Modeling for Project Portfolio Synergy Benefits Measurement

Libiao Bai[1*], Jiachen Lin[2], Luyao Zhang[3], Tong Pan[4], Yongjian Ke[5], Xinyu Zhou[6]

[1]*Professor, Ph.D., School of Economics and Management, Chang' an Univ, Xi'an, Shaanxi 710064, China (corresponding author).*

E-mail: lb.bai@chd.edu.cn

[2]*Master Student, School of Economics and Management, Chang' an Univ, Xi'an, Shaanxi 710064, China.*

E-mail: JC_Lin@chd.edu.cn

[3]*Master Student, School of Economics and Management, Chang' an Univ, Xi'an, Shaanxi 710064, China.*

E-mail: zhangl_y@chd.edu.cn

[4]*Master Student, School of Economics and Management, Chang' an Univ, Xi'an, Shaanxi 710064, China.*

E-mail: pantong@chd.edu.cn

[5]*Associate Professor, Ph.D., Univ Technol Sydney, Sch Built Environm, Sydney, NSW, Australia.*

E-mail: Yongjian.Ke@uts.edu.au

[6]*Master Student, School of Economics and Management, Chang' an Univ, Xi'an, Shaanxi 710064, China.*

E-mail: xinyu.zhou@chd.edu.cn

Modeling for Project Portfolio Synergy Benefits Measurement

Abstract: Generated by internal synergy relationships in project portfolio (PP), project portfolio synergy benefits (PPSBs) are essential for enterprises to achieve their strategic objectives. However, few studies have been conducted on measuring PPSBs, which hinders managers from making rational use of PP synergy relationships to realize and improve PPSBs. This research deals with this issue by constructing a PPSB measurement model. First, the PPSB measurement model elements, including PP synergy, PPSB measurement criteria, and PPSB influencing factors, are identified. At this stage, to integrate PP synergy into the measurement model, a new method that emphasizes project similarity based on the project niche is proposed to quantify it. Then, a system dynamics model is developed by quantifying the causal relationships within these elements to measure PPSBs. Finally, the proposed model is demonstrated and validated with a numerical example. Results show that this model can help managers to measure and optimize PPSBs. To our knowledge, this proposed model is the first to realize the measurement of PPSBs, enriching the literature on project portfolio management and providing managers with a tool for enhancing the PPSBs following the organization strategy.

Keywords: Project portfolio synergy benefits, Synergy relationships, Benefits measurement, System dynamics.

1. Introduction

In the current complex and dynamic market environment, project portfolio (PP) has become a common management mode to obtain benefits and achieve organizational strategic objective according to Project Management Institute [1]. Despite the strenuous efforts devoted to project portfolio management, numerous managers failed to perform well in realizing PP benefits, resulting in poor strategic results [2]. Thus, PP benefit realization management is urgently needed to reduce project failure rates from a strategic perspective via project management technology, and obtain the expected PP benefits [3]. Practically, managing PP benefits is not trouble-free because it entails coping with the individual projects benefits and project portfolio synergy benefits (PPSBs), as shown in Fig. 1. As an important component of PP benefits, PPSBs are the incremental benefits generated by the complex synergy relationships that work within PP [4]. These synergy relationships, referring to the sharing and utilization of resources, technologies, outcomes, and knowledge within a PP [5], could improve information sharing [6], revenue [7], success probability [8], and reduce resource consumption [9], schedule delay, cost waste [10]. Ultimately, PPSBs are generated through the PP synergy relationships and contribute to strategic fit of PP [11].

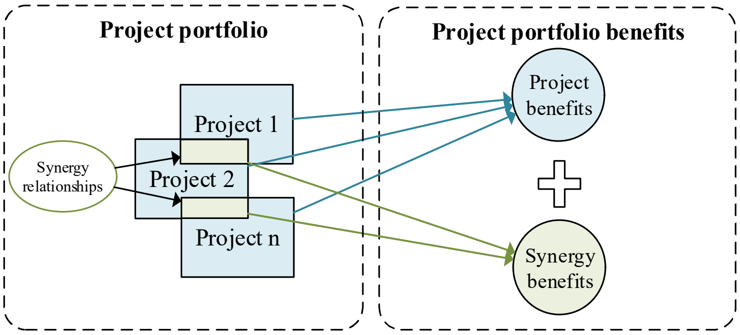


Fig. 1 Composition of project portfolio benefits

Effective management of synergy relationships in PP is critical for realizing PPSBs [2]. In nature, PP is implemented in organizations and managed by project portfolio managers. If the amount of shared resources or technologies in a PP exceeds the organization's sharing ability and the project portfolio manager's coordination ability, PPSBs may be reduced [10, 12]. Managers seem fail to achieve ideal PPSBs by managing synergy relationships. Therefore, it is urgent to measure PPSBs brought by the PP synergy and clarify synergy relationships management effect. On this basis, decision-makers (DMs) could determine the suitable sharing degree of resources and technologies for their PP, that is, the optimal synergy decisions, to effectively manage synergy relationships to obtain the optimal PPSBs. However, scholars mainly assumed PPSBs according to the preferences of DMs [13-15], ignoring the quantitative impacts of the PP synergy relationships on PPSBs. Many issues still need to be addressed concerning measuring PPSBs generated by PP synergy relationships. This limitation leads to managers' irrational cognition of management effects on PPSBs, hindering the acquisition of PPSBs. Against this background, this research seeks to address the following question: ***How much PPSBs can be produced by the PP synergy relationships?***

To answer this question, clarifying the causal relationships between diverse PP synergy relationships and PPSBs, and then measuring PPSBs are vital. Nevertheless, the question is complex and requires a dynamic approach to solve. Primarily, different types of PP synergy relationships will generate different benefits, which are interrelated [16, 17]. The generation process is also affected by many factors. These give rise to the complexity of clarifying causal relationship. Furthermore, the types and degrees of PP synergy are variable during the implementation of PP, which leads PPSB measurement to a dynamic issue. To solve them, the system dynamics (SD) approach is applied for its advantages in synthetically considering the relationships among the complex system elements and effectively displaying the dynamic system problems [18, 19]. Based on the above analysis, an SD model is proposed to measure PPSBs produced by PP synergy. With the goal to maximize PP benefits, this research focuses on the PPSBs under the PP implementation conditions. The model contributes to PP benefits management by providing a tool for the management of synergy relationships during the PP implementation. In this research, the elements of the PPSB measurement model are primarily determined, including PP synergy, the PPSB measurement criteria, and the PPSB influencing factors. Also, to quantify the input value of the PPSB measurement model, the project niche overlap, which reflects the degree of demand overlap between projects, and the trapezoidal fuzzy numbers are proposed to calculate the PP synergy degree and the value of influencing factors, respectively. Then, a PPSB measurement model could be constructed by clarifying the causal and quantitative relationships among elements using SD. Finally, a numerical example is used to verify the effectiveness and applicability of the established model.

The rest of this research is structured as follows. Literature on PPSBs and the application of SD in benefits management is illustrated in Section 2. In Section 3, by clarifying the elements of PPSB measurement model and their qualitative and quantitative relationships, a PPSB measurement model is constructed. The proposed model is further implemented using a numerical example, and the results are analyzed in Section 4. Section 5 is the discussion, and the final section concludes the research.

2. Literature review

2.1 Related literature on project portfolio synergy benefits

A PP is a collection of projects, programs, subsidiary portfolios, and operations to achieve strategic objectives [20]. As the goals pursued by enterprises to implement PP, PP benefits have received increasing attention from scholars. For instance, to ensure DMs select an appropriate PP to implement in advance, the PP benefits, including the sum of projects benefits and the PPSBs, are widely taken as the objective function when selecting PP [8, 15, 21, 22]. Furthermore, during the implementation of PP, Wang et al. [23] presented a PP implementation model while considering the synergetic effect among projects to monitor PP benefits achievement. To improve the PP benefits, Tian et al. [24] and Bai et al. [25] realized the quantification of PP benefits with synergy considerations. These models can help managers to clarify the PP implementation effect, providing the prerequisite for managers to take measures to optimize PP benefits in advance. In these studies, scholars have recognized the role of PPSBs brought by synergy relationships in improving PP benefits. However, studies on PPSBs are limited despite of their significance, and a profound study should be made.

The studies on PPSBs mainly focus on the generation mechanism and evaluation. With respect to the generation mechanism, scholars argue that PPSBs are generated by synergy relationships, and the realization of PPSBs is affected by many factors. As an illustration, Cho et al. [12] proposed that the improvement of organization sharing ability enhanced the realization of PP synergy and then boosted PPSBs. Specifically, they illustrated the influence of organization objective conditions on achieving PPSBs. Patanakul et al. [26] and Bathallath et al. [27] indicated that multitasking activities would be hindered due to the insufficient management skills of project portfolio managers. Such studies emphasize the impact of subjective management factors on the realization of PPSBs and complement the above study. In addition, many scholars also evaluated PPSBs when working on PP selection. Generally, the value of PPSBs in these studies is assumed by DMs based on the variation of PP cost, income and success probability [15, 21, 28]. Besides, according to Lopes et al. [29], PPSBs could also be assessed by converting the variation of cost or income into a linear or nonlinear value function. Moreover, Hemmatizadeh et al. [30] considered such a nonlinear function as an exponential form to express the synergistic impact of the PP. However, in the abovementioned literature, the evaluation results of PPSBs depend on DMs' assumption regardless of how they are converted and calculated.

Previous studies emphasize the promotion effect of synergy on the overall benefits, and some efforts have been made in PPSB evaluation. While as mentioned, the PPSB evaluation results greatly depend upon the preferences of DMs in these studies, neglecting the quantitative impacts of the PP synergy relationships on PPSBs. This leaves a gap in the current literature on measuring PPSBs, impeding the effective management of them. To fill this gap, this research measures PPSBs by integrating the impacts of PP synergy relationships on them to provide theoretical reference for scholars and practitioners.

