2014

ISSN : 0974 - 7435

Volume 10 Issue 11

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(11), 2014 [5415-5422]

Study on allocation of large-scale scientific instruments and sharing using bilevel programming model based on price elasticity

Li Chen, Yongbo Lv, Chi Chen
School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, (CHINA)
E-mail : 15120075616@163.com; aaa19850721@163.com; 10114199@bjtu.edu.cn

ABSTRACT

Large-scale scientific instruments are important scientific and technological resources, and a low efficient allocation can seriously hamper the improvement and development of regional scientific and technological strength. A large number of qualitative studies have been conducted by scholars at the macro level, but rarely at the micro level. This study develops the bilevel programming model based on price elasticity and designs the corresponding heuristic algorithm, taking full consideration of the management departments, research institutes and customers' interests. We verify its feasibility and effectiveness by application to real calculation, and summarize the shortcomings and directions of future studies.

KEYWORDS

Large-scale scientific instruments; Sharing; Bi-level programming; Heuristic algorithm.

INTRODUCTION

Over the last decade, although the inputs of China's provinces and major cities in scientific and technological resources such as large-scale scientific instruments have increased significantly, the inputs at the national level is still inadequate. Especially, the percentage of technological financial inputs in GDP is far smaller than the internationally recognized turning point level of 1.5%. Even so, "leaking" and misallocation frequently occur, causing great waste and seriously hampering the improvement and development of regional scientific and technological strength[1]. During the five years from 2008 to 2012, the number of large-scale scientific instruments in China had increased from 21,496 to 43,028, and the total amount of equipment at cost increased from 28.799 billion Yuan to 57.167 billion Yuan (Figure 1 left). Both had been doubled. The average equipment at cost remained at around 1.3 million Yuan without significant increase; the average annual effective working hours of instruments fluctuated around 1,200 hours/sets (Figure 1 middle) without significant decrease or obvious increase. The average annual foreign service hours of instruments as a indicator of instrument sharing did not increase. Instead, it decreased significantly (Figure 1 right) from 236.6 hours/sets in 2008 to 167.13 hours/sets in 2012, by 29.4%. This indicates that large-scale scientific instruments in China are not effectively allocated and shared. Therefore, only are the scientific instruments are rationally allocated and fully shared will their utilization value be maximized.

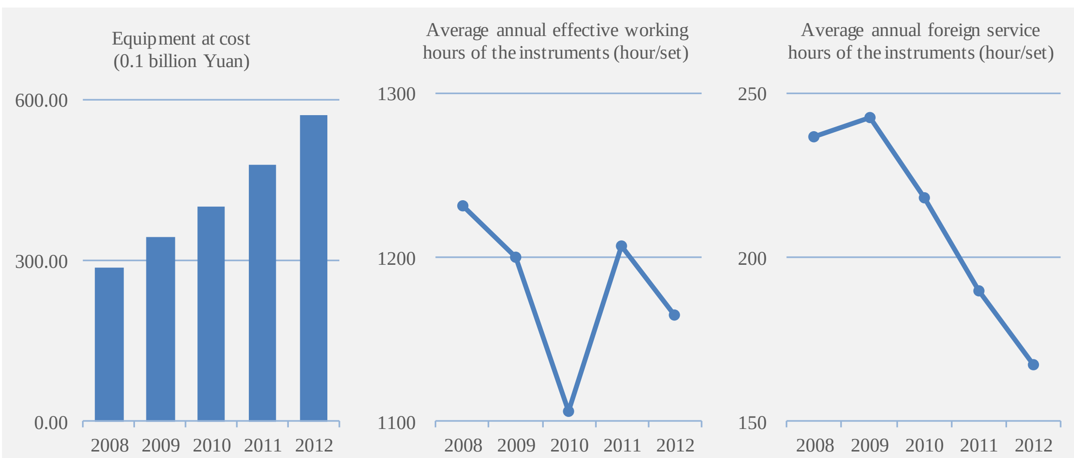

Figure 1 : Cost and sharing of China's large-scale scientific instruments (2008-2012)

Liu[2] (2008) and Zhang (2009)[3] adopted DEA method to measure the allocation efficiency of technology resources; Chen[4] (2010) evaluated and optimized the allocation efficiency of technology resources in coastal areas by developing optimal allocation model for inputs in technology resources; Suo[5] (2012) developed indicator system for evaluating the allocation efficiency of agricultural scientific and technology resources from the perspective of circular economy and conducted empirical analysis in some areas in China; Zhu[6] (2013) believed that to increase the allocation efficiency of technology resources, we need to start from the talent, company, industry, and technological services platform.

