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Article

Synergetic Evaluation of Project Portfolio Configuration Based on Data Envelopment Analysis

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Abstract: Project portfolio configuration (PPC) is an important approach to maintain the sustainable development of enterprises and achieve organizations' strategy. However, the synergetic efficacy of PPC which determines the degree of the project's strategic objectives achieved is a fuzzy problem and hard to be measured. To solve this problem, this paper takes the data envelopment analysis (DEA) as the tool to measure the efficacy of PPC under deterministic conditions. First, a portfolio evaluation index system which takes financial indicators and non-financial indicators into consideration is developed based on the review of the literature; Second, an evaluation model based on DEA is built to reduce the number of decision making-unit with the perspective of synergetic theory; Then, a computational experiment is studied to verify the feasibility of this proposed model. The results of this computational experiment show that this model can effectively narrow scope of decision-making, improve the decision-making level and provide a reference to decide the DEA effective project portfolio decision-making unit. To our knowledge, this study is the first time to apply the notion of synergetic efficacy and DEA to the PPC domain. It is hoped that this paper may shed lights on any further study about PPC and enterprise competitiveness of sustainable development.

Keywords: project portfolio configuration; synergetic management; data envelopment analysis; efficiency evaluation.

1. Introduction

Sustainable development is a new management paradigm, one whose principles can be used to improve how practitioners of all levels manage the complexity and dynamics of projects [1-3]. Following rapid economic development and growth, multi-projects executed in parallel has become the new norm for corporate business operations in a market of limited resources. The ability to reasonably combine and implement multiple projects simultaneously in order to strike a balance between efficiency and quality has become an increasingly important issue for enterprises adapting to market demand and sharpening its competitive edge. Project Portfolio Management (PPM) refers to methods and patterns that combine different components to achieve strategic objectives under certain constraints [4] (such as limited resource constraints and possible target conflicts between different projects) in order to maximize the effectiveness and profitability for the said organization. One of the most challenging tasks in project portfolio management is PPC, which is a guiding philosophy that aims to implement synergistic configuration and dynamic optimization for project components that ultimately delivers strategic organizational impact [5]. PPC is not only affected by various resource distribution constraints and internal conflicts between project objectives [6], but also a combination of factors such as post-benefit correlations and the relevance of the results [7].

Since early 2001, both domestic and overseas scholars have paid more and more effort into the study of PPC, which focused not only on theoretical research but also on a wide range of business practices [8-10]. Based on a review of the literature, many studies have been reported on the methods of maintaining a high degree of correlation between PPC and strategy, resources allocation across different projects and schedule optimization of the PPC [11], providing a basis for decision making when managers implement portfolio management [12-14]. Sascha [15] and his fellow scholars constructed a comprehensive conceptual model to ensure the realization of strategic organizational objectives which takes into account factors such as business strategy, the structure of project components, etc; these then further clarified the influence of synergetic effects of the project components on the organizational strategy. From the perspective of the dynamic environment, Petit [16] studied how uncertainties may effect project portfolio management, and then summarized the sources and distribution of uncertainties, thus contributing ideas to the study of uncertainties in project portfolio management [17-19].

The PPC co-management refers to the method and mode of synergistic management of different resource components, the resource constraints, the mutual influence of the multi-project objectives, the synergistic sharing of the project resources, etc., in order to achieve benefits that are greater than the sum of individual projects [20], However, as mentioned above, there are many factors to be considered in the project portfolio management, complicated cooperative relations among the factors [21], and difficulties in quantifying synergistic effects. Hence, there are relatively few research results from the field of studying project portfolio management.

DEA is an effective and objective method for evaluating production efficiency from the same type of decision-making unit [22]. Wang et al. [23] established an integrated approach that combines the grey forecasting model GM and DEA to evaluate the comparative efficiencies of 16 Green Logistics Providers and select the righter partner for sustainable development of enterprise that will lead to improved business performance and reduce carbon dioxide (CO2) emissions. From the prospect of sustainable development of real estate industry, DEA has been successfully used for predicting one company bankruptcy and the operation efficiency which emphasized on the levels of several financial indexes and the effect the strict regulating policies [24].Both domestic and foreign research have documented different forms of DEA evaluation models that have been widely used in various fields of study [25-27] , which further proved its importance of sustainable development of enterprises and its effectiveness in analyzing the technological and scale efficiency for the multi-inputs and multi-outputs. Hence this paper intends to establish a synergistic evaluation index system and model of PPC to analyze, evaluate and select the best project portfolio.

