Research on Library Collection Optimization Using Game Theory Combination Weighting Method: A Case Study of Hebei University of Technology Library (Postprint)

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Abstract

[Objective/Significance] Drawing on the equilibrium concept from game theory, this study investigates a quantitative and objective combination method for weights determined from different perspectives for library book procurement funds.

[Method/Process] A game-theoretic model is constructed using the game theory combination weighting method, and the interior point penalty function method is proposed to solve the model, thereby achieving the integration of weights from different perspectives. A case study is conducted using Hebei University of Technology as an example.

[Results/Conclusion] Through case study analysis, the feasibility of the proposed method is verified, the influence of subjective human-determined weights on results is eliminated, and a new approach for the optimal allocation of book procurement funds is provided.

Full Text

Preamble

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Abstract

[**Purpose/Significance**] This study draws upon the equilibrium concept from game theory to investigate quantitative and objective combination methods for determining weights for library book procurement funds from different perspectives. [**Method/Process**] The paper employs game theory combination weighting to construct a countermeasure model, proposes solving the model using the interior point penalty function method, achieves the assembly of weights from different perspectives, and conducts a case study using Hebei University of Technology as an example. [**Result/Conclusion**] Through empirical analysis, the feasibility of the proposed method is verified, the influence of subjective weight determination is avoided, and a new approach is provided for the optimal allocation of book procurement funds.

Keywords: Game Theory; Combination Weighting; Collection Optimization; Book Purchasing
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University libraries serve as the literature and information centers of their institutions, playing pivotal roles in teaching, research, and general education activities. Due to changes in educational policies, university enrollment has continuously expanded, leading to a sharp increase in student numbers. To meet the growing demand for literature resources, universities have increased library procurement budgets. However, faced with the diversification of literature carriers, the increasing proportion of funding required for electronic resources year by year, and rising prices of print books, budgets for print book procurement have become increasingly strained. How to purchase as many needed print books as possible under limited funding to best satisfy the demands of university discipline construction, scientific research, teaching, and general education is a crucial question worthy of consideration in library development.

While the structure of university departments serves as an important reference for optimizing library collection structures, allocating funds directly to departments is neither convenient for statistical verification nor consistent with the actual distribution of collections in most universities. Based on this, it has been proposed to shift the allocation point from departments to subject categories, conducting theoretical research from both departmental attributes and literature attributes. Song Wenfei et al. approached the issue from two perspectives—scientific research/teaching and book circulation/utilization—using book categories (Chinese Library Classification) as allocation points. They constructed a book procurement model using fuzzy bi-criteria programming to allocate book procurement funds, first determining weights for book categories from each perspective separately, then using empirical fuzzy methods to determine the proportion of each perspective, thereby obtaining comprehensive weights for each book category. This provided a new approach for book procurement fund allocation, though it still involved some subjectivity. Additionally, Shen Yang et al. also shifted the allocation point to subject categories based on the Chinese Library Classification, determining relative weights for each book category from three perspectives: readership, book utilization, and publication conditions of suitable books, finally using the Analytic Hierarchy Process (AHP) to determine the weight of each perspective. Although AHP provides a rational way to determine relative weights, some subjectivity may still exist. Regarding how to combine weights determined from different perspectives into a comprehensive weight for book categories, this paper explores the use of game theory combination weighting to provide new references for optimizing book procurement fund allocation.

2 Research Status

In recent years, scholars have conducted exploratory research on the optimal allocation of print book procurement funds from various perspectives. Han Lidong approached the issue from the departmental perspective, suggesting that libraries should allocate book purchase funds to secondary departments by discipline. However, Hua Suyong et al. argued that although departmental structure is important, direct allocation to departments is impractical. They proposed shifting the allocation point to subject categories based on the Chinese Library Classification, determining relative weights from three perspectives: readership, book utilization, and publication conditions, then using AHP to determine the weight of each angle. While AHP offers reasonable weight determination, subjectivity may persist. Song Wenfei et al. approached from research/teaching and circulation/utilization perspectives, using book categories as allocation points and constructing a fuzzy bi-criteria programming model. They first determined weights from each perspective separately, then used empirical fuzzy methods to combine them, providing a new approach albeit with some subjectivity. Shen Yang et al. similarly used subject categories, determining weights from three perspectives and combining them with AHP, though subjectivity remained. This paper addresses the combination of weights from different perspectives using game theory combination weighting.