2.2 System dynamics application in benefits management

The SD, introduced by Forrester [31], is an effective approach to presenting and analyzing a complex system's behavior to better understand what exactly occurs in the process [32]. SD is robust that it can incorporate individual subsystems into a general framework, analyze their interactions, and effectively describe system problems through observing the trend of system components in different time frames [33, 34]. The dynamic simulation characteristics for the complex system behavior of SD arouse its wide use in benefits management, mainly focusing on benefits assessment and benefits optimization.

In terms of benefits assessment, Bayer et al. [35] and Wang et al. [36] applied SD to assess the financial benefits in different industries. In addition to financial benefits, several scholars also applied SD to evaluate non-financial benefits, such as environmental benefits [37], social benefits [38, 39], and health benefits [40]. Based on the single-dimensional benefit measurement, several scholars set SD models of comprehensive benefits measurement by simulating dynamic relationships among benefit indicators [5, 41]. With respect to benefits optimization, apart from establishing a qualitative SD model to illustrate the benefits creation process to help managers to achieve greater benefits [32], many scholars used quantitative SD to propose suggestions for improving benefits. For instance, to promote financial benefits, a cost-benefit analysis model using SD was established to assist decision-making about cost-effectiveness [42, 43]. Additionally, considering its function in depicting the interdependencies and feedback processes of system variables, Martins et al. [44], Chaudhary et al. [45] and Li et al. [46] presented SD models to analyze the impacts of policy measures on interdependent systems to improve the non-financial benefits. Furthermore, in today's rapidly changing environment, firms must address uncontrollable events and identify solutions that will affect the success of their long-term benefits [47]. SD modeling could help managers enhance their understanding of the links between measures and future performance [48]. Therefore, Torres et al. [47] presented a protocol for supporting strategy development via SD modeling to realize long-term benefits. Wang et al. [23, 49] used SD to construct the value realization process of projects and portfolios under uncertainty, which helped managers take appropriate remedial actions to ensure the realization of project value. In this case, SD models are used to help managers adjust their management approaches to achieve more financial and non-financial benefits for enterprises now and in the future.

Clearly, the application of SD in benefits management is remarkably applicable field since there are various nonlinear feedback relations among system variables in benefits management [50]. These works provide useful references for the present research on PPSB measurement. As mentioned earlier, the measurement of PPSBs is more complex than project benefits because of the different effects of dynamic PP synergy on PPSB indicators. These characteristics make SD more appropriate for PPSB measurement. Therefore, SD is employed to develop the PPSB measurement model in the present research, which could narrow the gap in current research on lacking measuring PPSBs produced by synergy relationships. Using this model, PPSBs under diverse synergy decisions can be measured, allowing managers to carry out PP management and improve PPSBs.

3. PPSB measurement model development

This section utilizes SD to build a PPSB measurement model, formulated in two steps, as illustrated in Fig. 2. First, the constituent elements of PPSB measurement model, i.e., PP synergy, PPSBs, and influencing factors of PPSBs, are explicated to provide foundations for the measurement model construction. Second, the SD model is established by clarifying the causal and quantitative relationships among these elements to measure PPSBs, providing a basis for optimal synergy decisions identification.

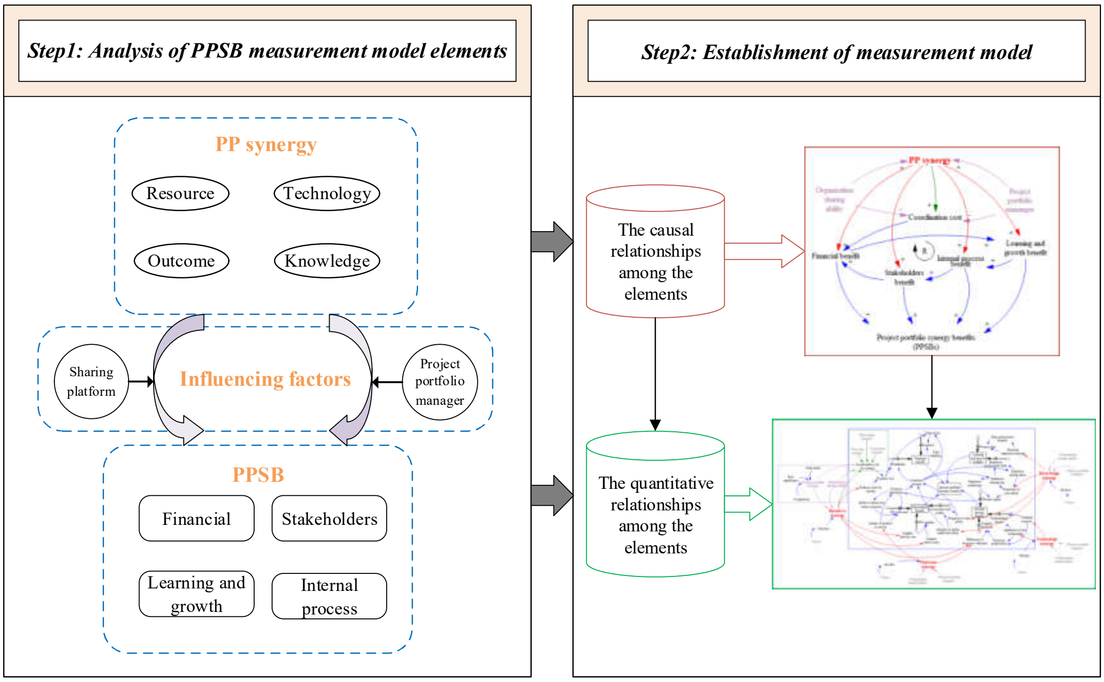


Fig. 2 Framework of PPSB measurement model construction

3.1 Analysis of PPSB measurement model elements

The PPSB measurement model involves many elements with complex relationships. This subsection aims to identify the elements of PPSB measurement model to lay a foundation for constructing the model. First, four types of PP synergy are identified to consider the benefits brought by different synergy relationships. Then, due to PP synergy impacting financial and non-financial benefits, the Balanced Scorecard (BSC) is adopted to clarify the measurement criteria of PPSBs. Finally, the influencing factors are explored in the generation process of PPSBs to build the PPSB measurement model.

3.1.1 Identification of project portfolio synergy

PP synergy arises from the same or similar requirements of resources, technologies, and knowledge among projects. This kind of overlapping demand can result in the corresponding variation in the cost and revenue of PP and then generate PPSBs [51]. The existence time of PPSBs correlates with that of PP synergy, which corresponds to its' concurrent or longitudinal mode [52]. The definitions and modes of four types of PP synergy are shown in Table 1. In the table, the synergy mode is concurrent when PP synergy occurs among multiple simultaneous projects, such as resource synergy. At this time, the existence time of resource synergy is consistent with the implementation time of these projects, and the synergy would not exist once any one of the projects ends. On the contrary, longitudinal knowledge synergy occurs when one project requires the knowledge and experience of the previous project, and the existence time of knowledge synergy is consistent with the implementation time of the last project.

Table 1 Types of PP synergy

Synergy type	Definition	Synergy mode	Reference
Resource synergy	Two or more projects share the same resources within the same PP.	Concurrent	[5], [21], [53]
Technology synergy	The usage of universal technologies within a PP.	Concurrent	[5], [21], [53]
Outcome synergy	1) When the total benefit amount (profit) of projects executed	Concurrent	[15]

	simultaneously differs from a situation in which the projects are executed individually.		
	2) Outcome produced in one project is to be used in another.	Longitudinal	[11], [54]
Knowledge synergy	Projects have similar contexts/content that a project can use the knowledge and experience of previous projects.	Longitudinal	[10], [54]

After determining the existence time of PP synergy, it is necessary to calculate the PP synergy degree to measure PPSBs. As mentioned above, PP has overlapping demand in resources, technologies, and knowledge, and this demand overlapping degree is the key to measuring PP synergy degree. Here, the concept of project niche overlap is employed for measuring the overlapping degree. The project niche can be defined as a status that results from the interdependent matching between projects and portfolio environment and reflects the characteristics of resource demand in the portfolio context [55]. As an indicator to measure the project niche, project niche overlap reflects the degree of demand overlap between projects with the same attributes, including resources, technologies and knowledge, thus crucial for measuring PP synergy degree. Therefore, it is significant to measure the degree of project niche overlap. This research employs the niche measurement model given by Pianka [56] to measure the overlapping degree between projects in a PP. Given a $PP = \{P_i | i = 1, 2, .., n\}$ and all the attributes $N = \{N_k | k = 1, 2, 3, 4\}$ related to PP synergy, each attribute consists of m sub-attributes. The sub-attributes of these four attributes are shown in Table 2. For illustration, the resource attribute n_1 includes three sub-attributes, which are human (n_{11}), materials (n_{12}), and mechanics (n_{13}) resources. The technology dimension contains five sub-attributes, which are referred by the World Intellectual Property Organization (WIPO). In addition, to help managers determine the dimensions of specific technology, the specific indicators corresponding to each sub-technology dimension are proposed, as revealed in Appendix A. According to the measurement model given by Pianka, the PP synergy degree can be expressed as Eq. (1):

$$S_{ijn_k} = \frac{\sum_{a=1}^{m} p_{in_{ka}} p_{jn_{ka}}}{\sqrt{\left(\sum_{a=1}^{m} p_{in_{ka}}^2\right)\left(\sum_{a=1}^{m} p_{jn_{ka}}^2\right)}} \qquad (1)$$

S_{ijn_k} refers to the synergy degree of projects i and project j on attribute n_k, where $k = 1,2,3,4$. The $p_{in_{ka}}$ refers to the utilization degree of project i in sub-attribute n_{ka}. The definition of $p_{in_{ka}}$ is shown as Eq. (2):

$$p_{in_{ka}} = \frac{Utilization\ of\ project\ i\ on\ sub\text{-}attribute\ n_{ka}}{Utilization\ of\ projects\ ij\ on\ sub\text{-}attribute\ n_{ka}} \qquad (2)$$