There is a lack of consideration given to the sharing and benefit of large-scale scientific instruments and the interests of the owners are ignored. This study performs quantitative analysis on regional authorities of scientific and technological management with respect to the allocation of large-scale scientific instruments using the following method.

DESCRIPTION OF THE PROBLEM

For a region within a certain period of time, a scientific and technological management department selects one or more research institutes from a number of options to allocate the limited technology resources to customers at some fee. On the part of management departments and research institutes, they hope to maximize the benefits obtained in resource allocation, while from the customers' perspective, they hope to use more large-scale scientific instruments at lower costs. Obviously, the selection involves two decision makers with significantly different objective functions, who are research institutes and customers. Therefore, it is appropriate to use the bi-level programming model to represent their relationship. The management departments' selection of research institutes for resource allocation is regarded as a Leader-Follower issue. The Leader is the management departments and research institute, while the Follower is the allocation of customers' (users of the technology resources) demand among different research institutes. The management departments can reduce the cost of technology resource allocation by selecting different research institutes and arranging the resources among research institutes according to customers' demand. Generally speaking, in order to get maximized benefits in the whole region, management departments will try to reduce the allocation costs, i.e., how to determine price, how to select research institutes for resource allocation, and how to increase the benefits obtained from allocation and sharing of the technology resources. Customers hope to minimize the cost of using large-scale scientific instruments. It is necessary find a balance between the two mutually influencing and restricting aspects.

Upper-level programming (U) is described as the instrument and fund allocation model determined by the scientific and technological management departments targeting the research institutes to get maximized benefit. Lower-level programming (L) is considered as the model for the allocation of customer demand for large-scale scientific instruments in the presence different research institutes to minimize the cost for customers.

MODEL ESTABLISHMENT AND SOLUTION

Hypotheses and meanings of symbols

Hypothesis: In different period of time, different research institutes charge different amount of sharing fee to the customers with different demand, but the scientific and technological management departments cannot learn this in real-time. Therefore, it is assumed that P is the estimated charges of large-scale scientific instrument sharing, and its value is the average charge of last year plus the estimated charge in this year. Q is the total number of large-scale scientific instruments allocated by the management departments, which is not an unlimited number.

Upper-level programming (U) is defined as the instrument allocation model determined by the scientific and technological management departments in the presence of local research institutes with the purpose of maximizing total income. Lower-level programming (L) is considered as the model for the allocation of customer demand for large-scale scientific instruments in the presence of different research institutes to minimize the sharing cost for customers.

The upper-level programming model is a site selection model.

Upper-level programming (U);

$$\max\ f_1 = PQ - \sum_{i=1}^{I}\sum_{j=1}^{J} c_{ij}\left(x_{ij}\right)x_{ij}z_i$$

s.t.

$$\sum_{i=1}^{I} z_i \geq 1 \qquad \textbf{(1)}$$

$$\sum_{i=1}^{I} x_i z_i = \sum_{j=1}^{J} D_j \tag{2}$$

$D_j = I_j - kP$: customer j's demand for large-scale scientific instruments. Price elasticity of demand dictates that when the price changes within a certain range, the relationship between demand and price can be regarded as linear function, where I_j is the j-th customer's demand for technology resources with the sharing cost of 0 (ideal situation); k is a constant; P is the estimated sharing cost per unit of technology resources.

i: serial number of the research institutes, i=1, 2,..., I; j: serial number of customers, j=1, 2,..., J.

x_{ij} is the amount of large-scale scientific instruments available for sharing in the i-th research institute used for j customer.

$c_{ij}(x_{ij})$ is the maintenance and labor costs of the i-th research institute in providing large-scale scientific instruments to the j customer.

z_i is 0-1 variable. Its value is 1 when the research institute is selected and 0 when it is not, $Z = \{z_1, z_2, \cdots, z_i, \cdots, z_I\}$.

