{ij} is the percentage of the number of equipment taking up the total number of equipments in i th area in the j th year; $V_{ij} = P_{1j} + P_{2j} + \cdots + P_{ij}$ is the percentage of accumulative equipments from the first area to the i th area accounted for the total number of equipments.

(4) The circulation of equipment allocation is commonly 3-5 years. During the planning period, if patients increase, increase equipments before it going beyond hospital equipment inspection capacity, and every hospital can add one set of equipment each time at most. At the same time, the allocation of equipment should meet the need of this period. A_{ij} is the demand in the i th region in the j th year; x_{ijk} is the demand of the k th hospital per year.

(5) There is an upper limit for equipment purchase funds; B is the unit price for equipment; A is the total budget.

CONCLUSION

(1) Because of many factors that affect the number of equipment allocation, a comprehensive assessment on relevant large-scale medical equipment allocation in medical institutions could be processed according to the evaluation of Lorenz Curve and gini coefficient and the theory of queuing theory, weighting each index by the Delphi and FUNNY weight allocation method, finding out main influence factors, then building the mathematical model which regards the economic benefits of medical institutions as the planning objectives, taking fairness, objectivity and equipment using efficiency as constraint conditions.

(2) Research is to use an abstract mathematical model to simulate the real system or a problem. Because there are many factors which cannot be quantified and some potential factors that are not easily found, so the model just reflects the relationship among the primary factors in the question or the system, not the whole situation of the question or system. Consequently, to make the system optimized and obtain an optimal solution, the large-scale medical equipment allocation ought to be decided not only based on the output results of the mathematical model but consider comprehensively combining the experience of managers and the particularity of the hospital.

(3) Aiming to solve the problem of unbalance distribution of the lager-scale medical equipment in hospitals, the traditional pattern that the ownership of lager-scale medical equipment only belongs to one hospital and is dominated by one hospital should be broken, attempting to set up a provincial diagnostic imaging and treatment

centre, sharing the resource[9]. In this way, it will short the patients waiting time in the large-scale hospital, and reduce the personnel waste that is due to lack of the lager-scale medical equipment. Sharing the lager-scale medical equipment, not only refers to the lager-scale medical equipment, but the medical staff, advanced medical technology and the inspection result. The indeed sharing still calls for the support from the government, and at the same time it demands the unified management for guarantee.

To sum up, the scientization and rationalization of the large-scale medical equipment allocation does not only benefit the optimization of the resource and patients' satisfaction, also increase the hospital's economic profits and social benefits, and furthermore it is also the inevitable requirement of hospital's management modernization.

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