When the enterprise's resources cannot satisfy the demands of projects, the implementation of one project may take resources away from other projects which share similar resources [23]. At this time, negative synergy will exist in this PP, and PPSBs may decrease [4]. Considering this situation, the parameter w_{ij}, which refers to the probability that enterprise resources could satisfy the demands of projects i and j, is proposed to calculate the PP synergy degree over a period. The amended calculation formula can be obtained, as Eq. (3):

$$S_{ijn_k} = \frac{\sum_{a=1}^{m}\left[w_{ij} p_{in_{ka}} p_{jn_{ka}} - (1-w_{ij}) p_{in_{ka}} p_{jn_{ka}}\right]}{\sqrt{\left(\sum_{a=1}^{m} p_{in_{ka}}^2\right)\left(\sum_{a=1}^{m} p_{jn_{ka}}^2\right)}} = \frac{\sum_{a=1}^{m}(2w_{ij}-1) p_{in_{ka}} p_{jn_{ka}}}{\sqrt{\left(\sum_{a=1}^{m} p_{in_{ka}}^2\right)\left(\sum_{a=1}^{m} p_{jn_{ka}}^2\right)}} \qquad (3)$$

Table 2 The attributes of PP synergy

PP synergy attributes	Sub attributes	Reference
Resource n_1	Human n_{11}	[15]
	Materials n_{12}	
	Mechanics n_{13}	
Technology n_2	Electrical engineering n_{21}	World Intellectual Property Organization. [57]
	Instruments n_{22}	
	Chemistry n_{23}	
	Mechanical engineering n_{24}	
	Other fields n_{25}	
Outcome n_3	Target market n_{31}	[8]
	Result utilization n_{32}	[54]
Knowledge n_4	Overt Knowledge n_{41}	[10]
	Recessive Knowledge n_{42}	

3.1.2 Establishment of the PPSB measurement criteria

To measure the financial and non-financial, long-term, and short-term benefits brought by PP synergy, the PPSB measurement criteria are classified with the application of BSC approach. The BSC shows the achievement of organizational strategic objectives through four performance indicators: financial, customer, learning and growth, and internal process [58, 59]. To the best of our knowledge, Bai et al. [5] firstly divided PP benefits into four parts according to the characteristics of PP based on BSC. Its include the financial benefits subsystem, stakeholder subsystem, portfolio growth potential subsystem, and internal synergy subsystem. The PPSBs, generated by the internal synergy subsystem, are included in PP benefits. Therefore, the PP benefit measurement criteria proposed by Bai et al. [5] is employed in this study. On this basis, the "internal synergy subsystem" is replaced by "internal process subsystem", that is, the external variables of the PPSB measurement model. Each dimension contains multiple factors and corresponding measurement indicators, which are acquired by referring to PP benefits influencing factors of Bai et al. [60], as shown in Appendix B.

3.1.3 Identification of the PPSB influencing factors

Synergy among projects plays an active role in the PP because it could generate PPSBs [61]. However, PPSBs are related to the PP synergy degree and many other influencing factors. As summarized in Section 2.1, the subjective and objective factors in the process of PP implementation, including the ability of project portfolio managers and organization sharing ability, would also affect the generation of PPSBs. Therefore, this research investigates the impact of these two factors on PPSBs based on the previous literature and expounds on their related concepts and measurement methods.

Project portfolio managers need to coordinate the shared resources among multi-interrelated projects to ensure the smooth implementation of the PP [62, 63]. When project portfolio managers lack appropriate management skills, they fail to allocate the shared resources to the required projects opportunely. This may lead to the delay of projects with synergy relationships and further reduce PPSBs [26]. Therefore, to comprehensively consider the impact of their ability on PPSBs, three indicators proposed by Jonas [64] are exploited to measure the coordination management ability of project portfolio managers, as shown in Table 3. In addition, the organization sharing ability also affect the performance of PPSBs. Projects with synergy relationships need to be coordinated to share common resources and technologies. The enterprise resources can be fully shared when the organization sharing platform is thorough, which can realize potential advantages brought by PP synergy and ultimately ensure the achievement of PPSBs [12]. In this regard, this study applies the perfection of the organization sharing platform to measure the organization sharing ability.

The prerequisite of integrating these two influencing factors into the model is to quantify them. The performances of these influencing factors can be evaluated by experts within the project portfolio management domain. Due to complex decision environments and empirical human thinking, it is difficult for experts to determine a precise value of the influencing factors in practical decisions. The trapezoidal fuzzy numbers are applied to deal with experts' fuzzy evaluation values since they are widely employed to handle fuzzy information problems involving uncertainty [65-67]. Generally, the experts evaluate the factors using a set of linguistic variables first and then convert them into a generalized trapezoidal fuzzy number, expressed as $\tilde{A} = (a_1, a_2, a_3, a_4)$. The linguistic variables and the corresponding trapezoidal fuzzy numbers (TrFNs) are shown in Table 4. This fuzzy number $\tilde{A}$ can be transformed into a crisp value via the Eq. (4) [68].

Table 3 Relevant indicators of project portfolio managers

Factor	Indicators	Explanations/ Evaluation criteria
Project portfolio managers	Role clarity	The degree to which the objectives and authorities of the project portfolio manager are clearly defined, affecting the degree of coordination management task execution.
	Role significance	The extent to which senior managers believe that the project portfolio manager is a key role in achieving strategic objectives, affecting the participation of project portfolio manager in the coordination management task.
	Competency	The perfection degree of personal professional skills in

	coordination management of project portfolio manager.

Table 4 Linguistic variables and fuzzy numbers comparison

Linguistic Variables	TrFNs
Very poor (VP)	(0, 0, 0.1, 0.2)
Poor (P)	(0.1, 0.2, 0.2, 0.3)
Medium poor (MP)	(0.2, 0.3, 0.4, 0.5)
Fair (F)	(0.4, 0.5, 0.5, 0.6)
Medium good (MG)	(0.5, 0.6, 0.7, 0.8)
Good (G)	(0.7, 0.8, 1.0, 1.0)
Very good (VG)	(0.8, 0.9, 1.0, 1.0)

$$Defuzz(\tilde{A}) = \frac{a_1+2a_2+2a_3+a_4}{6} \qquad (4)$$

3.2 Establishment of measurement model

Upon the presented elements analysis, in this subsection, the qualitative relationships among the PPSB measurement model elements are firstly identified and demonstrated using a causal loop diagram (CLD). Then, the stock-flow diagram (SFD) is constructed based on CLD to measure PPSBs.

3.2.1 Cause loop diagram

The CLD is a SD modeling tool that helps to map the cause and effect relationships among variables through curved arrows [18]. An arrow between two variables represents a causal relationship between them, and each arrow has an attached polarity. The polarity symbolized by ‘+’ ‘-’ indicates that the two related variables change in the same or two different directions, respectively [69]. In light of the three types elements analysis in PPSB measurement model, Fig. 3 summarizes the interrelations among the elements.

As shown in Fig. 3, the PP synergy produces PPSBs by influencing four benefit sub-indicators (see red variables and arrows), and there are mutual influence relationships among the sub-indicators of PPSBs (see black variables and blue arrows). Moreover, the generation process of PPSBs is affected by the organization sharing platform and the project portfolio manager (see purple variables and arrows). On the one hand, these two factors would affect the realization degree of PP synergy; On the other hand, they impact the coordination cost between different projects of the PP. The coordination cost, refers to the additional cost incurred when coordinating the shared resources of different projects, would affect the financial benefit of PPSBs [12]. Therefore, in addition to the various elements defined in Section 3.1, the "coordination cost" variable in Fig. 3 is added. The coordination cost required increases with the increase of PP synergy degree (see green arrow).

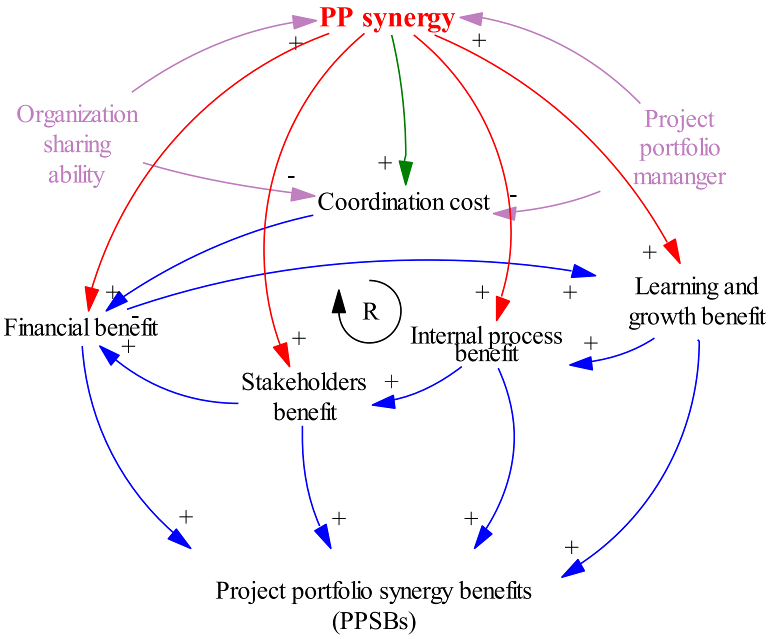


Fig. 3 The structural relationships among elements

3.2.2 Stock-flow diagram

The SFD, a quantitative SD model that can be simulated, is used to present the quantitative relationships among the system elements based on the CLD [18]. It can be applied for modeling and understanding the nonlinear behavior of a complex system over time using system variables and various functions [70]. When building a quantitative SD model, the elements in CLD should be primarily converted into system variables (stock, flow, auxiliary and constant variables). Then, the causal relationships are required to be quantified by inputting the mathematical and logical formulas into the model.

