http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (20): 5641-5645, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.5641.5645

Establishment of Quantity Optimization Model of Large-scale Medical Equipment Allocation

[1]Lu Xiao-Qing, [2]Song Li-Chuan and [3]Tian Ru-Yu
[1,3]College of Science,
[2]Modern Technology Education Centre,
Hebei United University, Tangshan, Hebei, 063000, China

Abstract: Use Gini coefficient and the theory of queuing as well as other relevant theories to assess and analyze the state of large-scale medical equipment allocation in medical institutions and apply Delphi Method and FUNNY Weight Distribution Method into the identification of each index's weight, finding the primary factors and taking medical institution profits as planning goal, limited by fairness, objectivity and equipment service efficiency, finally establish the mathematical model. Offer the scientific and reasonable solution on large-scale medical equipment allocation for medical institutions.

Key words: Large-scale medical equipment, allocation, mathematical model

INTRODUCTION

Large-scale medical equipment is one primary component of hospital assets. Medical equipments management has become the essential part of modern hospital management. Since the regulations on large-scale medical equipment management (Zhu and Wang, 2013) issued by Ministry of Health, macro frame of large-scale medical equipment management has been basically set up, meanwhile quota management system is also constructed in the national wide, to some extend, functioning as the guide for the equipment allocation planning in various places. However, there are still a lot of problems existed in some medical institutions, such as allocation out of control, unreasonable entire distribution, blind comparison, uneven service efficiency, lack of quality control awareness, lack of supervisory system on equipment serving and so on. Thus, designing a scientific and reasonable large-scale medical equipment allocation plan seems becoming more important in terms of balancing the profits between patients and medical institutions and avoiding medical resource waste.

Due to large-scale medical equipment allocation affected by various factors, Gini coefficient and the theory of queuing as well as other relevant theories are invited to universally assess the state of large-scale medical equipment allocation in medical institutions; apply Delphi Method and FUNNY Weight Distribution Method into the identification of each index's weight, finding the primary factors and taking medical institution profits as planning goal, limited by fairness, objectivity and equipment service efficiency, finally establish the mathematical model.

PRINCIPALS OF LARGE-SCALE MEDICAL EQUIPMENT ALLOCATION

Fairness: There are two main aspects of the fairness of large-scale medical equipment allocation: one is the fairness on regional distribution; the other is the fairness on the large-scale medical equipment allocation among the internal departments of hospital. The evaluation of the fairness on the large-scale medical equipment allocation can be processed by Gini coefficient (Yang and Huang, 2011).

Gini coefficient (also known as the Gini index or Gini ratio) is a measure of statistical dispersion intended to represent the income distribution of a nation's residents in the worldwide. Currently, many domestic and overseas scholars employ it to study the fairness of the allocation of institutions, human resource, beds, together with equipments. 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 equipment allocation will be found. Referring to the standards of Gini coefficient in economics, when the Gini

Corresponding Author: Lu Xiao-Qing, College of Science, Hebei United University, Tangshan, Hebei, 063000, China

coefficient is less than 0.3, it means the best state on average; when it is between 0.3 and 0.4, it means the normal state; if it is more than 0.4, the state is alarming; when it is above 0.6, the state belongs to the perilous state, rather unfair state (He *et al.,* 2012).

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

- Set the Lorenz Curve equation $y = 1_n x^n + a_{n-1} x^{n-1} + \ldots + a_1 x + a_0$
- Calculate parameters by regression method $a_n, a_{n-1}, \ldots, a_1, a_0$
- Calculate definite integral A, Get the area of OACB

$$= \int_0^1 \left(a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0\right) dx$$

- Calculate the Gini coefficient

Objectivity: We tried to collect information from various aspects and valid data as much as possible, fully considering various factors such as the source of funds, human resources, serving state, the capacity of equipment utilization and equipment service 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 proportion of the large-scale medical equipment value occupying the hospital total assets. Human resource should be given full consideration on the number of qualified personnel and doctors' recognition of large-scale medical equipments. The severing state is mainly determined by the serving quantity, service cost, serving quality and serving efficiency, etc.

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

The service fee is mainly constituted by two parts: One part refers to the loss generated by patients waiting unit time; the other is the service charge for each set of equipment per unit time. From the patients' point of view, for patients' stay, the shorter the better; for serving efficiency, the higher the better. From the medical institutions' aspect, the increase of the sets of equipment means more investment are required and meanwhile equipment idleness would lead to the waste of equipment. Assume that the time cost of every set of equipment was h and the loss generated by patients waiting unit time in the system was b, then the service fee function f would be the sum of service cost per unit time and waiting loss (Han *et al*., 2008), 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 in the system.