3 Using Game Theory Combination Weighting to Determine Comprehensive Weights for Book Categories

In game theory, when multiple decision-makers face several decision alternatives, each alternative can be assumed to be the result of rational decision-making, where decision-makers seek to maximize their own benefits or minimize their own losses. This competitive outcome is not controlled by any single decision-maker but is achieved collectively by all decision-makers. During the decision process, when all parties coordinate to seek maximized common interests, compromise emerges. Nash equilibrium represents finding consistency or compromise among different decision alternatives to achieve maximized common interests.

Introducing the equilibrium concept from game theory into the combination weighting of library book category fund allocation schemes: Suppose weights are assigned to each book category from L perspectives, with each perspective having its rationality. This yields L weight vectors representing L book fund allocation schemes. Treat these L schemes as game participants. Since each perspective's scheme has both rationality and limitations, to improve the scientific validity of book category weighting, we draw upon game theory's equilibrium concept to find consistency or compromise among the L weight vectors. This involves finding optimal combination weights that minimize the total deviation between the optimal weights and those determined by each scheme, thereby obtaining optimal comprehensive weights for book categories.

Model Construction and Solution

(1) Assume that from L perspectives, L methods are used to assign weights to m book categories, yielding L weight vectors (L allocation schemes). Let the weight vector from the l-th method be w = (w 1, w 2, …, w) , where m is the number of book categories and l = 1, 2, …, L. Denote any linear combination of the L weight vectors as:

$$\begin{pmatrix} \alpha_1 w_{11} + \alpha_2 w_{21} + \cdots + \alpha_L w_{L1} \\ \alpha_1 w_{12} + \alpha_2 w_{22} + \cdots + \alpha_L w_{L2} \\ \vdots \\ \alpha_1 w_{1m} + \alpha_2 w_{2m} + \cdots + \alpha_L w_{Lm} \end{pmatrix} = \begin{pmatrix} w_{11} & w_{21} & \cdots & w_{L1} \\ w_{12} & w_{22} & \cdots & w_{L2} \\ \vdots & \vdots & \ddots & \vdots \\ w_{1m} & w_{2m} & \cdots & w_{Lm} \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_L \end{pmatrix}$$

In formula (1), α are linear combination coefficients with $\alpha \geq 0$. The set of all possible book category weight vectors is {w | w = Σα w , α ≥ 0, Σα = 1}.

(2) Drawing on game theory's equilibrium concept, finding the most satisfactory weight vector w* can be reduced to optimizing the linear combination coefficients of the L vectors, i.e., finding optimal combination coefficients α *(k = 1, 2, …, L) that minimize the total deviation between w* and each w . This yields the following countermeasure model:

$$\min \sum_{l=1}^{L} \|w^* - w_l\|^2 \quad \text{s.t.} \quad \sum_{k=1}^{L} \alpha_k = 1, \alpha^* \geq 0$$

(3) Solve the countermeasure model using the interior point penalty function method. The interior point penalty function method is an effective approach for solving constrained nonlinear optimization problems. Specifically, if the original problem can be expressed as:

$$\min f(x) \quad \text{s.t.} \quad h(x) = 0; \quad g(x) \leq 0$$

A penalty function can be constructed to approximate the original problem as equation (4), where is the penalty factor (> 0):

$$\min f_\mu(x,s) = \min f(x) - \mu \sum \ln(s_q) \quad \text{s.t.} \quad h(x)=0; \quad g(x)+s=0$$

For equation (4), since inequality constraints g(x) exist in equation (3), slack variables s are added to facilitate solving, making g(x) + s = 0, where s_q is the q-th component of slack variable s. To ensure ln(s_q) remains bounded, s_q > 0 is required. As the penalty factor   gradually decreases to 0 through iterations, the minimum of f_ (x, s) converges to the minimum of f(x). The logarithmic term serves as a penalty function. Detailed descriptions of this method can be found in references [7-9].

