

Research Article

Application of Interaction Effect Multichoice Goal Programming in Project Portfolio Analysis

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How to choose the optimal project portfolio based on the enterprise objectives is very important for the survival and development of an enterprise. However, the current portfolio analysis needs to be improved in the aspects of interaction effect analysis, multichoice target planning, and method simplicity and practicability. The method of portfolio selection proposed in this study takes into consideration the complex interaction within the portfolio, which makes up for the deficiency of the existing research on portfolio selection. This paper illustrates the application of the multichoice object programming method in the analysis of the combination of two-project and three-project interaction effects by a series of examples. The results show that the method is applicable in portfolio evaluation. The method of multichoice goal programming of the interaction effect provides the basis for enterprise to measure the complex relationship within the portfolio and also provides a new method and idea for the selection of the enterprise project portfolio.

1. Introduction

With the increasingly diversified market economy and increasingly fierce market competition, managers continue to expand the scope of business to improve the competitiveness of enterprises, and enterprise alternative projects are also expanding their scope. To maximize the overall benefit and obtain sustainable development of enterprises, the managers of enterprises need to choose the most suitable project portfolio in the multiproject environment with high complexity and strong dynamic. Therefore, it is very important to choose a portfolio in the process of enterprise portfolio management. Portfolio selection problem refers to the situation when the project management decision-maker selects a subset of projects from a limited set of alternative projects under the constraints of time, resources, cost, and other constraints and then forms a group that can achieve the desired and optimized organizational goals [1]. Portfolio selection is not only an important link in the process of organizing project management but also a part of strategic decision-making of enterprises. Successful portfolio selection can help enterprises effectively achieve organizational strategic objectives, improve the market competitiveness,

and promote sustainable development of enterprises. Improper portfolio selection will not only increase the difficulty of project portfolio implementation and waste a large amount of resources but also reduce the competitive advantage, causing huge losses for enterprises. Therefore, how to choose the optimal project portfolio based on the enterprise objectives is very important for the survival and development of an enterprise.

However, owing to the wide range of enterprise management objectives, the complex interaction between different objectives, and the large number of enterprise alternative projects, there are resource, technology, and other related relationships among the projects. Therefore, how to choose the optimal project portfolio based on the enterprise objectives given the complex relationship between the projects and the strategic objectives has brought great challenges to the enterprise. Portfolio selection is the development and extension of project selection (PS) to meet the market requirements, and it is an important part of portfolio management. In the process of portfolio selection, decision-makers of organizations need to consider the constraints of resources, time, cost, and other conditions in addition to using the project research method to evaluate

and sort projects and then select a subset of projects from the alternative pool to form a portfolio so that the portfolio can meet the constraints and achieve the goal expected by decision-makers: the optimal organization goal [2].

The research on portfolio selection originated from the modern portfolio theory put forward by Markowitz in 1952, which was initially applied mainly in the field of investment [3]. With the further research on the project portfolio, Lorie and Savage extended the project portfolio theory to the field of project management [4]. As an important part of project portfolio management, portfolio selection has been widely concerned by scholars. The research on portfolio selection mainly focuses on the evaluation of portfolio selection and the construction of the portfolio selection model. In the aspect of portfolio selection and evaluation, some scholars are committed to building a scientifically reasonable portfolio selection and evaluation framework from different perspectives. Modern project portfolio selection should consider its cyclical characteristics from a dynamic perspective to meet the short-term and long-term strategic objectives of the organization. Portfolio selection is a classical combinatorial optimization (CO) issue [5]. For example, Santhanam and Kyparisis [6] aimed at the interaction between technology and revenue among projects; Jin and Kim [7] combined it with the multiobjective characteristics of portfolio selection; Badri and Davis [8] considered the preference information of decision-makers and improved the basic model. In addition, some scholars used the classical fuzzy theory [9], system dynamics [10], and other theories to construct the multistage portfolio selection problem under the fuzzy situation.

The research goal of project portfolio selection based on interaction effect (IE) is to maximize the contribution of project portfolio to the realization of organizational strategy by selecting appropriate projects from alternative projects and combining them under the premise of fully considering the interaction between projects. From the perspective of the number of projects with interaction relationship, Czajkowski and Jones [11], Schmidt [12], Dickinson, and other scholars have conducted quantitative research on the interaction effect between projects in different years; however, the main problem of the models proposed in these studies is that they only conducted quantitative analysis on the interaction relationship between two projects. The fact is that in the past few years, many scholars have tried to quantify it, but their researches are all improvements on the classical interaction effect formula.