Economic principal: Economic principal is an important index of large-scale medical equipment allocation. Large-scale medical equipment allocation should take economic law as an essential standard, considering the regional economy, population, hospital medical level as well as funding state and also have to analyze the economic benefits after investments.

There are a lot of medical equipment cost benefit analysis methods. Now the most common method is the cost payback period method. It is the method to identify economic benefit according to the time recovered the medical equipment cost. 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 salaries and expenses on training.

The medical equipment with shorter investment recovery period usually means the better economic benefits could be earned. Therefore, the focus for the hospital to improve business efficiency is to reduce waste, lower the consumption, promote work efficiency and avoid old excessive members and equipment idleness.

IDENTIFICATION OF THE EVALUATION INDEX OF LARGE-SCALE MEDICAL EQUIPMENT ALLOCATION

Selection of the index of the assessment system: With a combination of hospital features and actual demands, sum up the evaluation indexes of large-scale medical equipment allocation, containing the indexes presenting the quantity and the indexes presenting the quality. Concrete conducting methods: the original value could be obtained through questionnaire, interview and so on.

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 serving area, the structure of local population, the structure of local economy, the serving state 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 earned by the large-scale medical equipment.

Give each quantitive index and qualitative index their own value, ranging from 1 to 4, finally calculating the marks 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.

Identification of the weight of the assessment system: Because the accessibility standards of most of indexes is hard to control and the types of indexes are not completely unified, it is necessary for each index to accept the pretreatment after accessing to the indexes, making the type of indexes unified. Delphi (Ji, 2012) and FUNNY weight allocation method can be used to identify the weight coefficient of the each index and then find the primary factors, making a good preparation for later treatment. Its Formula is listed as follows:

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

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

ESTABLISHMENT OF THE OPTIMIZED MODEL OF THE QUANTITY OF LARGE-SCALE MEDICAL EQUIPMENT ALLOCATION

Condition and assumption of the model establishment: Establishment of the optimized model of the quantity of large-scale medical equipment allocation in this study chiefly employs the relevant knowledge of operations research to construct the mathematical model and nevertheless the key of the establishment of mathematical model is that find the relevant impact factors and then identify which are the dominant factors and clarify their internal connections. The factors impacting on large-scale medical equipment allocation include current state of large-scale medical equipment allocation, patients' demand, the qualification of medical staff, the purchase capacity of medical institution, prospective serving efficiency of large-scale medical equipment and so on. Due to the variety of factors, to reduce the complexity, identify the weight coefficient of each index based on Delphi method and FUNNY weight allocation method, finding out primary impact factors, making reasonable assumptions in order to conveniently obtain the solution. Assumptions are as following:

- There is a upper limit of the fund spent on medical equipment purchase in the hospital
- A sound testing and monitoring system of the large-scale medical equipments has been established already
- The medical staff are qualified
- Take the data collected in terms of current serving capacity of current large-scale medical equipments as the basic data
- 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 (Tao *et al*., 2012)

Setting up the mathematical model, on one hand, prospective profit of the large-scale medical equipment ought to be calculated; on the other hand, try to ensure that every patient could enjoy fair opportunity of examination and avoid the equipment idleness. Now taking medical institution profits as planning goal, limited by fairness, objectivity and equipment service efficiency (Doerner *et al.*, 2009; Lee *et al*., 2009), establish the mathematical model.

Target function:

- Minimum overall conducting cost of large-scale medical equipment: lowering the overall conducting cost of large-scale medical equipment is an elementary method to higher the profit of large-scale medical equipment and owing to overall conducting cost containing two parts: fixed cost and variable cost, the formula is as following:

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

cost is overall conducting cost, C_{gj} is fixed cost of overall conducting cost in the jth year; C_{bj} is variable cost of overall conducting cost in the jth year

- maximum serving efficiency of large-scale medical equipment: in order to maximize the profit of hospital, besides consider that keep the overall conducting cost of large-scale medical equipment minimum, serving efficiency of large-scale medical equipment also has to be taken into account to avoid the equipment idleness and the waste of health resource:

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

Z is utilization rate of annual serving capacity of large-scale medical equipment, Q_T is annual inspection person-time of the tth equipment;N is the annual average workload large-scale medical equipment;s is the total sets of large-scale medical equipments in this region.