Therefore, based on the countermeasure model in formula (2), construct the approximate optimization problem:

$$\min \sum_{k=1}^{L} \left\| \sum_{l=1}^{L} \alpha_l w_l - w_k \right\|^2 - \mu \sum \ln(s_q) \quad \text{s.t.} \quad \sum_{k=1}^{L} \alpha_k = 1; \quad -\alpha_k^* + s_q = 0; \quad k=q; \quad \mu > 0$$

Using MATLAB software, the linear combination coefficients are calculated as (α_1, α_2, …, α*_L), and the optimal combination weights for book categories can be obtained as: w* = Σα* w .

4 Case Study: Hebei University of Technology Library

Taking Hebei University of Technology Library as an example, we determine the discipline construction weights and circulation utilization weights for book categories from two perspectives—discipline construction and circulation utilization—then use game theory combination weighting to determine the comprehensive weights.

4.1 Determination of Discipline Construction Weights for Book Categories

Through literature review and expert interviews, the main influencing factors for optimal allocation of university library book procurement funds based on discipline construction goals [10] involve three aspects: discipline level, research level, and reader level. According to the impact level on university discipline development, discipline level can be divided into six categories: national key disciplines, provincial key disciplines, university-level key disciplines, emerging disciplines (established for less than 3 years), general disciplines (ordinary majors), and basic disciplines (public courses). Based on the level of research innovation projects, research level can be divided into three categories: number of national research projects, number of provincial research projects, and number of papers indexed in three major indexes (SCI, CSSCI, EI). According to different reader levels, reader level can be divided into six categories: number of doctoral supervisors, number of master's supervisors, number of other faculty (excluding doctoral and master's supervisors), number of doctoral students, number of master's students, and number of undergraduate students.

In summary, we select the above 3 first-level indicators and 15 second-level indicators as parameter indicators affecting university discipline construction goals for model construction. The hierarchical structure model built based on these discipline indicators is shown in Figure 1 [Figure 1: see original paper].

Using the Analytic Hierarchy Process, we can obtain the relative weights of various discipline indicators at the sub-criterion level, match each indicator with book categories, and finally obtain the discipline construction weights C for each book category:

$$C = \{c_i | c_i = \sum_{f=1}^{p} n_{if} w_f / \sum_{i=1}^{m} \sum_{f=1}^{p} n_{if} w_f\}$$

where i = 1, 2, …, m (m is the number of book categories), f = 1, 2, …, p (p is the number of discipline indicators), w_f is the weight of discipline indicator f, and n_{if} is the quantity of indicator f under book category i.

Based on formula (6) and the specific quantities of various discipline indicators in 2015, we obtain the discipline construction weights for each book category, with results shown in Table 1 , column 3. The table shows that book categories with larger discipline construction weights are TB (General Industrial Technology), TH (Mechanical and Instrument Industry), TQ (Chemical Industry), F (Economic Management), TP (Computer Technology and Automation), TM (Electrical Technology), O (Mathematics and Physics), TN (Telecommunications and Radio Electronics), and TU (Building Science). This aligns with the distribution of key and strong disciplines in this engineering-focused university. The discipline construction weights are derived based on the university's discipline structure and reflect the development goals of an engineering institution.

4.2 Determination of Circulation Utilization Weights for Book Categories

Through literature review and expert interviews, we identify circulation indicators for book categories. The actual number of borrowed volumes reflects relative demand for volumes in that category; the actual number of borrowed titles reflects relative demand for titles. The ratio of borrowed volumes to total holdings reflects turnover rate—"volume" includes copy factors, implying broader knowledge dissemination. However, turnover rate may obscure the fact that some books are never borrowed and cannot fully reflect actual utilization effectiveness. The ratio of borrowed titles to total titles reflects utilization rate—readers' demand for different book titles reflects demand for different knowledge units. With duplicate copies available, if even one copy is borrowed, it proves the title meets reader needs. "Title" represents different knowledge units; more titles mean more information available for borrowing.