At present, there are three types of interaction effect models. In the first model, only two-way interaction is considered. For example, the model proposed by Czajkowski and Jones [11] and Schmidt [12] only considers the interaction between two projects. Then, Santhanam and Kyparisis [6] put forward an interactive project selection model with three projects in 1995, which was widely used by Jin and Kim [7], Jin and Kim [13], and Klapka and Piños [14]. In the second model, there is no restriction on the items with interaction relationship. This model is proposed by Santhanam and Kyparisis [15] based on the polynomial model. This paper assumes that there are different project groups, and each group contains at least four projects and produces

additional contributions. The third model is proposed by Stummer and Heidenberger [16], which is improved based on the previous model and is thus more universal. This model is an extension of the one proposed by Santhanam and Kyparisis [6]. This model was adopted by Doerner et al. [17] and other scholars and can be used when all the alternative projects are implemented at the same time.

As an important part of project portfolio management, portfolio selection and optimization has gained attention from many scholars for a long time. Eilat et al. [18] used data envelopment analysis (DEA) in the evaluation of the interaction effect portfolio. Dickinson et al. [19] solved the portfolio selection optimization problem under uncertainty by introducing interval valued fuzzy (IVF). Carazo [2] used scatter search for the project portfolio selection (SS-PPS) mathematical method to solve the problem of portfolio selection and planning and carried out empirical verification. Stewart [20] proposed multiobjective portfolio selection based on the reference point. In recent years, the research of interaction effect project portfolio selection (IE-PPS) has achieved good results. However, owing to the complexity of model construction and solution technology, the basic model of IE-PPS involves less research on multiproject interaction, and the improved model only considers the situation where the interaction effect exists between two projects; in the dynamic perspective, the start and end time of the project is restricted; whether resources can be transferred is limited; thus, the gap between the model and the real solution environment has been enlarged; under the background of considering decision-maker's preference, it usually appears as a reference value and is not fitted in the solving model.

As a complex decision support system, the complexity of IE-PPS will increase geometrically along with the number of subprojects. Throughout the existing IE-PPS research, we need to face the following challenges: the final result of the portfolio selection problem is to provide decision support tools for project managers; therefore, the coupling of decision-maker's preference and portfolio problem has become a challenge of this research. How to give the appropriate portfolio selection solution from the perspective of decision-maker and guide decision-maker to make the right choice is another challenge of this research. In the research process of portfolio selection based on the interaction effect, the research of project selection should also be included. Taking the key success factors as the measurement tool of project selection, we first make an early evaluation of the project itself, then use the project portfolio selection method on the basis of the interaction effect, which can help obtain the results of project portfolio selection by combining theory with practice, and finally make the research integrated.

The research motivation of this study is to develop a new portfolio evaluation method. This evaluation method should accurately measure the interaction effects between projects and their impact on the overall portfolio. To solve the above problems, this study set the following research objectives: to improve the existing evaluation model and to construct a portfolio selection evaluation model, which can solve the problem caused by the interaction effect. In this paper, the interaction effect relationship is embedded into the

multichoice goal programming model (MCGP) to construct the multiobjective optimization model of portfolio selection. Then, a series of examples are given to verify the practicability and advanced nature of the model.

2. Materials and Methods

This paper illustrates the application of the MCGP method in the analysis of the combination of two-project and three-project interaction effects by a series of examples.

2.1. Interaction Effect MCGP. With the increase of the number of alternative projects, it is found that when some projects are executed at the same time, they will have a dependency relationship and can influence each other in one or more dimensions, such as resources, benefits, risks, and so on; that is to say, it will lead to the collaborative results of projects in one or more dimensions, and these projects are considered interactive. The interaction between projects or between the project and project portfolio increases the uncertainty of enterprise project selection decision. Identifying the interaction effect brought by this interaction relationship will provide strong support for enterprises to the realization of the optimal allocation of resources and the control of risks.