This paper is structured as follows: Section 2 establishes a scientific and rational evaluation index system of PPC which takes both financial and non-financial objectives into consideration, via an extensive literature review. Section 3 evaluates the value of the index and Section 4 proposes a synergetic evaluation model of the PPC based on the DEA. Section 5 verifies the effectiveness and feasibility of the model using a computational experiment. Section 6 draws conclusions.

2. Construction of Synergetic Evaluation Index System of the PPC

The success of a project's implementation is affected by not only the amount of capital investment but also the decision-maker's maturity, managerial skill-sets within the organization, as well as the components of the project itself. The organization will benefit from financial gains, further development promotions as well as positive social influence. On the basis of a review of the existing literature, this paper puts forward the synergetic evaluation of the PPC management index system, shown as Fig. 1 [10, 11][25-27]:

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Synergetic Evaluation of Project Portfolio Configuration Management Index System

- Input Indices
  - Capital Cost I_1
  - Organizational Capacity I_2
  - Component Function I_3
- Output Indices
  - Economic Revenue Y1
  - Strategic Fit Y_2
  - Social Satisfaction Y_3
- Auxiliary Index: Success Probability P

Figure 1 Synergetic Evaluation of the PPC Index System

PPC synergistic management evaluation index system consists of input indices, output Indices and auxiliary Indices. By considering the uncertainties both within the organization and the external social environment, it is too difficult to be absolutely sure about the success of any projects. Therefore, this paper introduces supporting Indices in the evaluation index system that will indicate the probability of a project's success under the influence of such uncertainties. The figures of the supporting Indices were based on the experts' review as well as conclusions from their years of experience.

The organization currently has n available projects to choose from, which is noted as project set E, $E = \{i_1, i_2, \dots\dots, i_n\}$, randomly taking z($2 \le z \le n$) projects from project set E will forms a new project portfolio K. The explanations to the indices and the interaction between the indices under the synergies are as follows.

2.1 Input Indices

2.1.1 Capital Cost

Investment funds play the most important role in the implementation of any project. Due to the synergies between the resources of the project, the capital costs (X_1) of the project portfolio is not equal to the sum cost of each individual project. Under the management of project portfolio synergistic configuration, the cost of capital formula is shown as below:

$$x_{1j_1} + x_{1j_2} + \cdots x_{1j_z} + V_1^K = X_1^K \quad (1)$$

Equation (1) shows that under the influence of synergies, by carrying out each project z separately, project portfolio K demands less capital X_1 towards the aggregate capital cost X_1^K . In the formula, x_{1j_z}represents the amount of investment capital for investing project j_z which is part of the project portfolio$K$. X_1^K represents the total amount of capital cost for investing project portfolio K, V_1^K(negative value) represents the synergistic effect of the cost of capital under the PPC synergistic management.

2.1.2 Organizational Capacity

Organizational management is the most direct and effective management model within project management. Organizational capacity (X_2) refers to the project manager's management skill which includes management of funds, manpower, and machinery, etc.

$$x_{2j_1} + x_{2j_2} + \cdots x_{2j_z} + V_2^K = X_2^K \quad (2)$$

Equation (2) shows that due to the synergistic effect, rather than carrying out each project Z separately, project portfolio K requires less organizational capacity (X_2) towards aggregate organizational capacity (X_2^K) . In the formula, x_{2j_z} represents the effort of organizational capacity for investing project j_z which is part of the project portfolio K. X_2^K means the total amount of capital

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cost for investing project portfolio K, V_2^K (negative values) represents the synergistic effect of the organizational capacity under the synergistic management of the PPC.