The upper-level objective function considers the interests of the scientific and technological management departments with the purpose of maximizing the benefits for the research institutes and minimizing the maintenance and labor costs. The first part is the estimated gross income and the second part is maintenance and labor management costs of the instruments. Formula (1) ensures that at least one research institute is selected for allocation; formula (2) indicates that the number of large-scale scientific instruments equals to customer demand. It is noted that x_{ij} in U is obtained by lower-level programming (L).

Lower-level programming (L):

$$\min f_2 = \sum_{i=1}^{I}\sum_{j=1}^{J}\int_0^{x_{ij}} h_{ij}(\omega)d\omega$$

s.t.

$$\sum_{i=1}^{I} x_{ij} z_i \le D_j \text{ ; } j = 1, 2, ..., J \text{ ;} \tag{3}$$

$$\sum_{j=1}^{J} x_{ij} z_i = x_i \text{ ; } i = 1, 2, ..., I \text{ ;} \tag{4}$$

$$\sum_{i=1}^{I} x_i = Q \text{ ; } i = 1, 2, ..., I \text{ ;} \tag{5}$$

$x_{ij} \le Mz_i$ **;** i **=1, 2,...,** I **;** j **=1, 2,...,** J **;** **(6)**

$x_i \ge 0$**,** $x_{ij} \ge 0$**;** i **=1, 2,...,** I **;** j **=1, 2,...,** J **;** **(7)**

$h_{ij}\left(x_{ij}\right) = a_{ij}\left(x_{ij}\right)^{b_{ij}} - \upsilon_{ij}$ is the cost function of customer j in the broader sense when it is the i -th research institute providing large-scale scientific instruments. The cost varies with different types of instruments, and a_{ij}, b_{ij} and v_{ij} are all parameters.

x_i is the total number of large-scale scientific instruments allocated to the i -th research institute by the scientific and technological management departments.

M is the arbitrarily large positive integer.

Lower-level programming indicates that customers select the optimal research institute to use the instruments to minimize total costs and maximize the benefit. Formula (3) indicates the fulfilment of customer demand; formula (4) is share volume balance; formula (5) is full allocation of the instruments to avoid idleness; formula (6) assures that the instruments are allocated among the research institutes; formula (7) is the non-negative constraints for variables.

Model solution

Bi-level programming model is a complex optimal model, i.e., NP-hard problem, and there is no polynomial algorithm for this. Therefore, even if the bi-level programming model is solved, the solution is only the locally optimal solution instead of the global optimal solution. Yang[7] (1995) et al adopted sensitivity analysis method to solve traffic control problems; for linear bi-level programming, penalty function can be used for solution. Zhao[8] (2005) et al studied global optimization using penalty function to solve linear bi-level programming; Zhong[9] (2006) et al also designed the same penalty function and heuristic algorithm for bi-level programming model. However, some variables of the model in this study are discrete 0-1 variables and the model is not entirely a linear bi-level programming model. The sensitivity analysis method and linear penalty function mentioned above cannot be used. The stability analysis for the mathematical model is a significant problem solved by Wang[10,11]. Therefore, heuristic algorithm suitable for this model should be designed.

Constraint (9) is the relationship between the amount of technology resources allocated to each research institute and the allocation scheme selected by the research institutes under a balance condition. Because $\sum_{j=1}^{J} x_{ij} z_i = x_i$, $x_i \le Mz_i$. In order to get the specific form of the response function, it is converted into the following form:

$x_i = Mz_i - Y_i$**,** $\forall i$ **=1, 2,...,** I **(8)**

Where Y_i is slack variable. Given a set of $Z^0 = \left\{z_1, z_2, \cdots, z_I\right\}$, set $S \subset Z^0$ is taken. S is the serial number of selected research institute among the initial given values. In order to get the optimal solution, we can use the principle of greedy algorithm to design heuristic algorithm according to the specific characteristics of the model.