Some scholars have pointed out that the interaction between projects should be considered in project selection decision-making when project selection still relies on a single indicator for decision-making [21, 22]. However, it was not until the 1980s that scholars did bring the interaction between projects into the research system. In 1980, Gear and Cowie [23] pointed out that there may be an internal interaction effect between projects, that is, the demand for resources or benefits of a project will affect whether other projects are selected. In addition, there is an interaction relationship between the project and the external environment, and the interaction between the internal and external factors will affect whether the project is selected. Bard et al. [24] pointed out that the interaction between projects and the ongoing project portfolio should be paid attention to in the project portfolio management. After that, some scholars have gradually noticed the importance of the relationship between projects for the project portfolio management and have tried to measure the interaction effect between projects from different angles.

There are several characteristics of the interaction effect between projects: the subjects involved are both projects and the project portfolio. Two or more subjects are involved. The root causes of the interaction effect between projects are as follows: the diversification strategy of enterprises requires the implementation of multiple projects at the same time and the project presents a variety of relationships such as competition and coordination on the production factors represented by resources. The characteristics of product development process and the logical relationship of project implementation lead to the interaction of project in the dimensions of knowledge and technology. The quantitative calculation of the interaction effect between projects can be obtained by solving resource interaction, revenue interaction, and technology interaction. However, with the increase of the number of interaction projects, the solution of interaction effect becomes more complex and the uncertainty of interaction effect on organization also increases. The interaction effect between projects may be "positive" or "negative," that is, the interaction effect between projects is directional. In a group of interactive projects, the interaction effect of project A on project B is not equal to that of project B on project A. The interaction effect of the project portfolio is the sum of the interaction effects of related projects in different dimensions. Considering the interaction effect between projects is helpful for the organization to predict the follow-up results of a decision, which makes the decision more forward-looking.

To reflect the resource interaction and revenue interaction in the model, the objective function and constraints need to reflect some additional instructions. For example, the total contribution is equal to the sum of the respective contributions of the candidate projects plus or minus the additional contributions due to interaction, as shown in equation (1).

$$Z(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \dots + c_nx_n + y(x_1, x_2, \dots, x_n), \quad (1)$$

where c_q represents the independent distribution of the q -th item and y represents the algebraic sum of additional items due to the interaction between items.

MCGP proposed by Chang [25, 26] has been widely used to resolve many practical decision-making problems in recent years [27, 28]. The MCGP method is described as follows:

$$\begin{aligned} & \text{Objective function: } \text{Min} \sum_{i=1}^n (d_i^+ + d_i^-) + \sum_{i=1}^n (e_i^+ + e_i^-) \\ & \text{Constraints: } \begin{cases} f_i(x) - d_i^+ + d_i^- = g_i, & i = 1, 2, \dots, n \\ x \in X = \{x_1, x_2, \dots, x_n\} \\ g_i - e_i^+ + e_i^- = g_{i, \max}, & i = 1, 2, \dots, n \\ g_{i, \min} \leq g_i \leq g_{i, \max}, & i = 1, 2, \dots, n \\ d_i^+, d_i^-, e_i^+, e_i^- \geq 0, & i = 1, 2, \dots, n \\ X \in F, & (F \text{ is the set of feasible solutions}). \end{cases} \end{aligned} \quad (2)$$

Here, d_i^+ , d_i^- indicates the value of the i -th goal exceeding and not reaching the expected value of the goal. $f_i(x)$ is the function of the i -th object. X is the decision variable, representing m alternatives (x_1, x_2, \dots, x_m) . g_i is the expected level for the i -th goal. e_i^+ and e_i^- are close to positive and

negative deviation variables of $|g_i - g_{i,\max}|$, respectively. $g_{i,\min}$ and $g_{i,\max}$ are the lower and upper limits of the target for g_i , respectively.

Considering the symbiotic relationship [29, 30], new constraints need to be added to the above model:

$$\begin{aligned} \text{Objective function: } & \text{Min} \sum_{i=1}^n (d_i^+ + d_i^-) + \sum_{i=1}^n (e_i^+ + e_i^-) \\ \text{Constraints: } & \begin{cases} f_i(x) - d_i^+ + d_i^- = g_i, & i = 1, 2, \dots, n \\ x \in X = \{x_1, x_2, \dots, x_n\} \\ g_i - e_i^+ + e_i^- = g_{i,\max}, & i = 1, 2, \dots, n \\ g_{i,\min} \leq g_i \leq g_{i,\max}, & i = 1, 2, \dots, n \\ d_i^+, d_i^-, e_i^+, e_i^- \geq 0, & i = 1, 2, \dots, n \\ X \in F, & (F \text{ is the set of feasible solutions}) \\ Z(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \dots + c_nx_n + y(x_1, x_2, \dots, x_n). \end{cases} \end{aligned} \quad (3)$$

The problem is solved using the LINGO [31] software.