2.1.3 Component Function

While there are strategic objectives for the organization, the objectives of different projects are not always the same. For instance, some projects are for financial gains, while others are for obtaining market share. Component function (X_3) refers to project component's contribution to the overall strategic target of the organization.

$$x_{3j_1} + x_{3j_2} + \cdots x_{3j_z} + V_3^K = X_3^K \tag{3}$$

Equation (3) shows that due to the synergistic effect, rather than carry out each project Z separately, project portfolio K requires less organizational capacity X_3 towards aggregate organizational capacity (X_3^K) . x_{3j_z} represents the amount of component function involved in investing project j_z which is part of the project portfolio K. X_3^K means the total amount of component function required for investing project portfolio K, V_3^K(negative values) represents the synergistic effect of the organizational capacity under the synergistic management of the PPC.

2.2 Output Indices

2.2.1 Economic revenue

Economic revenue (Y_1) refers to the net present value of the project, which is the core for organization development and smooth implementation of projects. The basic requirement for the PPC is to achieve higher profits from the synergies of the project portfolio rather than from the profits of individual projects.

$$y_{1j_1} + y_{1j_2} + \cdots y_{1j_z} + U_1^K = Y_1^K \tag{4}$$

Equation (4) shows that due to the synergistic effect, the increase in the total economic revenue Y_1^K generated by the Z projects in the form of project portfolio K. y_{1j_z} represents the revenue generated by the j_z project in the project portfolio K, Y_1^Krefers to the total revenue generated by project portfolio K. U_1^K (positive value) means the synergistic effect of the value of economic revenue under the influence of the PPC synergies.

2.2.2 Strategic fit

Strategic management theory can effectively improve the performance of project portfolio management[28], Through building conceptual model which is based on the analysis of interaction among project portfolio, corporate strategy and business success, Sascha Meskendah[9] [15] proved strategy does effect the project portfolio and business success; Corporate strategic fitness has become an international important index for evaluating the effectiveness of the project portfolio[25, 26] [29].

$$y_{2j_1} + y_{2j_2} + \cdots y_{2j_z} + U_2^K = Y_2^K \tag{5}$$

Equation (5) shows that due to the influence of synergies, there is improvement of strategic fit Y_2^K by undertaking Z projects in the form of project portfolio K. y_{2j_z} shows how j_z project in the project portfolio K may affect organizational strategic fit, Y_2^K refers to the aggregate strategic fit that project portfolio K may generate. U_2^K (positive value) represents the synergistic effect of strategic fit under the influence of the PPC synergistic.

2.2.3 Social Satisfaction

Social satisfaction (Y_3) has a direct influence on the long-term development of project portfolio and the corporate social image. Those projects that pursue social satisfaction can help achieve or even exceed customer expectations, and this may further improve social recognition for current and future projects. By establishing customer loyalty and by improving consumer expectations for future projects, there will not only be increases in economic revenue as well as benefits to strategic fit, but will also garner the support of government and other organizations.

$$y_{3j_1} + y_{3j_2} + \cdots y_{3j_z} + U_3^K = Y_3^K \tag{6}$$

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The equation (6) shows that due to the influence of synergies, there will be improvement of social satisfaction Y_3^K by undertaking the Z projects in the form of project portfolio K. y_{3j_z} indicates how j_z project in the project portfolio K may affect social satisfaction, Y_3^K refers to the aggregate social satisfaction that project portfolio K may bring. U_3^K (positive value) represents the synergistic effect of social satisfaction under the influence of the PPC synergies.

3. Determination the value of evaluation index

Since the evaluation indexes have different characteristics, the data of the six indexes cannot be in the same numerical range. Normalization is a simplified method that can eliminate the difference of the numerical differences between the different evaluation indexes. Based on data normalization method such as linear normalization, energy normalization and component whitening, this paper adopts the improved energy normalization method to deal with the index value.