Obviously, given the initial value $Z^0 = \left\{z_1, z_2, \cdots, z_I\right\}$, when $z_i = 0$, $x_{ij} = 0$. In greedy algorithm: for each customer (demand point) j, the research institutes ensuring the maximized benefit are selected. Based on this, the institute with maximized per unit benefit is allocated with sufficient technological resources that will be accessed by the customers, and at the same time, the management department allocate the corresponding number of technology resources to research institutes. Corresponding x_i' and x_{ij}' can be obtained using greedy algorithm. According to formula (11), x_{ij}' can be used to get Y_{ij}', thus

$$x_{ij} = Mz_i - Y_{ij}' , \forall i = 1, 2, ..., I \qquad \textbf{(9)}$$

Formula (9) is introduced into the upper-level objective function to get a new set of $Z^k = \{z_1, z_2, \cdots, z_I\}$ using Lingo software, and then the lower-level problem is solved. The allocation of customer demand among research institutes can be finally achieved, that is, the amount of large-scale scientific instruments allocated to the research institute so as to be shared is obtained. The optimal solution of the bilevel programming model can be finally obtained through repetition of the steps mentioned above. The specific steps are as follows:

Step 1: Given an initial solution $Z^0 = \{z_1, z_2, \cdots, z_I\}$, let the number of iterations be k =0.

Step 2: Initialize j =1, and for given Z^0, x_{ij}^k can be obtained by solving the lower-level problem.

Step 3: Y_{ij}^k is calculated according to formula (9), and equation $x_{ij} = Mz_i - Y_{ij}'$ is introduced into upper-level objective function and solve it to get a new set of $Z^0 = \{z_1, z_2, \cdots, z_I\}$.

Step 4: x_i^k is obtained by solving the lower-level problem. Y_i^k is calculated according to formula (11). $x_i = Mz_i - Y_i$ is introduced into upper-level objective function to get a new set of Z^{k+1} using the software.

Step 5: if $\left| f_1^{k+1} - f_1^k \right| \le \varepsilon$, stop and return to Step 1; otherwise, let $k = k$ +1, and return to Step 2; ε is iteration accuracy.

This algorithm is a heuristic algorithm and the selection of initial solution has a great impact on the convergence and convergence speed of the algorithm. Therefore, we need to select different initial solutions for trial calculation when solving specific problems.

EXAMPLES

Suppose there are three research institutes (A_1, A_2, A_3) and three customers with demand (B_1, B_2, B_3). Customers' (demand points) basic demand is I_1=220, I_2=250, I_3=280, respectively, k =10; the research institutes' sharing capacity with respect to large-scale scientific instruments is Q_1=160, Q_2 =180, Q_3=220; the research institutes' maintenance cost per unit of technology resources is λ_1=0.3, λ_2 =0.4, λ_3=0.5, respectively. Parameters a_{ij}, b_{ij} and v_{ij} in the cost function $h_{ij}\left(x_{ij}\right) = a_{ij}\left(x_{ij}\right)^{b_{ij}} - \upsilon_{ij}$ of research institutes in the broader sense are shown in TABLE 1.

TABLE 1 : Parameters of cost function in the broader sense

ij	Parameter			ij	Parameter			ij	Parameter		
	a	b	v		a	b	v		a	b	v
11	0.2	1	6	21	0.4	1	5	31	0.2	1	7
12	0.4	1	4	22	0.2	1	3	32	0.4	1	8
13	0.2	1	7	23	0.2	1	4	33	0.2	1	5

Research institutes' maintenance and labor costs in providing large-scale scientific instruments to customers are c_{11} =2, c_{12} =2.5, c_{13} =2, c_{21} =1.5, c_{22} =2, c_{23} =2.5, c_{31} =2, c_{32} =1.5, c_{33} =2. Let M =1,000, P =13.

The calculation steps are as follows:

Step 1: Let $Z^0 = (1,1,1)$ and P =20, and the demand at the corresponding price is calculated as D_1 =20, D_2 =50, D_3 =80, respectively.

Step 2: Solve the lower-level model to obtain the allocation x_{ij} and response function of each customer demand among different research institutes.

$$X = \begin{pmatrix} 7.5 & 16 & 51.25 \\ 0.0 & 7 & 8.13 \\ 12.5 & 27 & 20.62 \end{pmatrix}$$

x_{11} =1000-992.5, x_{12} =1000-1000, x_{13} =1000-987.5, x_{21} =1000-984, x_{22} =1000-993, x_{23} =1000-973, x_{31} =1000-948.75, x_{32} =1000-991.87, x_{33} =1000-979.38.

Step 3: Introduce the response function mentioned above into upper-level objective function to get f_1 =1224.9.