2.2. Two Sample Project Portfolios. This example evaluates the project portfolio from the scenarios of a single-objective, multiple objectives, a two-project portfolio, and a three-project portfolio. First, this paper gives an example of single-objective portfolio analysis. This paper takes a company's portfolio management process as an example to verify the effectiveness of the proposed portfolio allocation evaluation model. According to the company's basic strategic objectives, two projects are selected from the four alternative projects to be implemented to form the optimal project portfolio so as to achieve the business objectives of two projects simultaneously, and the higher the income, the better.

The characteristic attributes of investment projects can be expressed using formula (4):

$$P_i: Y_i = ax_i - b, \quad (4)$$

where P_i represents the i -th project and Y_i represents the total income of the project (unit: 10,000 yuan). X_i refers to the investment in the operation period of the project (unit: 10,000 yuan). B refers to the investment in the construction period of the project (unit: 10,000 yuan). A is the profit coefficient of the operation period of the project. The properties of the four basic investment projects are as follows:

$$\begin{aligned} P_1: Y_1 &= 0.56x_1 - 17600 \\ P_2: Y_2 &= 0.66x_2 - 25000 \\ P_3: Y_3 &= 0.70x_3 - 15800 \\ P_4: Y_4 &= 0.58x_4 - 24000 \end{aligned}$$

First, this example evaluates the single-factor project portfolio. In the evaluation of a single-factor project portfolio, the income level of the project portfolio is mainly

considered. The bigger the portfolio, the better. Without considering the interaction effect, the six project portfolios have the following characteristics:

$$\begin{aligned} PP_1: Y_1 + Y_2 &= 0.56x_1 - 17600 + 0.66x_2 - 25000 \\ PP_2: Y_1 + Y_3 &= 0.56x_1 - 17600 + 0.70x_3 - 15800 \\ PP_3: Y_1 + Y_4 &= 0.56x_1 - 17600 + 0.58x_4 - 24000 \\ PP_4: Y_2 + Y_3 &= 0.66x_2 - 25000 + 0.70x_3 - 15800 \\ PP_5: Y_2 + Y_4 &= 0.66x_2 - 25000 + 0.58x_4 - 24000 \\ PP_6: Y_3 + Y_4 &= 0.70x_3 - 15800 + 0.58x_4 - 24000 \end{aligned}$$

When considering the interaction effect between the returns of a single project, the six project portfolios have the following attributes:

$$\begin{aligned} PP_1: Y_1 + Y_2 &= 0.56x_1 - 17600 + 0.66x_2 - 25000 + (8.10 \times 10^{-7}) x_1x_2 \\ PP_2: Y_1 + Y_3 &= 0.56x_1 - 17600 + 0.70x_3 - 15800 + (-1.22 \times 10^{-6}) x_1x_3 \\ PP_3: Y_1 + Y_4 &= 0.56x_1 - 17600 + 0.58x_4 - 24000 + (-6.30 \times 10^{-7}) x_1x_4 \\ PP_4: Y_2 + Y_3 &= 0.66x_2 - 25000 + 0.70x_3 - 15800 + (9.40 \times 10^{-7}) x_2x_3 \\ PP_5: Y_2 + Y_4 &= 0.66x_2 - 25000 + 0.58x_4 - 24000 + (1.93 \times 10^{-6}) x_2x_4 \\ PP_6: Y_3 + Y_4 &= 0.70x_3 - 15800 + 0.58x_4 - 24000 + (7.90 \times 10^{-7}) x_3x_4 \end{aligned}$$

As shown in Table 1, whether the interaction effect is considered or not has an important impact on the evaluation of project portfolio. In this case, when the interaction effect is not considered, PP_2 has the best return. After adding the influence of interaction effect, the income of PP_2 ranked second in the alternatives and the income of PP_4 ranked first. This example shows that the interaction effects between projects need to be considered in portfolio evaluation.

TABLE 1: Income measurement of the project portfolio.