Numbers 1 to 6 are respectively assigned to capital cost, organizational capacity, component function, economic revenue, strategic fit, and social satisfaction. As mentioned above, project portfolio K has z projects, each project has 6 indices, $\alpha_J{}^K$ represents the value index of J $(1 \le J \le 6)$ project from project portfolio$K$. $\alpha_J{}^{K\prime}$ stands for the index value of J from project portfolio Kafter normalized. The energy normalization can be calculated by the following equation 7 [30]:

$$\alpha_J{}^{K\prime} = \frac{\alpha_J{}^K}{\|\alpha_J\|} \tag{7}$$

Where K has z projects and J is one of the indictors. In equation (7), $\| \alpha_J \|$ is the vector norm of J, and $\| \alpha_J \| = \alpha_{J1} + \alpha_{J2} + \cdots + \alpha_{JZ}$, where α_{JZ} represents the value index of J $(1 \le J \le 6)$ for project Z. As the traditional energy normalization method ignores the actual situation of the corporation and their reasonable expectations of the project, equation 7 cannot be directly applied to the DEA efficiency evaluation of project portfolio. To take the capital cost as an example, according to equation 7, $\| \alpha_1 \|$represents the total investment of project portfolio K. The traditional energy normalization method ignores the financial affordability of the enterprise; in other words, by assuming the enterprise's highest capital investment is $\overset{\frown}{\alpha_J}$, When the project portfolio K's capital investment is greater than $\overset{\frown}{\alpha_J}$, the data processing is meaningless. Therefore, the synergetic evaluation of the PPC should always consider the organization's situation in reality as well as its reasonable expectations of the project.

3.1 Determination the value of quantitative index

Capital Cost and Economic revenue are quantitative indices and the values of Capital Cost and Economic revenue for the Decision Making Unit can be estimated accurately. The value of the capital cost and economic revenue after normalized can be obtained by equation (8)-(9):

$$\alpha_1{}^{K\prime} = \frac{\alpha_1{}^K}{\overset{\frown}{\alpha_1}} \tag{8}$$

$$\alpha_4{}^{K\prime} = \frac{\alpha_4{}^K}{\overset{\frown}{\alpha_4}} \tag{9}$$

In equation (8), $\alpha_1{}^K$ represents the total number of investments to the project portfolio K, $\overset{\frown}{\alpha_1}$ is the enterprise's highest capital investment, $\alpha_1{}^{K'}$ is the value of capital cost after normalized. In equation 9, $\alpha_4{}^K$ refers to the revenue generated by project portfolio K, $\overset{\frown}{\alpha_4}$ is the income criterion and $\alpha_4{}^{K'}$ is the economic revenue after normalized. Then, the normalized value of these quantitative indices can be calculated accurately.

3.2 Determination the value of qualitative index

The values of the qualitative indices such as organizational capacity, component function and strategic fit are with a very strong sense of uncertainty, it is difficult to get the accurate value for them. In order to get them, the peer experts are invited to score the value of the input indices (X_2, X_3) and output indices (Y_2, Y_3) and assess the highest capital investment of (X_2, X_3) and the optimum value of (Y_2, Y_3) by the Likert Scale Method[31,32]. The values of qualitative indices are shown as Table 1:

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Table 1. Values of Qualitative Indices

Indices \ Times of scored \ Score	1	3	5	7	9	Means
Organizational Capacity	ρ_{21}	ρ_{22}	ρ_{23}	ρ_{24}	ρ_{25}	$\alpha_2{}^K = (\rho_{21} + 3\times\rho_{22} + 5\times\rho_{23} + 7\times\rho_{24} + 9\times\rho_{25})/\sum_{f=1}^{5}\rho_{2f}$
Component Function	ρ_{31}	ρ_{32}	ρ_{33}	ρ_{34}	ρ_{35}	$\alpha_3{}^K = (\rho_{31} + 3\times\rho_{32} + 5\times\rho_{33} + 7\times\rho_{34} + 9\times\rho_{35})/\sum_{f=1}^{5}\rho_{3f}$
Strategic Fit	ρ_{51}	ρ_{52}	ρ_{53}	ρ_{54}	ρ_{55}	$\alpha_5{}^K = (\rho_{51} + 3\times\rho_{52} + 5\times\rho_{53} + 7\times\rho_{54} + 9\times\rho_{55})/\sum_{f=1}^{5}\rho_{5f}$
Social Satisfaction	ρ_{61}	ρ_{62}	ρ_{63}	ρ_{64}	ρ_{65}	$\alpha_6{}^K = (\rho_{61} + 3\times\rho_{62} + 5\times\rho_{63} + 7\times\rho_{64} + 9\times\rho_{65})/\sum_{f=1}^{5}\rho_{6f}$