By refining the variables in Fig. 3 based on Section 3.1, the constructed PPSB measurement model could be obtained and shown in Fig. 4, including four stock variables, ten flow variables, and 33 auxiliary variables. The indicators and arrows in the blue, green, and purple boxes, refer to the PPSB measurement criteria, coordination cost, influencing factors, and the relationships among them. The red variables represent the PP synergy, which needs to be obtained according to the sharing relationships of project attributes within a PP. The quantitative relationships of related variables include many formulas. The coefficient in these formulas between the PPSB indicators is obtained by Analytic Hierarchy Process (see Appendix B). Moreover, due to the existing mathematical functions being difficult to express the nonlinear relationships between PP synergy and PPSB criteria, the table function is applied to express their relationship. As a customized function of a special nonlinear relationship between reaction elements, the specific relationships of table functions between variables are determined by experts using a 0–1 range. The judgment experts have skilled knowledge in project portfolio management. In addition, they also have sufficient abilities and experience to manage projects contained in a program. Therefore, the effectiveness and correctness of the evaluation results can be ensured. It should be noted that for PP with different functions in diverse enterprises, the contributions of sub-benefits to PPSBs and the values of the table function are also different. Managers should adjust these parameters for a specific PP when using this model.

To correctly measure the actual change trend of the system, the final step is testing to ensure the validity of the constructed model. This model is validated by VENSIM DSS software in the next section, mainly including the test for structural validity and behavioral validity [71]. Structural validity ensures that the model is developed correctly or works properly [72, 73]. It is mainly realized by model tests and equation tests. The behavioral validity confirms that the simulated behavior of the model can exhibit the observed behavior or anticipated trends of the real system [74, 75]. One of the test methods of behavior validity is the extreme condition test, which aims to explore whether the model conforms to the actual system in extreme cases [71]. After passing these two tests, the validity of the model can be ensured. The valid model can be utilized to measure PPSBs under different synergy degrees. Accordingly, managers could determine the synergy decisions in their PPs to achieve the optimal PPSBs.

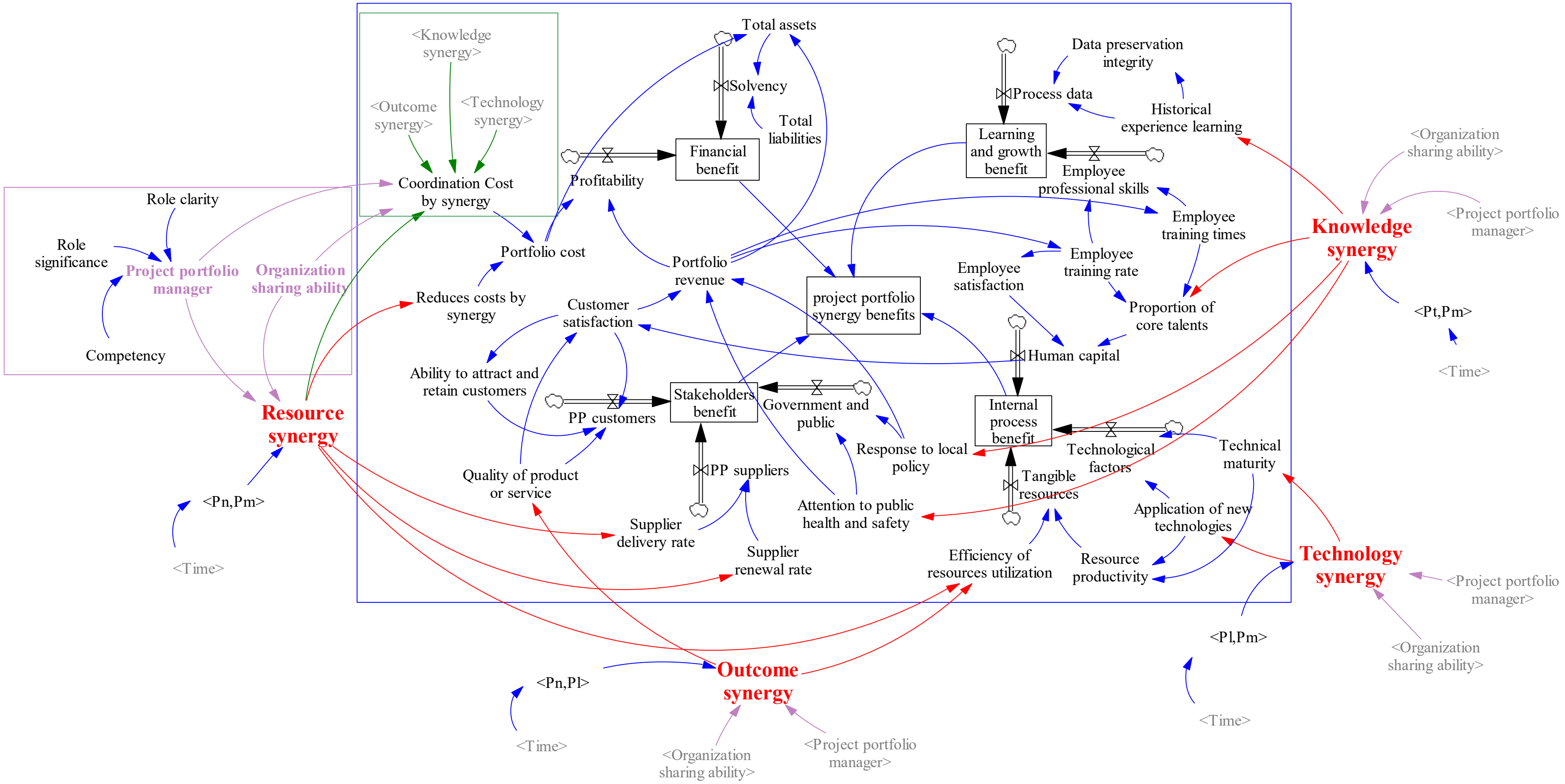


Fig. 4 A basic PPSB measurement model

4. Numerical example

This section presents a numerical example to illustrate the proposed model's applicability and effectiveness. As shown in Fig. 5, the application of the model mainly includes two steps: PPSB measurement model construction and simulation results analysis. First, the PPSB measurement model is constructed according to the PP synergy relationships, and the model is validated. Then, after the calculated values are brought into the model for simulation, the basic run results of PPSBs are obtained. In addition, different synergy degrees are set for scenario analysis to find the optimal synergy decisions for achieving the optimal PPSBs of the PP.

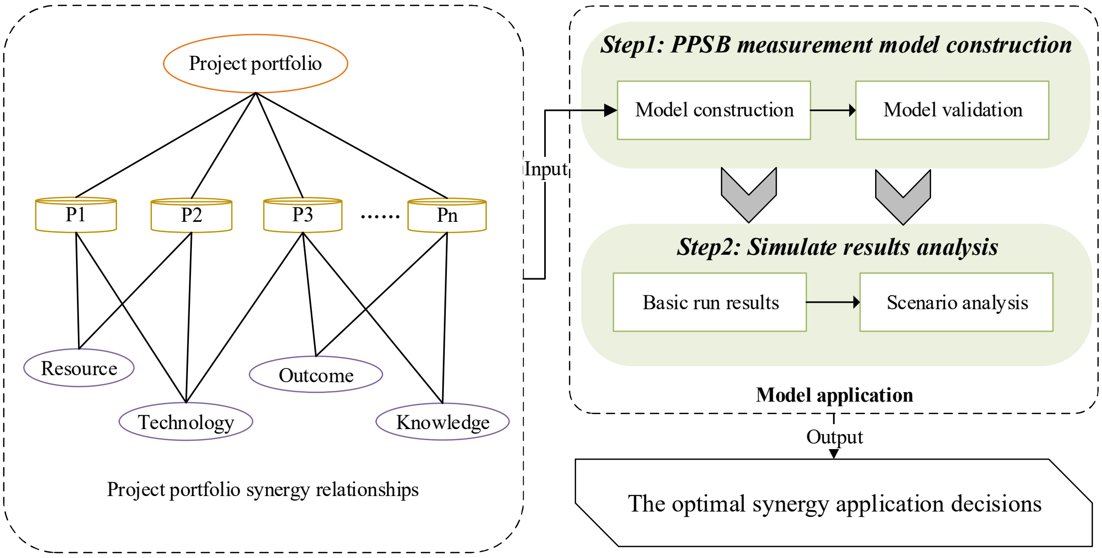


Fig. 5 The general steps of the model

4.1 Background of the numerical example

This example derives from a reputable construction enterprise mainly responsible for design, construction, and sales projects. The enterprise is planning to invest in a PP containing five projects with an implementation time of 24 months. To achieve the PP benefits, the PPSBs should be measured, and the optimal synergy decisions demand to be formulated in advance. Available project information about the PP synergy relationships is shown in Table 5. For illustration, H1 represents the human resources of project 1, 20% H1 + 80% H2 represents that 20% of the human resources utilized in project 2 are the same as that of project 1, and the remaining 80% are the unique human resources of project 2. The overlap of human resources means resource synergy exists between projects 1 and 2. As mentioned in Table 1, the mode of resource is transverse. Consequently, resource synergy between projects 1 and 2 exists from the 1st to the 8th month. All the types and existence times of PP synergy are shown in Appendix C.