Project portfolio	Composition of the project portfolio	Investment in the operation period	Investment in the construction period	Income coefficient	Income	Interaction effects are not considered			Consider interaction effects		
						Portfolio income	Ranking	Interaction coefficient	Interaction benefit	Portfolio income	Ranking
1	1	40000	17600	0.56	4800	6200	4	8.10×10^{-7}	1296	7496	4
	2	40000	25000	0.66	1400	17000	1	-1.22×10^{-6}	-1952	15048	2
2	1	40000	17600	0.56	4800	4000	5	-6.30×10^{-7}	-1008	2992	6
	3	40000	15800	0.70	12200	13600	2	9.40×10^{-7}	1504	15104	1
3	1	40000	17600	0.56	4800	600	6	1.93×10^{-6}	3088	3688	5
	4	40000	24000	0.58	-800	11400	3	7.90×10^{-7}	1264	12664	3
4	2	40000	25000	0.66	1400	13600	2	9.40×10^{-7}	1504	15104	1
	3	40000	15800	0.70	12200	13600	2	9.40×10^{-7}	1504	15104	1
5	2	40000	25000	0.66	1400	600	6	1.93×10^{-6}	3088	3688	5
	4	40000	24000	0.58	-800	11400	3	7.90×10^{-7}	1264	12664	3
6	3	40000	15800	0.70	12200	11400	3	7.90×10^{-7}	1264	12664	3
	4	40000	24000	0.58	-800	11400	3	7.90×10^{-7}	1264	12664	3

As shown in Table 2, the project portfolio evaluation method based on the optimization results of the MCGP model is obviously different from the simple project portfolio evaluation method. MCGP can analyze data better and deal with problems that cannot be solved by traditional methods. To sum up, the method proposed in this paper is effective in a single goal situation. Now, we will do an example analysis in the multiobjective situation. In the above example, the constraint target of the number of personnel is added. Different investment projects require a different number of employees. Suppose that the number of employees (M_i) of a single project (P_i) is as follows:

$$P_1: M_1 = 0.02x_1 \text{ (Unit: person)}$$

$$P_2: M_2 = 0.01x_2 \text{ (Unit: person)}$$

$$P_3: M_3 = 0.03x_3 \text{ (Unit: person)}$$

$$P_4: M_4 = 0.01x_4 \text{ (Unit: person)}$$

The total number of employees in the project portfolio should not exceed 1,200, and the number of individual employees should exceed 200. Owing to the simplicity of the example analysis, this paper does not consider the interaction effect of project personnel requirements. In this case, the investment in the operation period of the project portfolio is not more than 80 million yuan. Therefore, the constraints of different project portfolios are as follows:

$$PP_1: Y_1 + Y_2 = 0.56x_1 - 17600 + 0.66x_2 - 25000 + (8.10 \times 10^{-7}) x_1x_2$$

$$x_1 + x_2 \leq 80000;$$

$$M_1 + M_2 = 0.02x_1 + 0.01x_2, \quad M_1 + M_2 \leq 1200, \quad M_1 \geq 200, \quad M_2 \geq 200;$$

$$PP_2: Y_1 + Y_3 = 0.56x_1 - 17600 + 0.70x_3 - 15800 + (-1.22 \times 10^{-6}) x_1x_3;$$

$$x_1 + x_3 \leq 80000$$

$$M_1 + M_3 = 0.02x_1 + 0.03x_3, \quad M_1 + M_3 \leq 1200, \quad M_1 \geq 200, \quad M_3 \geq 200$$

$$PP_3: Y_1 + Y_4 = 0.56x_1 - 17600 + 0.58x_4 - 24000 + (-6.30 \times 10^{-7}) x_1x_4$$

$$x_1 + x_4 \leq 80000$$

$$M_1 + M_4 = 0.02x_1 + 0.01x_4, \quad M_1 + M_4 \leq 1200, \quad M_1 \geq 200, \quad M_4 \geq 200$$

$$PP_4: Y_2 + Y_3 = 0.66x_2 - 25000 + 0.70x_3 - 15800 + (9.40 \times 10^{-7}) x_2x_3$$

$$x_2 + x_3 \leq 80000$$

$$M_2 + M_3 = 0.02x_2 + 0.03x_3, \quad M_2 + M_3 \leq 1200, \quad M_2 \geq 200, \quad M_3 \geq 200$$

$$PP_5: Y_2 + Y_4 = 0.66x_2 - 25000 + 0.58x_4 - 24000 + (1.93 \times 10^{-6}) x_2x_4$$

$$x_2 + x_4 \leq 80000$$

$$M_2 + M_4 = 0.01x_2 + 0.01x_4, \quad M_2 + M_4 \leq 1200, \quad M_2 \geq 200, \quad M_4 \geq 200$$

$$PP_6: Y_3 + Y_4 = 0.70x_3 - 15800 + 0.58x_4 - 24000 + (7.90 \times 10^{-7}) x_3x_4$$

$$x_3 + x_4 \leq 80000$$

$$M_3 + M_4 = 0.03x_3 + 0.01x_4, \quad M_3 + M_4 \leq 1200, \quad M_3 \geq 200, \quad M_4 \geq 200$$