In Table 1, the ρ_{Jf} represents the number of times that the index J has be scored, where $f = (1,2,3,4,5)$, and the score of this indices are equation to 1 or 3 or 5 or 7 or 9 according to their actual situation. Then, on the basis of equations (8)-(9) , the values of these qualitative indices after normalized can be calculated as equations (10)-(11):

$$\alpha_\beta{}^{K'} = \frac{\alpha_\beta{}^K}{\overset{\frown}{\alpha}_\beta} \quad (\beta = 2,3) \tag{10}$$

$$\alpha_\gamma{}^{K'} = \frac{\alpha_\gamma{}^K}{\overset{\frown}{\alpha}_\gamma} \quad (\beta = 5,6) \tag{11}$$

In equations (10)-(11), $\alpha_\beta{}^K$ and $\alpha_\gamma{}^K$are the score of the qualitative input and output indices, $\overset{\frown}{\alpha}_\beta$ represents the enterprise's highest capital investment for the qualitative input indices and $\overset{\frown}{\alpha}_\gamma$ is the optimum value of the qualitative output indices, $\alpha_\beta{}^{K'}$ and $\alpha_\gamma{}^{K'}$ are the final value of these qualitative input and output indices after normalized. Here, the quantized and normalized values of these quantitative indices can be calculated.

4 Construction of the Evaluation Model

CCR model is a typical DEA analysis method with the advantages of simple, practical, operable, and the results in many applications show that it has a strong advantage in analyzing the technological and scale efficiency for the decision-making units of multi-inputs and multi-outputs [33], which is highly suitable to evaluate the synergetic of PPC. So, this paper puts forward a synergetic evaluation model of PPC from the perspective of inputs as following steps:

(1) Absolute effect of single project.

(2) Absolute effect of project portfolio.

(3) Build the synergetic evaluation model of the PPC.

The absolute effect of single project and project portfolio could ensure the feasibility of the decision-making units, which may not only enable enterprises do not make wrong decisions in the non-effective projects, but also can target to carry on an DEA analysis for the project portfolio in the feasible solution region .

4.1 Absolute effect of single project

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In order to ensure all selected projects in keeping with corporate strategic objectives, the absolute effect of single project before proposes a project portfolio is necessary. Assuming the number of decision-making units DMU is n_1, the input and output indices of each decision-making unit is known, $x_{\beta j}$ is the βth input of DMU_k (the decision-making unit of project portfolio K) and X_β is the maximum of the βth input of DMU_k, y_{rj} $(j = 1,2, \dots \dots n_1)$ is the γth output of DMU_k and Y_r is the minimum expectation of the γth output of DMU_k in the premise of given amount of investment resources. The amount of investment resources is not more than the X_β and the amount of outputs is not less than Y_r. Therefore, the equation of absolute effect of project j can be shown as equation (12):

$$\begin{cases} x_{\beta j} \leq X_\beta \ \ (\beta = 1,2,3) \\ y_{\gamma j} \geq Y_\gamma \ \ (\gamma = 1,2,3) \end{cases} \tag{12}$$

4.2 Absolute effect of project portfolio

Assuming the number of decision-making units by absolute effect of single project is n_2, the amount of the possible portfolios which needed to through the absolute effect is 2^{n_2}. It is obviously that the demand amount of investment resources for the project portfolio K is not more than total amount of investment resource X_β and the amount of outputs for project portfolio K is not less than the minimum expectation Y_r. Therefore the equation of absolute effect of project portfolio can be shown as equation (13):

$$\begin{cases} X_\beta^k \leq X_\beta (\beta = 1,2,3) \\ Y_\gamma^k \geq Y_\gamma (r = 1,2,3) \end{cases} \tag{13}$$

In equation (13), X_β^K represents the total amount of investment resource β for project portfolio K, the X_β represents the total amount of investment resource β, Y_γ^k refers to the aggregate amount of γth output that project portfolio K may bring and Y_r is the minimum expectation for the γth output in the premise of given amount of investment resources that project portfolio K may bring.