Table 5 Project information

Projects		1	2	3	4	5
Type		Construction	Design & Construction	Sale	Construction	Sale
Time		1-8	1-11	12-24	9-19	13-24
Resource	Human	H1 (30%)	20%H1+ 80%H2	H3 (30%)	H4	25%H3+ 75%H5
	Material	Ma1	Ma2	Ma3 (25%)	Ma4	15%Ma3+ 85%Ma5
	Mechanics	Me1 (20%)	30%Me1+ 70%Me2	Me3	Me4	Me5
Technology	Type2	<T2>1	<T2>2	<T2>3	<T2>2	<T2>5
	Type4	<T4>1	<T4>2	<T4>3	<T4>2+ <T4>4	<T4>5
Outcome	Result utilization	O1	O2	O3 (62%O2)	O4	O5
Knowledge	Overt K	Ov1	Ov2	Ov3	Ov1+Ov4	Ov5
	Recessive K	Re1	Re1	Re1	Re1+Re4	Re5

4.2 PPSB measurement model construction

4.2.1 Model construction

By concretizing the synergy projects (the $< Pn, Pm >$, $< Pn, Pl >$, $< Pl, Pm >$, and $< Pt, Pm >$variables) in Fig. 4, the PPSB measurement model of the PP could be constructed, shown as Fig. 6. After constructing the measurement model, the model's input values, including the value of PP synergy degree and influencing factors, should be determined to measure PPSBs.

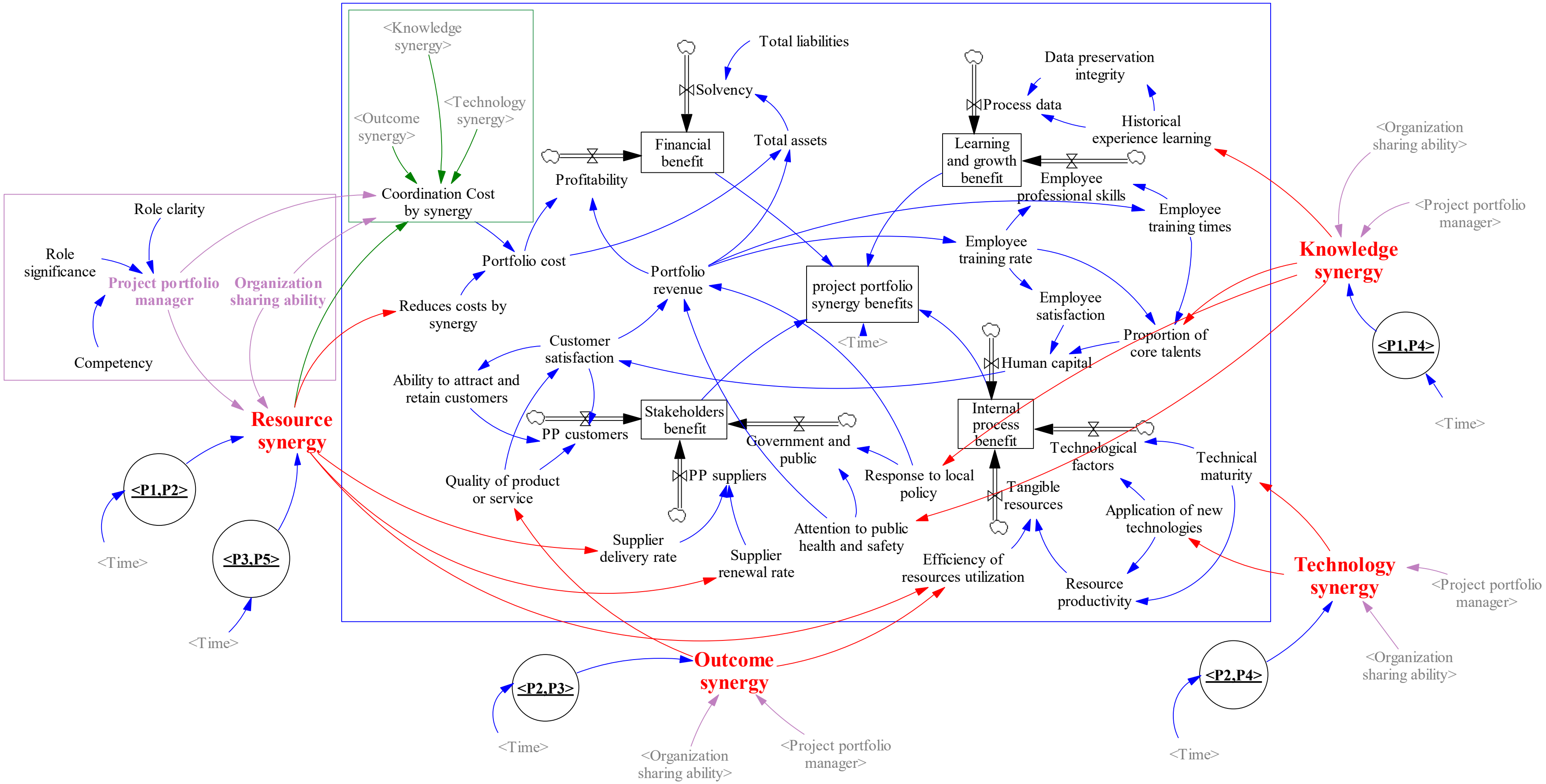


Fig. 6 PPSB measurement model of the PP

(1) The determination of PP synergy degree

The PP synergy degree could be calculated by Eq. (3), where $p_{in_{ka}}$ is calculated by the data in Table 5. The calculation results of the PP synergy degree are listed in Appendix C.

For example, resource synergy exists in projects 1 and 2 due to the sharing of humans and mechanics (see Appendix C) from the 1st to the 8th month. It can be perceived that the 30% human resources of project 1 are equal to the 20% human resources of project 2, so the human resources of project 1 are 1.5 times that of project 2. At the same time, it is estimated that about 30% of human resources will be saved when projects 1 and 2 are simultaneously implemented. According to Eq. (2), the p value of projects 1 and 2 in the human (a_{11}) dimension can be calculated:

$$p_{1a_{11}}=\frac{1}{1+1.5-0.3}=0.45 \qquad p_{2a_{11}}=\frac{1.5}{1+1.5-0.3}=0.68$$

Similarly, the p value of projects 1 and 2 in mechanics (a_{13}) can be obtained:

$$p_{1a_{13}}=\frac{1.5}{1+1.5-0.3}=0.68 \qquad p_{2a_{13}}=\frac{1}{1+1.5-0.3}=0.45$$

Finally, according to Eq. (3), the resource synergy degree of projects 1 and 2 from the 1st to the 8th month S_{12R} can be obtained:

$$S_{12R}=\frac{(2\times 0.93-1)\times 0.45\times 0.68+(2\times 0.94-1)\times 0.68\times 0.45}{\sqrt{(0.45^2+0.68^2)(0.68^2+0.45^2)}}=0.8$$

Ultimately, all types of synergy degrees during PP implementation could be obtained, shown as Appendix C.

(2) The determination of influencing factors

In this example, three experts from different functional departments of the enterprise determine the performance of PPSB influencing factors. Table 6 shows the evaluation results of each expert on different indicators. Based on Table 4, the evaluation results of experts can be converted into TrFNs and defuzzified to the specific values by Eq. (4). The defuzzification results are listed in Table 6.

For example, the expert evaluation results of “Role clarity” are “Medium good (MG)”, “Medium good (MG)” and “Good (G)”. To convert the fuzzy evaluation results into specific values, Eq. (4) is utilized to defuzzify. This paper also takes the median value to integrate expert evaluation results. The performance of "Role clarity" is as follows:

$$V = \frac{\frac{0.5 + 2 \times 0.6 + 2 \times 0.7 + 0.8}{6} + \frac{0.5 + 2 \times 0.6 + 2 \times 0.7 + 0.8}{6} + \frac{0.7 + 2 \times 0.8 + 2 \times 1 + 1}{6}}{3} = 0.73$$

The defuzzification value of the "Fair (F)" index is 0.5, which indicates that the index performance is satisfactory when the value exceeds 0.5. Therefore, the project portfolio manager's ability is satisfactory, and the organization sharing platform is fair, according to Table 6.

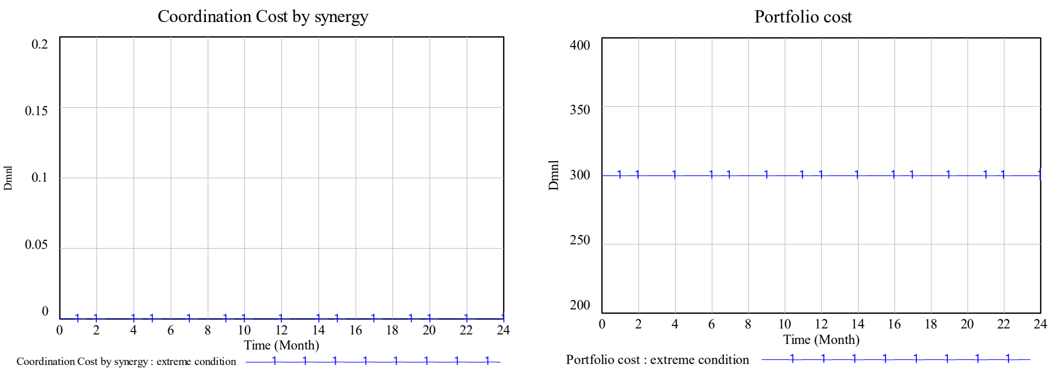
Table 6 Evaluation results of influencing factors

Factors	**Indicators**	**Expert evaluation results**	**TrFNs**	**Defuzzification value**
Project portfolio manager	Role clarity	MG	(0.5, 0.6, 0.7, 0.8)	0.73
		MG	(0.5, 0.6, 0.7, 0.8)	
		G	(0.7, 0.8, 1.0, 1.0)	
	Role significance	F	(0.4, 0.5, 0.5, 0.6)	0.6
		MG	(0.5, 0.6, 0.7, 0.8)	
		MG	(0.5, 0.6, 0.7, 0.8)	
	Competency	G	(0.7, 0.8, 1.0, 1.0)	0.7
		MG	(0.5, 0.6, 0.7, 0.8)	
		F	(0.4, 0.5, 0.5, 0.6)	
Organization sharing ability	Sharing platforms	MP	(0.2, 0.3, 0.4, 0.5)	0.5
		F	(0.4, 0.5, 0.5, 0.6)	
		MG	(0.5, 0.6, 0.7, 0.8)	

4.2.2 Model validation

To ensure the scientificity and validity of the model, the structural validity test and behavioral validity test are carried out. In terms of structural validity test, "Check Syntax" is conducted to check the equations of the model when setting the variable equation. Following the construction of the model, "Model Check" is used to check the overall model. This research corrects the model according to the reported error information until it passes the structural validity test.