As shown in Table 3, after the personnel arrangement is added to the evaluation objective of the project portfolio, the evaluation ranking of the project portfolio has changed significantly. This shows that the interaction effect MCGP model can deal with the multiobjective portfolio evaluation well. To compare the effect of multiobjective evaluation, this paper uses the DEA evaluation method for comparative analysis. The DEA method is also a common method for portfolio evaluation [18]. What is the difference between the DEA method and the interaction effect MCGP model in portfolio evaluation?

As shown in Table 4, this paper selects investment and the number of employees as input indicators and project portfolio income as output indicators. Before the operation, the data is normalized. The results of data envelopment analysis are shown in Table 5.

As shown in Table 5, the DEA method cannot distinguish the advantages and disadvantages of portfolio 5 and portfolio 6. Therefore, the interaction effect MCGP model is more effective in portfolio evaluation.

2.3. Three-Project Portfolio Examples. In this example, the total number of employees in the project portfolio is not more than 1200 and the number of individual employees is not less than 200. The investment in the operation period of the project portfolio shall not exceed 80,000. Therefore, the constraints of different project portfolios are as follows:

$$PP'_1: Y_1 + Y_2 + Y_3 = 0.56x_1 - 17600 + 0.66x_2 - 25000 + 0.70x_3 - 15800 + (-9.88 \times 10^{-12}) x_1x_2x_3$$

$$x_1 + x_2 + x_3 \leq 80000$$

$$M_1 + M_2 + M_3 = 0.02x_1 + 0.01x_2 + 0.03x_3, \quad M_1 + M_2 + M_3 \leq 1200, \quad M_1 \geq 200, \quad M_2 \geq 200; \quad M_3 \geq 200$$

$$PP'_2: Y_1 + Y_2 + Y_4 = 0.56x_1 - 17600 + 0.66x_2 - 25000 + 0.58x_4 - 24000 + (-1.22 \times 10^{-11}) x_1x_2x_4$$

$$x_1 + x_2 + x_4 \leq 80000$$

$$M_1 + M_2 + M_4 = 0.02x_1 + 0.02x_2 + 0.01x_4, \quad M_1 + M_2 + M_4 \leq 1200, \quad M_1 \geq 200, \quad M_2 \geq 200; \quad M_4 \geq 200$$

$$PP'_3: Y_1 + Y_3 + Y_4 = 0.56x_1 - 17600 + 0.70x_3 - 15800 + 0.58x_4 - 24000 + (-9.64 \times 10^{-12}) x_1x_3x_4$$

$$x_1 + x_3 + x_4 \leq 80000$$

$$M_1 + M_3 + M_4 = 0.02x_1 + 0.03x_3 + 0.01x_4, \quad M_1 + M_3 + M_4 \leq 1200, \quad M_1 \geq 200, \quad M_3 \geq 200; \quad M_4 \geq 200$$

$$PP'_4: Y_2 + Y_3 + Y_4 = 0.66x_2 - 25000 + 0.70x_3 - 15800 + 0.58x_4 - 24000 + (7.43 \times 10^{-12}) x_2x_3x_4$$

$$x_2 + x_3 + x_4 \leq 80000$$

$$M_2 + M_3 + M_4 = 0.02x_2 + 0.03x_3 + 0.01x_4, \quad M_2 + M_3 + M_4 \leq 1200, \quad M_2 \geq 200, \quad M_3 \geq 200; \quad M_4 \geq 200$$

As shown in Table 6, this method can well distinguish the advantages and disadvantages of different project portfolios. Because of the strict resource constraints, the profit of different project combinations is less than zero. Therefore, we should increase the upper limit of resource constraints

TABLE 2: Optimization results of the MCGP model for the project portfolio.