4.3 Evaluation model of PPC

Assuming the number of decision-making units by absolute effect of project portfolio is n_3, the amount of the possible portfolios is 2^{n_3}. According to equation 13, X_β^K represents the total amount of investment resource β for project portfolio K and Y_γ^k refers to the aggregate amount of γth output that project portfolio K may bring, the vector of input indices and the output indices are $X^K = (X_1^K, X_2^K, X_3^K)^T$ and $Y^K = (Y_1^K, Y_2^K, Y_3^K)^T$ respectively. According to the DEA principles, the weight vectors of input and output indices are $V = (V_1, V_2, V_3)^T, U = (U_1, U_2, U_3)^T$, the effectiveness of decision-making units K is $h_K = \frac{U^T Y^K}{V^T X^K}$. Take the effectiveness of all decision-making units as the restrictions, a CCR model to measure the relative efficiency of the decision-making units K could be constructed, as equation (14) [34]:

$$\begin{gathered} h_K = max \frac{U^T Y^K}{V^T X^K} = \max \frac{\sum_{\gamma=1}^{3} U_\gamma Y_\gamma^K}{\sum_{\beta=1}^{3} V_\beta X_\beta^K} \\ \begin{cases} s.t. \\ \frac{U^T Y^k}{V^T X^k} \leq 1, k = 1,2,3 \dots, 2^{n_3} \\ U \geq 0, V \geq 0 \\ \end{cases} \end{gathered} \tag{14}$$

Let $s = \frac{1}{V^T X^K}$, $w = sV, \sigma = sU$, the equation 14 could be converted into a linear programming problem through the Charnes-Cooper transform, shown as equation 15:

$$\begin{gathered} maxh_K = \sigma^T Y^K \\ \begin{cases} s.t. \\ w^T X^k - \sigma^T Y^k \geq 0, k = 1,2,3 \dots, 2^{n_3} \\ w^T X^K = 1 \\ w \geq 0, \sigma \geq 0 \end{cases} \end{gathered} \tag{15}$$

Solving the dual programming of equation 15, bring the slack variables into this problem, the synergetic evaluation model of the PPC could be proposed, shown as equation (16):

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$$\min \theta \quad s.t. \begin{cases} \sum_{k=1}^{2^{n_3}} \lambda_k X^k + S^- = \Theta X^K \\ \sum_{k=1}^{2^{n_3}} \lambda_k Y^k - S^+ = Y^K \\ S^-, S^+ \geq 0 \end{cases} \tag{16}$$

In equation (16), (X^K, Y^K) is the solution set of $\begin{cases} \sum_{k=1}^{2^{n_3}-1} \lambda_k X^k \leq X^K \\ \sum_{k=1}^{2^{n_3}-1} \lambda_k Y^k \geq Y^K \end{cases}$, Θ is the objective function represents the minimum of the investment if the output Y^K constant. According to DEA principles, only Θ=1, $S^- = 0$, $S^+ = 0$, the DMU project portfolio K in this CCR model is valid and the vector of input indices is optimal. Otherwise, the DEA is invalid. Then, the synergetic evaluation model of the PPC is built, which will provide a reference for project portfolio decision making.

5. Computational Experiment and Results

In order to prove the effectiveness and scientific of the above methods, this paper takes company A as a case study. The company is required to choose three out of nine available projects to run simultaneously with a RMB 5.9 billion budget while aiming to find the optimal combination of the PPC. Based on the annual corporate strategic objectives, the experts' reviews as well as the company's input Indices (capital cost X_1, organizational capacity X_2 and component function X_3) and output Indices (economic profit Y_1, enterprise adaptation Y_2 and social satisfaction Y_3), the probability of success for the project, and the synergistic effect between projects under synergistic configuration are shown in the Table 2 below:

Table 2. Initial data of different projects

Project	Output Indices			Input Indices			Probability of Success
	Economic Profit	Enterprise Adaptation	Social Satisfaction	Capital Cost	Organizational Capacity	Component Function	
1	7700	4.53	6.71	17500	6.63	6.81	0.75
2	3100	8.2	5.53	25000	4.38	7.33	0.65
3	7500	6.14	8.01	19000	6.3	6.93	0.55
4	7000	7.84	7.45	17000	7.3	8.25	0.4
5	6200	8.53	7.23	15800	7.93	6.4	0.7
6	2250	7.54	6.01	23900	4.50	7.53	0.58
7	5600	7.65	5.15	10100	8.13	7.94	0.5
8	6820	5.54	6.84	41900	3.47	5.64	0.7
9	8890	3.92	7.25	34000	2.87	6.93	0.65

U^1_{34}=300 U^2_{23}=2 U^3_{12}=2 V^1_{23}=-2300 V^2_{68}=-1 V^3_{13}=-2 P_{23}=0.1 U^1_{35}=200
U^2_{35}=3 U^3_{89}=1 V^1_{13}=-2700 V^1_{35}=-1400 V^2_{23}=-1 V^3_{35}=-3 U^1_{68}=100 U^2_{29}=2 V^2_{14}=-2

Based on the basic conditions of the company such as capital limit and reasonable yield thresholds, resource constraints, 10 kinds of portfolios through the absolute effect can be obtained according equation 12-13, and the normalized data and the efficiency of decision-making units can be calculated by equation 10-16, and the results of them are shown in Table 3:

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Table 3. Values of indices and results for DMU of project portfolio

DMUs of project portfolio	**composition of project portfolio**	**output indices**			**input indices**			**θ**
		Y1	**Y2**	**Y3**	**X1**	**X2**	**X3**	
PP-DMU 1	Project 1,2,3	0.6561	0.5279	0.569	0.9417	0.6041	0.7063	1.000
PP-DMU 2	Project 1,2,4	0.5085	0.4394	0.466	0.9917	0.6041	0.8293	0.825
PP-DMU 3	Project 1,2,5	0.5945	0.5444	0.5431	0.9717	0.7015	0.7607	0.916
PP-DMU 4	Project 1,3,4	0.6943	0.367	0.4599	0.8917	0.6752	0.7404	0.931
PP-DMU 5	Project 1,3,5	0.856	0.5149	0.537	0.8033	0.7726	0.5607	1.000
PP-DMU 6	Project 1,4,5	0.7336	0.4631	0.4842	0.8383	0.7356	0.7948	0.903
PP-DMU 7	Project 2,3,4	0.5013	0.4917	0.4568	0.9783	0.6289	0.8337	0.825
PP-DMU 8	Project 2,3,5	0.5979	0.666	0.5339	0.9350	0.6522	0.6541	1.000
PP-DMU 9	Project 2,4,5	0.4525	0.5347	0.431	0.9633	0.7263	0.8141	0.781
PP-DMU10	Project 3,4,5	0.667	0.5051	0.461	0.8400	0.7974	0.6881	0.896

In Table 3, the efficiency of PP-DMU1, PP-DMU5,PP-DMU8 are 1.000, so these DMUs are valid, and the others are invalid .Analyze these invalid DMUs can obtain the obstacles to the further development of the company, which will provide the decision-making advice for managers.

5.1 Analysis of invalid DMUs

By analyzing the slack of input and output indices will contribute to find the reasons why the decision-making units are invalid and provide a direction for adjusting the input-output scale. The slack of inputs and outputs for DMUs are shown as Table 4:

Table 4. Slack of inputs and outputs for DMUs

DMUs of project portfolio	Insufficient output			Redundant input		
	Y1	Y2	Y3	X1	X2	X3
PP-DMU 2	0.028	0	0	0.045	0	0.106
PP-DMU 3	0.083	0	0	0	0	0.049
PP-DMU 4	0	0.071	0	0.128	0	0.192
PP-DMU 6	0	0	0.002	0.015	0	0.192
PP-DMU 7	0.018	0	0	0.031	0	0.124
PP-DMU 9	0.035	0	0	0	0.038	0.110
PP-DMU10	0	0	0.461	0	0.074	0.091
Mean	0.016	0.007	0.001	0.022	0.011	0.086

Compared to other project portfolio decision making units, the organizational capacity in PP-DMU9 and PP-DMU10 has exceeded the optimal actual demand, however, this is not a bad thing to the management process as it reflects the fact that the managers in PP-DMU9 and PP-DMU10 could manage more complex projects, which puts forward some favorable suggestions for manager to allocate its' the human resource.