Concerning the behavioral validity test, the extreme condition test is carried out by assigning “0” to the variables $< \mathrm{P1}, \mathrm{P2} >$, $< \mathrm{P3}, \mathrm{P5} >$, $< \mathrm{P2}, \mathrm{P3} >$, $< \mathrm{P2}, \mathrm{P4} >$, and $< \mathrm{P1}, \mathrm{P4} >$ (no synergy within the PP) and observing the simulation results of the model. In this case, there are no coordination costs within the PP, and the total cost of the PP is the same as the initial value (the value is 300). As shown in Fig. 7, the simulation results are consistent with the actual situation, and the model passes the extreme conditions test. Consequently, the validity of the model is ensured, and it can be adopted in the simulation phase.



(a) (b)

Fig. 7 Results of extreme conditions test

4.3 Simulation results analysis

4.3.1 Basic run results

The model is set to run over 24 months in the simulation phase, consistent with the PP execution time. The basic run simulation results (Fig. 8) are achieved using parameter values illustrated in Section 4.2. The horizontal axis represents the simulation time, and the vertical axis represents the value of PPSBs.

As shown in Fig. 8, PPSBs continue to grow during implementation. Only resource synergy presents in the PP from the 1st to the 8th month according to Appendix A, and the growth trend of PPSBs is stable. From the 9th to the 19th month, technology and knowledge synergy exist in the PP. The coordination costs required to manage these synergy relationships have increased in such circumstances, and PPSBs rise in fluctuations. From the 20th to the 24th month, the growth trend of PPSBs becomes faster, and there are two inflection points. First, as sales projects obtain financial benefits for PP, the financial benefits received by sharing resources in projects 3 and 5 are also greater. In addition, the weight of financial benefit is relatively greater. Therefore, PPSBs increase rapidly in the metaphase and anaphase of projects 3 and 5, at which time the first inflection point appears. Second, project 4 closes in the 19th month, PPSBs generated by knowledge synergy would not exist at this point, and the growth of PPSBs becomes relatively slower, leading to a second inflection point. Ultimately, PPSBs reach 0.1401 in the 24th month.

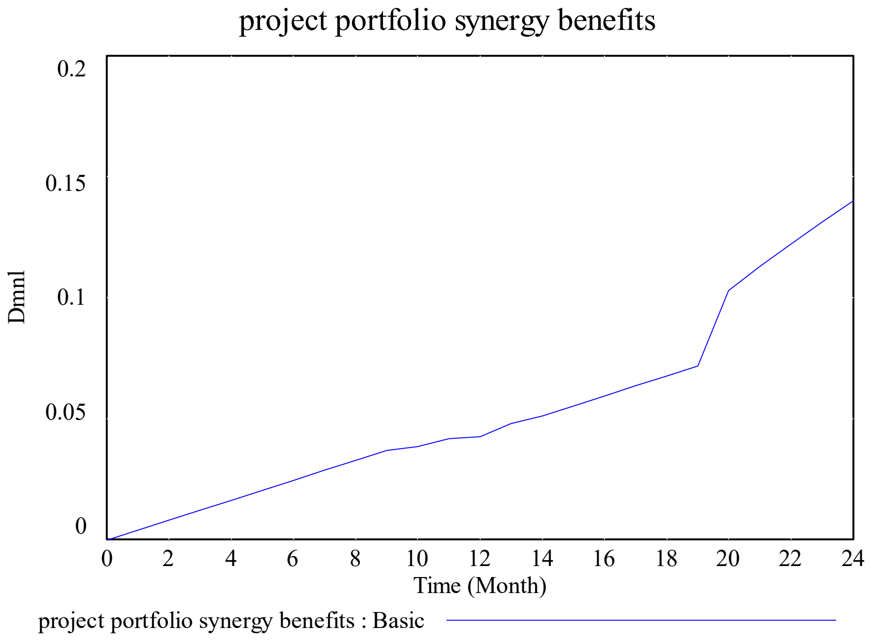


Fig. 8 Simulation results of project portfolio synergy benefits

4.3.2 Scenario analysis

As aforementioned in Section 4.3.1, PPSBs would reach 0.1401 if fully shared and reused the resources, technologies, outcomes and knowledge in the PP. However, based on the level of organizational sharing and the management ability of project portfolio managers, the synergy decisions for realizing the maximum PPSBs may differ from the basic scenario. To manage PPSBs more effectively, exploring the synergy decisions to achieve the optimal PPSBs, in this case, is necessary. Therefore, scenario analysis is conducted to simulate PPSBs under different PP synergy degrees, providing support for determining the optimal synergy decisions of the PP.

Projects may have different amounts and types of synergy in different phases as the PP synergy relationships change with the project implementation time. To fully use the synergy relationships in each stage to improve the overall PPSBs, this research divides the PP implementation cycle into five simulation stages according to the project implementation time, as shown in Fig. 9. Three application decisions are set for each synergy degree: high, medium, and low synergy. The high synergy degree indicates the maximum sharing and reutilization capability that PP can achieve, which is calculated according to project information, shown as Appendix C. The low synergy degree is set to 0.1 (hardly sharing resources, technologies, outcomes, and knowledge). The medium synergy degree takes the median value of the high and low synergy degrees. The specific information of the final simulation scenario is shown in Table 7. In Table 7, three simulation scenarios in stage 1 (high, medium, and low) are set because the concurrent resource synergy exists in the PP from the 1st to the 8th month, and the corresponding synergy degree is (0.8, 0.45, 0.1). Similarly, two types of synergy in PP are combined into nine simulation scenarios from the 9th to the 11th month. Then, VENSIM DSS software is used to simulate and analyze these various scenarios during the PP implementation. The specific simulation results are shown in Fig. 10, and each figure represents the simulation results of one stage. As can be observed, each stage has an optimal synergy decision. For example, as shown in Fig. 10 (d), the optimal synergy decisions are high outcome synergy, low knowledge synergy, and high resource synergy in stage 4. The value of PPSBs will reach 0.1634 in the 24th month when adopting the above synergy decisions in stage 4.

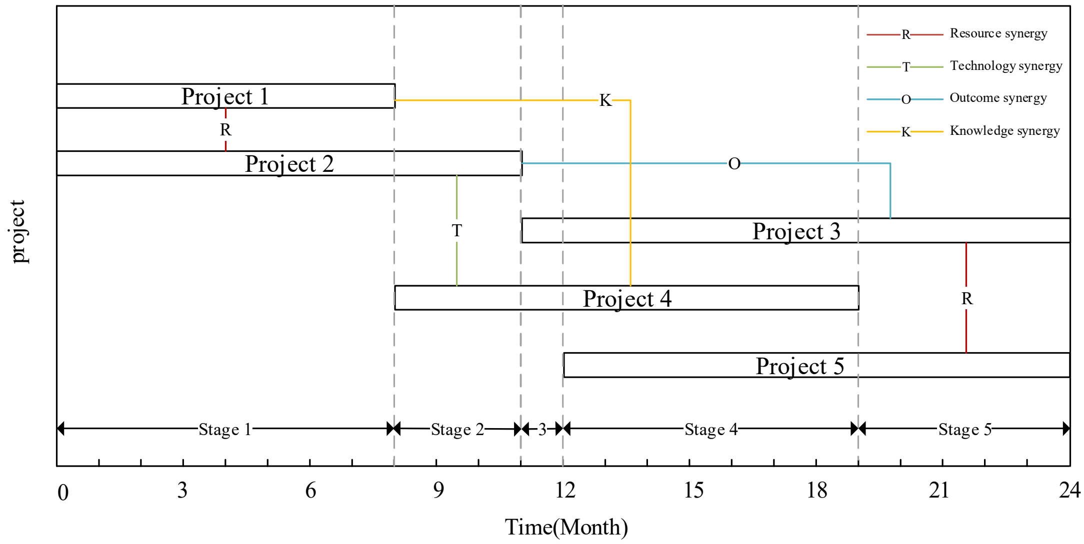
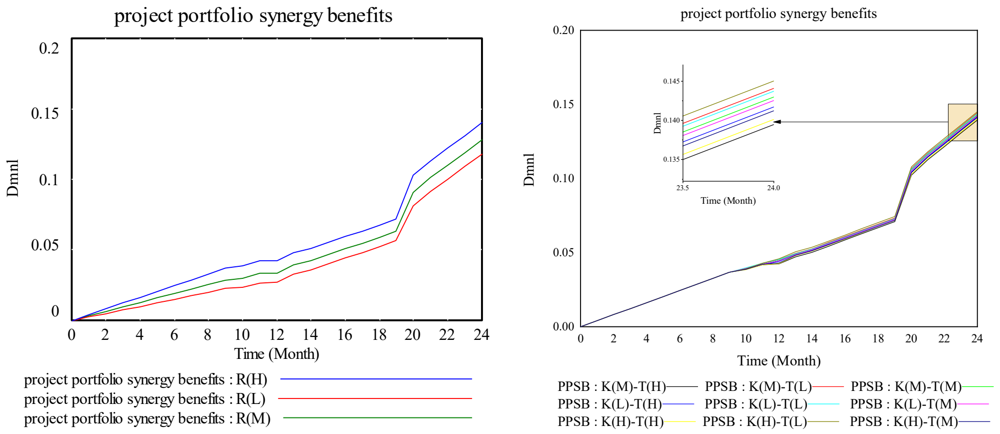