Project portfolio	Composition of the project portfolio	Investment in the operation period	Investment in the construction period	Income coefficient	Income	Portfolio income	Ranking
1	1	10000	17600	0.56	-12000	9767	4
	2	70000	25000	0.66	21200		
2	1	10000	17600	0.56	-12000	20346	1
	3	70000	15800	0.70	33200		
3	1	70000	17600	0.56	21600	2959	6
	4	10000	24000	0.58	-18200		
4	2	18723	25000	0.66	-12643	15529	3
	3	61276	15800	0.70	27093		
5	2	60725	25000	0.66	15079	4516	5
	4	19274	24000	0.58	-12821		
6	3	70000	15800	0.70	33200	15553	2
	4	10000	24000	0.58	-18200		

TABLE 3: Optimization results of the MCGP model for the interaction effect of the project portfolio.

Project portfolio	Composition of the project portfolio	Investment in the operation period	Investment in the construction period	Income coefficient	Income	Portfolio income	Number of employees	Ranking
1	1	40000	17600	0.56	4800	7496	1000	2
	2	40000	25000	0.66	1400		200	
2	1	45000	17600	0.56	7600	-1749	1000	6
	3	10000	15800	0.70	-8800		200	
3	1	10000	17600	0.56	-12000	4159	700	4
	4	70000	24000	0.58	16600		200	
4	2	50493	25000	0.66	8325	0	200	5
	3	10000	15800	0.70	-8800		1000	
5	2	60725	25000	0.66	15079	4516	600	3
	4	19274	24000	0.58	-12821		200	
6	3	20000	15800	0.70	-1800	9948	1000	1
	4	60000	24000	0.58	10800		200	

TABLE 4: Input output data of the project portfolio.

Project portfolio	Output		Input	
	Portfolio income	Total investment		Number of employees
1	7496	122600		1200
2	-1749	88400		1200
3	4159	121600		900
4	0	101293		1200
5	4516	128999		800
6	9948	119800		1200

TABLE 5: DEA results of the project portfolio.

Project portfolio (PP_i)	Crste	Vrste	Scale
1	0.762	0.836	0.911
2	0.000	1.000	0.000
3	0.863	1.000	0.863
4	0.365	0.773	0.472
5	1.000	1.000	1.000
6	1.000	1.000	1.000
Mean	0.662	0.935	0.708

crste = technical efficiency from CRS DEA, vrste = technical efficiency from VRS DEA, scale = scale efficiency = crste/vrste.

TABLE 6: Three-project portfolio evaluation results.

Project portfolio	Ranking	Composition of the project portfolio	Investment in the operation period	Investment in the construction period	Number of employees	Portfolio income
1	1	1	10000	17600	800	-6082
		2	55000	25000	200	
		3	15000	15800	200	
2	4	1	10000	17600	500	-15673
		2	60000	25000	200	
		4	10000	24000	200	
3	2	1	10000	17600	800	-9480
		3	15000	15800	200	
		4	55000	24000	200	
4	3	2	20000	25000	800	-15526
		3	10000	15800	200	
		4	50000	24000	200	

when evaluating similar portfolio problems. The total number of employees in our project portfolio is no more than 1800, and the number of individual employees is no less than 200. The investment in the operation period of the project portfolio shall not exceed 120,000. Therefore, the constraints of different project portfolios are as follows:

$$PP'_1: Y_1 + Y_2 + Y_3 = 0.56x_1 - 17600 + 0.66x_2 - 25000 + 0.70x_3 - 15800 + (-9.88 \times 10^{-12}) x_1x_2x_3$$

$$x_1 + x_2 + x_3 \leq 120000$$

$$M_1 + M_2 + M_3 = 0.02x_1 + 0.01x_2 + 0.03x_3,$$

$$M_1 + M_2 + M_3 \leq 1800, M_1 \geq 200, M_2 \geq 200; M_3 \geq 200$$

$$PP'_2: Y_1 + Y_2 + Y_4 = 0.56x_1 - 17600 + 0.66x_2 - 25000 + 0.58x_4 - 24000 + (-1.22 \times 10^{-11}) x_1x_2x_4$$

$$x_1 + x_2 + x_4 \leq 120000$$

$$M_1 + M_2 + M_4 = 0.02x_1 + 0.02x_2 + 0.01x_4, \quad M_1 + M_2 + M_4 \leq 1800, M_1 \geq 200, M_2 \geq 200; M_4 \geq 200$$