5.2 Analysis of valid DMUs

From the economic interpretation of this CCR model, the PP-DMU, PP-DMU 5 and PP-DMU 8 are both valid in technological and scale efficiency. These 3 valid DMUs which composed of 3 different projects could help the company managers to narrow the scope of decision-making and improve the level of decision-making. However, the amount of funds (59 million yuan) cannot meet the demand of three valid projects running at the same time. Therefore, based on the needs of the company's development at this stage, it is very necessary to select the optimal project portfolio from these valid DMUs based on the needs of the company's development at current stage.

According to the nature of valid DEA, just consider the situation that different output in the same input vector could meet the needs of the analysis of valid DEA. This paper analyzes the valid items of DEA from three different situations, and determines the optimal project portfolio, the results are shown in Table 5:

Table 5. Results of different situations

	DY1	DY2	DY3
PP-DMU 1	0.980	0.856	1.000
PP-DMU 5	1.000	0.902	1.000
PP-DMU 8	0.827	1.000	0.964

In Table 5, taking output Y_1 , Y_2 and Y_3 as the study objects, taking X_1, X_2 and X_3 as input indices, the economic revenue, strategic fit and social satisfaction can be calculated to reflect the DEA efficiency of project portfolio respectively. When the output Y_1 was considered as the study object, the PP-DMU 5 is relatively valid, which reflects that the project portfolio is composed of project 1, 3 and 5 is the best when the economic revenue is considered as the main measurement indices. Therefore ,when take the output Y_1 and Y_2 as study objects, the best project portfolio in different situation such as take strategic fit and social satisfaction as main measurement indices could be selected in the same way ,which will provide decision basis for the managers to select the best project portfolio according to the different requirements.

6. Conclusions

This paper studies the efficiency of the PPC synergistic management by using the DEA method under a certain environment. For the selection of Indices, we built up a scientific and rational evaluation index system based on the existing research results which takes both financial and non-financial objectives into consideration. The scope of this system covers the input indices such as capital cost, organizational capacity component function and the output indices includes economic revenue, strategic fit and social satisfaction, as well as the auxiliary index: success probability. And this system makes it easier to build a synergetic evaluation model of the PPC based on DEA. For data processing, an improved energy normalization method is used to eliminate the numerical differences between different evaluate Indices. Prior to the evaluation of project portfolio coordination, reasonable yield thresholds, resource constraints, and other conditions are set. Subsequently, absolute effect on single projects and project portfolio can effectively screen out alternative options and further reduce the number of decisions required. Then, a model for selecting the optimal DEA effective project portfolio which will provide insights to decision-makers and improve the decision-making is proposed, and the results of a computational experiment suggest that this model is reasonably for selecting the optimal project portfolio.

To our knowledge, this is the first time to apply the notion of synergetic evaluation and DEA to the PPC domain, which enriches the theories of project management and makes an important contribution to integrating a group of projects into a project portfolio in the synergistic perspective and helping an organization optimize its multi-project management. This model is verified by a computational experiment from the database of the Chinese firm, and provides a basis for selecting the best project portfolio, which contributes to decisions making on the PPC. Practitioners may benefit most from applying the finding that the synergetic relationship must be considered and in an integrated fashion to achieve the optimal PPC.

There are also some shortcomings in this study. (1) the systematic deficiencies of the indices are induced by the negative synergistic relationship between indices having not been taken into account, and might affect the scientific nature of the evaluation results; (2) The evaluation method of PPC synergistic management based on DEA only considers the project at a very specific period of time. However, in reality, synergistic effect of projects appears differently at different stages, while demand for resources also varies. Therefore, the PPC multi-stage efficiency analysis will be the authors' future direction of research. (3) the effectiveness and feasibility of this proposed model can be verified by a computational experiment, but the selected projects to be implemented only consistent for the problem of synergetic evaluation and the results of the computational experiment initially cannot be generalized. These limitations would be further study in the future.

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