Step 4: When $Z = (1,1,1)$, the value of Z at different prices is calculated. As TABLE 2 shows, when $Z = (1,1,1)$, P^* =18, f_1^* =1277.7.

TABLE 2 : Values of f_1 at different prices

P	**20**	**19**	**18**	**17**	**16**	**15**	**14**
f_1	1224.9	1161.2	1277.7	702.58	305.29	47.68	12.35

Step 5: When $\left| f_1^{k+1} - f_1^k \right| \geq 0.1$, the selection scheme (shown in TABLE 3) under different Z and P^* and f_1^* under the corresponding plans can be calculated by repeating the four steps mentioned above.

TABLE 3 : Selection schemes and the corresponding income under different allocation plans

Z	P	f_1
1,1,1	18	1277.7
1,1,0	19	1402.3
1,0,1	20	1605.9
0,1,1	20	1037.9
1,0,0	18	1213.3
0,1,0	19	1430.1
0,0,1	19	1195.8

After iterations, the price and rational research institute selection scheme with maximized benefit are P =18, z_1 =1, z_2 =0, z_3 =1, and the maximized benefit f_1 =1605.9.

$$X = \begin{pmatrix} 34 & 24 & 67.5 \\ 2 & 23 & 16.25 \\ 4 & 23 & 16.25 \end{pmatrix}$$

CONCLUSIONS

(1) This study conducts quantitative analysis on the allocation of large-scale scientific instruments by adopting a bilevel programming model and taking full consideration of the management departments, research institutes, and customers' interests. The consideration of price elasticity makes the model more valuable under the uncertainty of customer demand for technology resources.

(2) The model is only applied to ideal conditions. Future studies will consider the factors of the number of scientific and technological management departments, various types of technological resources, and different income functions for the research institutes. We should also consider the selection scheme when the sharing services provided by the research institutes are differentiated.

ACKNOWLEDGEMENTS

This work is supported by Special fund for national basic technological platform, the Project of Ministry of Science and Technology (2013 DDJ1ZY06)

REFERENCES

[1] Wang Haifeng, Wang Jin; Preliminary evaluation of large-scale scientific instruments and resources sharing in Beijing. China Science & Technology Resources Review, **1**, 104-109 **(2014)**.

[2] Liu Lingli; Measurement of allocation efficiency of China's technology resources. Statistics and Decision. **14**, 47-50 **(2008)**.

[3] Zhang Xiaorui; Study on allocation efficiency of China's regional technology resources. Industrial Technology & Economy, **28(1)**, 116-118 **(2009)**.

[4] Cai-Li Zhang, Zheng-Biao Li, Yang Zhao; Local fractional derivative boundary value problems for Tricomi equation arising in fractal transonic flow. Abstract and Applied Analysis, **2014(2014)**, 1-9 **(2014)**.

[5] Yang Zhao; Robust Predictive Control of Input Constraints and Interference Suppression for Semi-Trailer System. International Journal of Control and Automation, **7(7)**, 371-382 **(2014)**.

[6] Zhu Hui, Fu Weizhong, Liu Yanhua; Study on allocation efficiency of technology resources and the influencing factors in Anhui Province. Journal of Hefei University of Technology (Social Sciences), **27(4)**, 13-19 **(2013)**.

[7] Yang Zhao; Study on Predictive Control for Trajectory Tracking of Robotic Manipulator. Journal of Engineering Science and Technology Review, **7(1)**, 45-51 **(2014)**.

[8] Zhao Maoxian, Gao Ziyou; Global optimization methods for solution to linear bilevel programming using penalty function. Journal of Operations Management, **04**, 25-28 **(2005)**.

[9] Zhong Leigang, Li Yungang, Zhang Cuihua; Secondary distribution network model in bilevel programming based on price elasticity. Computer Integrated Manufacturing Systems, **10**, 1596-1599 **(2006)**.

[10] Wang Yunji; A conceptual cellular interaction model of left ventricular remodeling post-MI: dynamic network with exit-entry competition strategy, BMC Systems Biology, **4**, Suppl 1, S5 **(2010)**.

[11] Yang Tianyi; Mathematical modeling of left ventricular dimensional changes in mice during aging, BMC Systems Biology, **6**, Suppl 3, S10 **(2012)**.