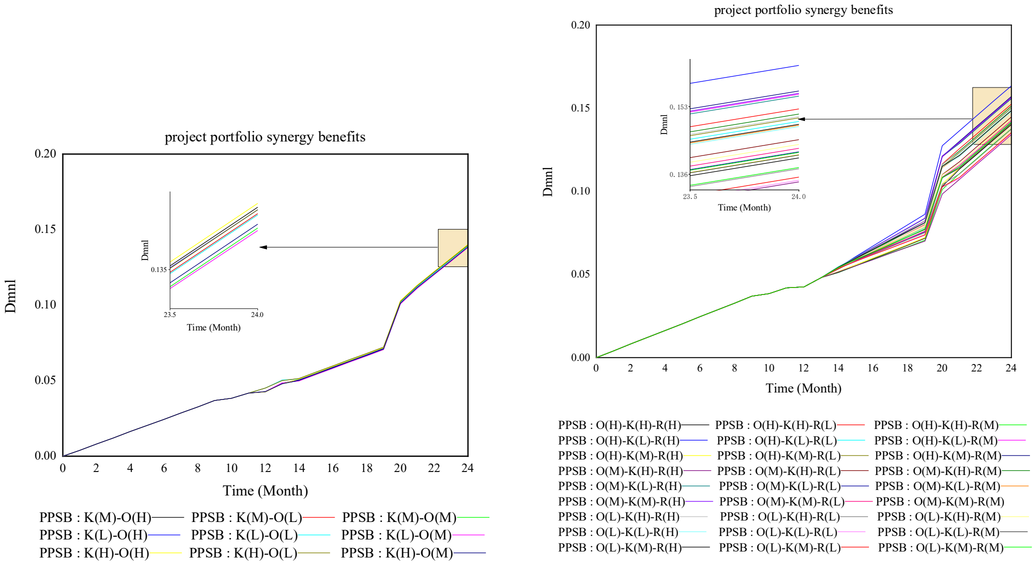
Fig. 9 Simulation stages of the PP

Table 7 Simulation scenario of the PP

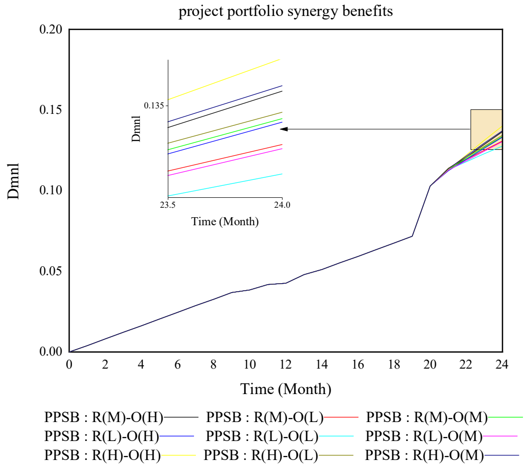
Synergy **Time (Month)**	Resource	Technology	Outcome	Knowledge	**Scenario**
Stage 1 (1-8)	(0.8, 0.45, 0.1)				3
Stage 2 (9-11)		(0.6, 0.35, 0.1)		(0.6, 0.35, 0.1)	3*3=9
Stage 3 (12)			(0.5, 0.3, 0.1)	(0.6, 0.35, 0.1)	3*3=9
Stage 4 (13-19)	(0.7, 0.4, 0.1)		(0.5, 0.3, 0.1)	(0.6, 0.35, 0.1)	3*3*3=27
Stage 5 (20-24)	(0.7, 0.4, 0.1)		(0.5, 0.3, 0.1)		3*3=9
Projects	1&2(Stage1) 3&5(Stage4、5)	2&4	2&3	1&4	



(a) Simulation results of stage 1. (b) Simulation results of stage 2.



(c) Simulation results of stage 3. (d) Simulation results of stage 4.



(e) Simulation results of stage 5.

Fig. 10 The simulation results of scenario analysis

The optimal synergy decisions are proposed in light of scenario analysis results. Table 8 shows the synergy decisions of the PP implementation stage by integrating the optimal synergy decisions in each stage. Counterintuitively, low synergy decision exists in the decisions to realize the optimal PPSBs. For example, when projects 2 and 4 adopt the low technology synergy decision from the 9th to the 11th month, the optimal PPSBs could be achieved. This is because although the technology similarity between projects 2 and 4 is high, guaranteeing its sharing is difficult due to the fair organization sharing platform referring to Table 6. Fully sharing technologies in this PP will increase the coordination costs and thus reducing PPSBs. Therefore, the degree of technology sharing between projects 2 and 4 should be minimized. In addition, projects 1 and 4 should adopt the low knowledge synergy decision from the 13th to the 19th month, while the high knowledge synergy is from the 9th to the 12th month. Since project 1 closes in the 8th month, its relevant knowledge and experience can be used in the early implementation stage of project 4. However, in the later implementation stage of project 4, the experience of project 1 may not be applicable to project 4 due to the changeable external environment. It is necessary for project 4 to selectively learn from project 1 in combination with its implementation environment to receive a high PPSB.

Table 8 The optimal synergy decisions

Time (Month)	**Projects**	**Synergy type**	**Decision**
Stage 1 (1-8)	1、2	Resource	High
Stage 2 (9-11)	2、4	Technology	Low
	1、4	Knowledge	High
Stage 3 (12)	2、3	Outcome	High
	1、4	Knowledge	High
Stage 4 (13-19)	3、5	Resource	High
	1、4	Knowledge	Low
	2、3	Outcome	High
Stage 5 (20-24)	2、3	Outcome	High
	3、5	Resource	High

Integrating the optimal synergy decisions in Table 8 into the PPSB measurement model and the simulation results can be acquired. As shown in Fig. 11, the PPSBs have been improved compared with the basic scenario. This means that the PP obtains better PPSBs in the implementation stage.

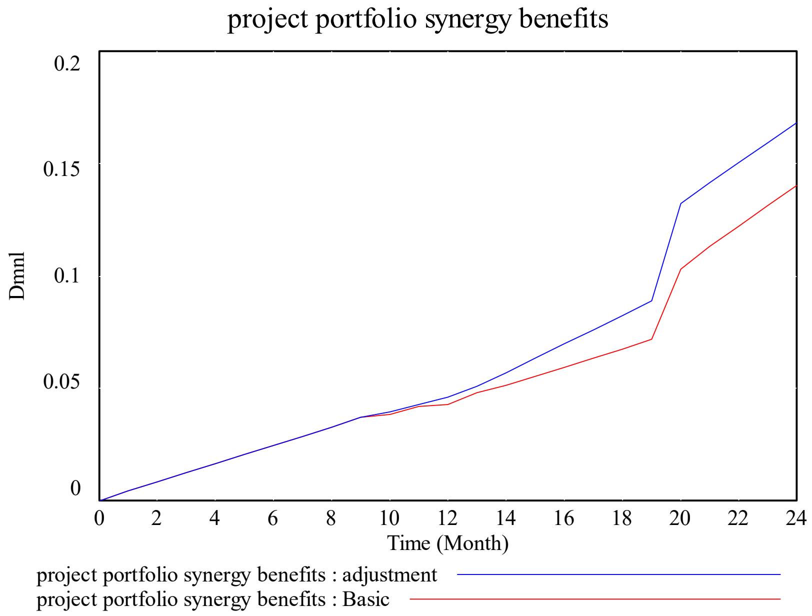


Fig. 11 Comparison of the project portfolio synergy benefits simulation results

5. Discussion

The PPSB measurement model proposed in this study could measure PPSBs under different synergy degrees. Herein, this study provides significant implications in theory and practice and can be used as a basis for future study.

5.1 Theoretical implications

This research proposes a PPSB measurement model, enriching the existing theories in PP benefits management and helping to narrow the gap between PP synergy management and benefits realization.

First, to our knowledge, this research is the first to measure PPSBs from the perspective of its generation. Although many scholars have proposed various methods for PPSBs assessment [8, 29, 76], most methods are based on the DMs' judgment without exploring the quantitative relationships of the PP synergy and PPSBs. This research complements the current literature by developing a measurement model that elaborates on the influence of PP synergy on PPSBs and links the relevant influencing factors in the generation process. This research lays a foundation for future research, which could be used in PP selection and benefits evaluation.

Second, a new calculation method for PP synergy degree is proposed. By investigating the internal overlapping characteristics of PP synergy, the concept of project niche overlap is introduced to calculate the PP synergy degree. Furthermore, the formula is modified to simultaneously consider the positive and negative synergy for more consistent with reality. The integration of ecology and project portfolio management provides insights for following PP synergy research.

Third, the research contributes to the advancement of the present body of knowledge on PP benefits management. This study makes an in-depth analysis about the mechanism of PPSBs from four types of synergy relationships, as distinct from the previous literature that emphasizes the PP synergy effects between projects [23, 24]. The presented SD model is capable of clearly describing the interrelationships among variables affecting PPSBs, improving the understanding of how PPSBs relate to the PP synergy and influencing factors. This gives insight for future research to explore a deeper PPSB generation mechanism and clarify its internal relationship with project benefits.

5.2 Practical implications

The PPSB measurement model intends to support managers in promoting PPSBs with appropriate management. The practical implications of this research are twofold.

First, the constructed model in the present study proposes an effective technique for managers to measure PPSBs. According to the sharing information on resources and technology in a specific PP, the measurement model for the PP can be acquired by replacing the “synergy projects” variables in Fig. 4. In addition, PP synergy degree and the value of PPSB influencing factors can be calculated. By performing calculations, managers could utilize this model to simulate PPSBs in implementing a PP at any moment. The simulation results show the incremental effect of the PP synergy relationship, providing a quantitative basis for managers to improve PPSBs.

Second, the proposed process of PPSB management offers managers an instrument for optimizing PPSBs [48]. The synergy decisions to achieve the optimal PPSBs are distinct for different PP in different companies. The SD model is intuitive and convenient for DMs to set different PP synergy degrees for scenario analysis before implementing a PP. With the early assessment and comparison of PPSBs of diverse synergy decisions, optimal synergy decisions can be subsequently developed. This consequently gives managers indications for properly using PP synergy relationships to realize the optimal PPSBs.