$$PP'_3: Y_1 + Y_3 + Y_4 = 0.56x_1 - 17600 + 0.70x_3 - 15800 + 0.58x_4 - 24000 + (-9.64 \times 10^{-12}) x_1x_3x_4$$

$$x_1 + x_3 + x_4 \leq 120000$$

$$M_1 + M_3 + M_4 = 0.02x_1 + 0.03x_3 + 0.01x_4,$$

$$M_1 + M_3 + M_4 \leq 1800, M_1 \geq 200, M_3 \geq 200; M_4 \geq 200$$

$$PP'_4: Y_2 + Y_3 + Y_4 = 0.66x_2 - 25000 + 0.70x_3 - 15800 + 0.58x_4 - 24000 + (7.43 \times 10^{-12}) x_2x_3x_4$$

$$x_2 + x_3 + x_4 \leq 120000$$

$$M_2 + M_3 + M_4 = 0.02x_2 + 0.03x_3 + 0.01x_4,$$

$$M_2 + M_3 + M_4 \leq 1800, M_2 \geq 200, M_3 \geq 200; M_4 \geq 200$$

As shown in Table 7, when the total resources of the project portfolio are sufficient, the income of the project portfolio is greater than zero. It can be seen that the interaction effect MCGP model is also very effective in the three-project portfolio evaluations.

3. Results and Discussion

As an effective method to achieve organizational strategic objectives, the project portfolio has been favored by many enterprises. As an important part of project portfolio

management, project portfolio selection has an important impact on the successful implementation of project portfolio. With the increasingly fierce market competition and enterprises gradually expanding their business scope, the scope and number of alternative projects with complex relationship between each other are expanding and the organization has many strategic objectives. All these factors combined bring great challenges for the organization to choose a reasonable project portfolio. This study constructs a project portfolio selection model based on collaborative relationship, which provides a reference for enterprise project portfolio selection. The specific research contents of this study are summarized as follows: the project portfolio selection method considering collaborative relationship proposed in this study further improves and expands the project portfolio selection method and enriches the project portfolio management theory. It also provides a new perspective and ideas for enterprises to measure the collaborative relationship among the alternatives and select the optimal project portfolio. Compared with the fuzzy theory [9, 32, 33] and system dynamics [10], this method is simpler and easier to operate. Compared with the DEA method [18], the method in this paper can distinguish better. Compared with the collaborative relationship project portfolio [34, 35], this method is more universal. Because the relationship between many projects is not necessarily collaborative, the interaction effect is more consistent with the description of the relationship between projects.

The theoretical contributions of this paper are mainly reflected as follows: (1) this paper expands the research perspective of portfolio evaluation and carries out portfolio analysis from the interaction effect between projects. (2) An effective model is developed to evaluate the interaction effects of projects and their impact on project portfolio. (3) A series of examples show the adaptability and effectiveness of the method. This paper has a wide range of industrial applications, such as product portfolio analysis, investment project portfolio research, innovation project evaluation, financial investment, and derivatives trading.

TABLE 7: Evaluation results of three-project portfolios with sufficient resources.

Project portfolio	Ranking	Composition of the project portfolio	Investment in the operation period	Investment in the construction period	Number of employees	Portfolio income
1	1	1	10000	17600	1100	20101
		2	100000	25000	200	
		3	10000	15800	200	
2	3	1	10000	17600	900	10678
		2	100000	25000	200	
		4	10000	24000	200	
3	2	1	10000	17600	1400	14795
		3	25000	15800	200	
		4	85000	24000	200	
4	4	2	30592	25000	1400	9261
		3	14704	15800	200	
		4	74704	24000	200	

4. Conclusion

In this paper, the interaction effect MCGP model is constructed to solve the problem of portfolio evaluation, considering the interaction effect between projects. The results of example analysis show that the interaction effect MCGP model can better evaluate the two-project portfolio and three-project portfolio. It is found that in comparison with the DEA method, the interaction effect MCGP model has a better ability to distinguish the project portfolio. The project portfolio selection method proposed in this study takes into consideration the complex interaction relationship within the project portfolio, which makes up for the deficiency of interaction relationship analysis in the existing project portfolio selection research, provides a basis for enterprises to measure the complex relationship within the project portfolio, and also provides new methods and ideas for enterprise project portfolio selection.

Data Availability

The experimental data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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