Based on this analysis, we propose using four indicators to determine circulation utilization weights: reader volume demand, reader title demand, book utilization rate, and book turnover rate.

The steps for using the entropy method to solve for relative weights of circulation indicators [14] are:

(1) Standardize the original indicator data to obtain dimensionless standardized data R = (x'*{ij})*{m×n}:

$$x'_{ij} = \frac{x_{ij} - \min(x_{i1}, x_{i2}, ..., x_{im})}{\max(x_{i1}, x_{i2}, ..., x_{im}) - \min(x_{i1}, x_{i2}, ..., x_{im})}$$

where i = 1, 2, …, m; j = 1, 2, …, n; 0 ≤ x'*{ij} ≤ 1. Here m is the number of book categories and n is the number of evaluation indicators. x*{ij} represents the original value of book category i under indicator j, and x'_{ij} represents the standardized value.

(2) Calculate the proportion p_{ij} of book category i's evaluation value under indicator j:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}}, \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n$$

(3) Calculate the entropy value H_j of indicator j:

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln(p_{ij}), \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n$$

(4) Calculate the difference coefficient g_j of indicator j:

$$g_j = 1 - H_j, \quad j = 1, 2, ..., n$$

Larger g_j indicates more important indicators.

(5) Calculate the weight e_j of indicator j:

$$e_j = \frac{g_j}{\sum_{j=1}^{n} g_j}, \quad j = 1, 2, ..., n$$

This yields the weight vector E = (e_1, e_2, …, e_n) for circulation indicators.

The basic steps for using the TOPSIS method to determine circulation utilization weights [15] are:

(1) Normalize the original data matrix and establish the corresponding matrix. The conversion formula is:

$$a_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}$$

where X_{ij} represents the value of book category i under evaluation indicator j. The normalized matrix A is:

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

(2) From matrix A, obtain the optimal value vector A^+ and worst value vector A^- (the best and worst solutions among all book categories):

Optimal solution: $A^+ = (a^+$*{i1}, a*$^+${i2}, …, a^+*{ij}, …, a*$^+${in})
where a^+_{ij} represents the maximum ratio value under indicator j.

Worst solution: $A^- = (a^-$*{i1}, a*$^-${i2}, …, a^-*{ij}, …, a*$^-${in})
where a^-_{ij} represents the minimum ratio value under indicator j.

(3) Calculate the distances D^+_i and D^-_i between each book category and the optimal/worst solutions:

Distance to optimal solution:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} e_j (a_{ij}^+ - a_{ij})^2}$$

Distance to worst solution:

$$D_i^- = \sqrt{\sum_{j=1}^{n} e_j (a_{ij}^- - a_{ij})^2}$$

where D^+_i and D^-*i represent the distances between book category i and the optimal/worst solutions; a*{ij} is the value of book category i under indicator j; and e_j is the weight coefficient of indicator j determined by the entropy method.

(4) Calculate the closeness degree B_i of each book category to the optimal solution:

$$B_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

where B_i ranges between 0 and 1. Values closer to 1 indicate the evaluation object is nearer to the optimal level; values closer to 0 indicate it is nearer to the worst level.

(5) Normalize B_i to obtain circulation utilization weights D_i for each book category:

$$D = \{D_i | D_i = B_i / \sum_{i=1}^{m} B_i\}, \quad i = 1, 2, ..., m$$

where m is the number of book categories.

Using the entropy-TOPSIS method and 2015 circulation data, we obtain circulation utilization weights for book categories, shown in Table 1 , column 4. The results indicate that book categories with larger circulation utilization weights are TP (Computer Technology and Automation), I (Literature), O (Mathematics and Physics), H (Language), F (Economic Management), B (Philosophy and Religion), and K (History and Geography). These relate to the university's general education, as basic disciplines and literature have broad readership. Circulation utilization weights are derived from actual borrowing patterns, reflecting readers' real demands.