Constraint conditions:

- **Gini coefficient constraint:** Gini coefficient ranges from 0.2 to 0.3, showing that large-scale medical equipment allocation is comparatively reasonable:

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

Y_{ij} is to describe that how much percentage of the total population is occupied by the population of the ith region in the jth year; P_{ij} is to show how much percentage of the total number of equipments is taken up by the equipments in the ith region in the jth year; $V_{ij} = P_{1j}+P_{2j}+\ldots+P_{ij}$ is the percentage to display the sum of equipments from the first area to the ith area accounting for the total number of equipments in the region

- **Quantity constraint of large-scale medical equipment allocation:** The circulation of large-scale medical equipment allocation is commonly 3-5 years. During the planning period, if patients increase, equipments should be equipped more correspondingly before the patients increase going beyond hospital equipment inspection capacity and every hospital can add one set of equipment each time at most. At the same time, the large-scale medical equipment allocation should be able to meet the need of this stage:

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

A_{ij} is the demand in the ith region in the jth year; x_{ijk} is annual demand of the kth hospital

- **Fund budget constraint:** The purchase fund of the large-scale medical equipment has upper constraint, that is:

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

B is the unit price of the large-scale medical equipment; A is the total fund budget

Optimized model of the quantity of large-scale medical equipment allocation: To sum up, the optimized model of the quantity of large-scale medical equipment allocation is that:

Target function:

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

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

Constraint condition:

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

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

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

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

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

CONCLUSION AND SUGGESTIONS

- Identifying the optimized model of the quantity of large-scale medical equipment allocation ought to obey the principals of objectivity, fairness and economic principal, not only considering the internal indexes of the medical institutions, such as human resource, funding, work efficiency and so on, also taking external indexes into account, like patients' satisfaction, Gini coefficient and so on, making overall conducting cost of large-scale medical equipment minimized but profit maximized
- This optimized model is belonging to multi-objective decision-making model, able to transfer the multi-objective optimized issue into single-objective optimized issue and then get the solution. The methods to get the solution mainly contain: TOPSIS, ranking weight method, the weighted arithmetic average, the weighted geometric average, the risk preference coefficient method, multiply divide, fuzzy dynamic program and so on. To get the solution through this model, two sub-aims can be transferred into single-objective issue by the risk preference coefficient method, the optimized solution able to be obtained by genetic algorithm (Tao *et al*., 2012)
- Owing to various factors unable to be quantified and some potential factors having not been easily seen, this model only reflects and represents the relationship among several primary factors in the system, not the entire state of the system. Therefore, to make the system perfect and the problem solved excellently, do not only refer to the output of the mathematical model but also have to combine the experience of managers with the specific state of hospital universally to decide the quantity of large-scale medical equipment allocation

REFERENCES

Doerner, K. F., W.J. Gutjahr and P.C. Nolz, 2009. Multi-Criteria location planning for public facilities in tsunami-prone coastal areas. OR Spectr., 31: 651-678.

Han, X.H., P.S. Zhu and J. Wu, 2008. Optimization decision analysis of queuing model in the hospital management system. J. Math. Med., 21: 16-17.

He, D., J.Q. Liu, Q. Gu, F. Liang, X.Z. Hu and Y.Y. Chen, 2012. Analyzing the equity of allocating large scale medical equipment of class. Chinese Health Serv. Manage., 15: 126-128.

Ji, L.X., 2012. A comprehensive evaluation system of configuration feasibility for large medical equipment. Chinese J. Hospital Admin., 28: 47-50.

Lee, A.H.I., H.H. Chen and H.Y. Kang, 2009. Multi-criteria decision making on strategic selection of wind farms. Renewable Energy, 34: 120-126.

Tao, X.Q., R.C. Wu, L.J. Guo and K. Zhang, 2012. Construction of time sequence optimization model for large medical equipment allocation. Chinese J. Hospital Manage., 19: 1035-1036.

Yang, J. and J.Y. Huang, 2011. Analysis on evaluation indicators of large medical equipment allocation. Chinese Health Qual. Manage., 18: 75-78.

Zhu, P.H. and Q.Q. Wang, 2013. Situation and challenge of large medical equipment in configuration and utilization management. China Med. Devices, 28: 73-74.