4.3 Determination of Comprehensive Weights for Book Categories

Based on the determined discipline construction weights and circulation utilization weights, we apply game theory combination weighting to find consistency or compromise between different weights. This involves finding optimal combination weights that minimize the overall deviation from weights determined by each scheme, thereby obtaining optimal comprehensive weights.

Following the proposed game theory combination weighting method and solution approach, MATLAB software is used to calculate the optimal linear combination coefficients as $(\alpha_1, \alpha_2) = (0.5266, 0.4734)$. The resulting optimal comprehensive weights for book categories are shown in Table 1 , column 5. Budget percentages for each book category can be allocated according to these comprehensive weights.

The results show that book categories with larger comprehensive weights are TP (Computer Technology and Automation), O (Mathematics and Physics), I (Literature), F (Economic Management), TB (General Industrial Technology), TH (Mechanical and Instrument Industry), TQ (Chemical Industry), H (Language), TM (Electrical Technology), TU (Building Science), and TN (Telecommunications and Radio Electronics). These reflect both actual reader demand and the development goals of serving discipline construction in an engineering university. The rational combination of weights from two perspectives has strong mathematical theoretical foundations and avoids human subjectivity.

4.4 Comparative Analysis

Analysis of 2015 data can provide references for 2016 budget allocation. To verify the rationality of our method, we conduct two comparative analyses: First, we compare the proximity of discipline construction weights, circulation utilization weights, and comprehensive weights to the actual 2016 procurement proportions (Table 1 , column 6). The distances are 0.2199, 0.2454, and 0.1729 respectively, showing that comprehensive weights calculated by our method are closer to actual procurement proportions. This indirectly confirms that the library's collection development considers both circulation utilization and discipline construction.

Second, comparing column 5 (comprehensive weights) with column 6 (actual 2016 procurement proportions) reveals that categories J (Art) received disproportionately large funding, while TP (Computer Technology and Automation) received insufficient funding. This indicates that actual fund allocation was not entirely reasonable and has room for improvement.

Therefore, compared to traditional methods relying on experience or single-perspective weights, our approach is more objective and reasonable. It avoids excessive subjectivity from pure experience while preventing one-sidedness from single weights, providing valuable guidance for transitioning library fund allocation from extensive to intensive management. Figure 2 [Figure 2: see original paper] illustrates the comparison of relative weights for book categories.

Conclusion

How to allocate book procurement funds scientifically is a question every university must consider. Based on determining allocation weights for each book category from different impact perspectives, this paper proposes using game theory combination weighting to integrate these weights into comprehensive weights. This method has strong mathematical theoretical foundations and avoids subjective weight determination. The case study of Hebei University of Technology verifies the feasibility of our method and provides a new approach for optimizing book procurement fund allocation.

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Author Contributions

Sun Weizhong: Overall paper control, task assignment, and writing guidance;
Wang Zhibo: Model construction, solution, and paper writing;
Gao Yingping: Logical thinking, language organization, and writing guidance;
Li Yahan: Data collection for discipline construction indicators in case analysis;
Ning Ning: Data collection for circulation indicators in case analysis.

Research on the Optimization of Library Collection by Game Theory Combination Weighting—Taking Hebei University of Technology Library as an Example

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Abstract: [Purpose/significance] Learning from the balanced thinking in game theory, this research investigates quantitative and objective combination methods for weights determined from different perspectives for library book procurement funds. [Method/process] The paper uses game theory combination weighting to construct a countermeasure model, proposes solving the model using the interior point penalty function method, realizes the assembly of weights from different perspectives, and conducts empirical analysis using Hebei University of Technology as an example. [Result/conclusion] Through example analysis, the feasibility of the method is verified, the influence of subjective weight determination is avoided, and a new idea is provided for the optimal allocation of book procurement funds.

Keywords: game theory; combination weighting; collection optimization; purchasing books

Note: Figure translations are in progress. See original paper for figures.