5.3 Limitations and future research directions

The proposed model measures PPSBs under the internal influencing factors during the PP implementation. However, the external factors of PP also affect the generation of PPSBs. To better support the decision-making of project portfolio managers, future research could measure the changing external influencing factors to incorporate into the PPSB measurement model. In addition, the numerical example used for model verification is a small scale, which may lead to unknown applicability in large PPs. Further research can be conducted to validate the model in larger companies and PPs.

6. Conclusion

Measuring PPSBs brought by diverse PP synergy relationships is conducive to achieving the optimal PPSBs and promoting the overall benefits of the enterprise. However, the existing literature mainly emphasizes and evaluates synergy's promotion effect in line with DMs' preferences, ignoring the quantitative impacts of the PP synergy relationships on PPSBs. The main research question remains unsolved: ***How much PPSBs can be produced by the PP synergy relationships?*** This study provides a model for measuring PPSBs to answer this question. PPSBs are generated by PP synergy and are affected by many factors. This paper primarily determines the elements of the PPSB measurement model, including PP synergy, PPSB measurement criteria, and the influencing factors of PPSBs. In addition, PP synergy changes dynamically with the implementation of PP, and the relationships between PP synergy and PPSBs are complex. Therefore, the SD is used to quantify the relationships among the elements to build the PPSB measurement model. Finally, a numerical example is used to verify the effectiveness and applicability of the model and illustrate how to manage PPSBs based on the simulation results. The results show that the proposed model can provide useful information for managers to determine the optimal PP synergy decisions for realizing the ideal PPSBs following the organization strategy.

Compared with the previous research, the contributions of this research are threefold. First, this research is the initial to realize the PPSB measurement by describing the interrelationships among elements of the PPSB measurement model, pushing the boundaries of PP benefits studies. Second, the proposed model can simulate PPSBs under different PP synergy degrees and provides guidance for managers to determine the optimal PP synergy decisions to achieve ideal PPSBs. Third, this research introduces the concept of project niche overlap to calculate the PP synergy degree more scientifically from the similarity of project attributes, providing a new perspective for the research of PP synergy.

Acknowledgment: This work was supported by the [National Natural Science Foundation of China #1] under Grant [number 72002018; 72171025]; [Innovation Capacity Support Plan of Shaanxi Province #2] under Grant [number 2020KJXX-054]; [Soft Science Projects of Shaanxi Province #3] under Grant [number 2022KRM012]; [Youth Innovation Team of Shaanxi Universities #4] under Grant [number 21JP009]; and [Fundamental Research Funds for the Central Universities #5] under Grant [number 300102232601; 300102231639].

Declaration of interest statement: The authors report there are no competing interests to declare.

References

[1]PMI. Success rates rise: transforming the high cost of low performance: Pulse of the Profession; 2017.

[2]Maqsoom, A. , M. Hamad , H. Ashraf, et al. Managerial control mechanisms and their influence on project performance: an investigation of the moderating role of complexity risk. Eng Constr Archit Ma. 2020; 27(9): 2451-2475.

[3]Serra, C. , M. Kunc. Benefits Realisation Management and its influence on project success and on the execution of business strategies. Int J Proj Manag. 2015; 33(1): 53-66.

[4]Tavana, M. , G. Khosrojerdi , H. Mina, et al. A new dynamic two-stage mathematical programming model under uncertainty for project evaluation and selection. Comput Ind Eng. 2020; 149: 106795.

[5]Bai, L. , Y. Sun , H. Shi, et al. Dynamic assessment modelling for project portfolio benefits. J Oper Rec Soc. 2022; 73(7): 1596-1619.

[6]Formentini, M. , P. Romano. Using value analysis to support knowledge transfer in the multi-project setting. Int J Prod Econ. 2011; 131(2): 545-560.

[7]Kosztyán, Z. T. , A. I. Katona , K. Kuppens, et al. Exploring the structures and design effects of EU-funded R&D&I project portfolios. Technol Forecast Soc. 2022; 180.

[8]Nabati, M. M. , M. Ashrafi. Modeling projects interdependencies to measure their synergic impacts on a project portfolio. J Proj Manage. 2021; 6(3): 143-156.

[9]Martinsuo, M. Project portfolio management in practice and in context. Int J Proj Manag. 2013; 31(6): 794-803.

[10]Bathallath, S. , Å. Smedberg , H. Kjellin. Managing project interdependencies in IT/IS project portfolios: a review of managerial issues. IJISPM-Int J of Inf Sys. 2016; 4(1): 67-82.

[11]Arifin, R. S. , S. S. Moersidik , E. T. B. Soesilo, et al. Dynamic project interdependencies (PI) in optimizing project portfolio management (PPM). Int J Technol. 2015; 6(5): 828-837.

[12]Cho, W. , M. J. Shaw , H. D. Kwon. The effect of synergy enhancement on information technology portfolio selection. Inform Technol Manag. 2012; 14(2): 125-142.

[13]Heinrich, B. , D. Kundisch , S. Zimmermann. Analyzing cost and risk interaction effects in it project portfolios. Bank Inform Technol. 2014; 15(1): 8-20.

[14]Kundisch, D. , C. Meier. A new perspective on resource interactions in IT/IS project portfolio selection; 19th European Conference on Information Systems; 2011.

[15]Albano, T. , E. C. Baptista , F. Armellini, et al. Proposal and solution of a mixed-integer nonlinear optimization model that incorporates future preparedness for project portfolio selection. IEEE T Eng Manage. 2021; 68(4): 1014-1026.

[16]Liu, B. , J. Wang , M. Xu, et al. Evaluation of the comprehensive benefit of

various marine exploitation activities in China. Mar Policy. 2020; 116(5): 103924.

[17]Mcleod, F. N. , T. J. Cherrett , T. Bektas, et al. Quantifying environmental and financial benefits of using porters and cycle couriers for last-mile parcel delivery. Transport Res D-Tr E. 2020; 82: 102311.

[18]Sterman, J. D. Business dynamics: system thinking and modeling for a complex world: MIT Sloan School of Management; 2003.

[19]Sayyadi, R. , A. Awasthi. A system dynamics based simulation model to evaluate regulatory policies for sustainable transportation planning. Int J Model Simulat. 2016; 37(1): 25-35.

[20]PMI. The standard for project management and a guide to the project management body of knowledge (PMBOK guide); 2021.

[21]Wang, Z. , M. O. Esangbedo , S. Bai. Project portfolio selection based on multi-project synergy. J Ind Manag Optim. 2021.

[22]Pérez, F. , T. Gómez , R. Caballero, et al. Project portfolio selection and planning with fuzzy constraints. Technol Forecast Soc. 2018; 131: 117-129.

[23]Wang, L. , M. Kunc , J. Li. Project portfolio implementation under uncertainty and interdependencies: A simulation study of behavioural responses. J Oper Rec Soc. 2019; 71(9): 1426-1436.

[24]Tian, Y. , L. Bai , L. Wei, et al. Modeling for project portfolio benefit prediction via a GA-BP neural network. Technol Forecast Soc. 2022; 183: 121939.

[25]Bai, L. , Y. An , Y. Sun. Measurement of Project Portfolio Benefits With a GA-BP Neural Network Group. IEEE T Eng Manage. 2023.

[26]Patanakul, P. , D. Milosevic. The effectiveness in managing a group of multiple projects: Factors of influence and measurement criteria. Int J Proj Manag. 2009; 27(3): 216-233.

[27]Bathallath, S. , A. Smedberg , H. Kjellin. Impediments to effective management of project interdependencies: A study of IT/IS project portfolios. J Electron Commer Or. 2017; 15(2): 16-30.

[28]Schmidt, R. L. A model for R&D project selection with combined benefit, outcome and resource interactions. IEEE T Eng Manage. 1993; 40(4): 403-410.

[29]Lopes, Y. G. , A. D. Almeida. Assessment of synergies for selecting a project portfolio in the petroleum industry based on a multi-attribute utility function. J Petrol Sci Eng. 2015; 126: 131-140.

[30]Hemmatizadeh, M. , E. Mohammadi. Project portfolio selection problem with exponential synergistic effects. J Proj Manage. 2019; 4(3): 241-248.

[31]Forrester, J. W. Industrial dynamics. MIT Press: Cambridge, MA, USA; 1961.

[32]Pargar, F. , J. Kujala , K. Aaltonen, et al. Value creation dynamics in a project alliance. Int J Proj Manag. 2019; 37(5): 716-730.

[33]Lyneis, J. M. , D. N. Ford. System dynamics applied to project management: a survey, assessment, and directions for future research. Syst Dyn Rev. 2007; 23(2-

3): 157-189.

[34]Shafieezadeh, M. , M. Kalantar Hormozi , E. Hassannayebi, et al. A system dynamics simulation model to evaluate project planning policies. Int J Model Simulat. 2019; 40(3): 201-216.

[35]Bayer, S. , K. Eom , N. Sivapragasam, et al. Estimating costs and benefits of stroke management: A population-based simulation model. J Oper Rec Soc. 2020; 72(9): 2122-2134.

[36]Wang, L. , H. W. Tan. Economic analysis of animal husbandry based on system dynamics. Comptu Intel Neurosc. 2022; 2022.

[37]Ding, Z. , M. Zhu , V. W. Y. Tam, et al. A system dynamics-based environmental benefit assessment model of construction waste reduction management at the design and construction stages. J Clean Prod. 2018; 176: 676-692.

[38]Wang, W. , X. You. Benefits analysis of classification of municipal solid waste based on system dynamics. J Clean Prod. 2021; 279: 123686.

[39]Nguyen, T. , S. Cook , V. Ireland. Application of system dynamics to evaluate the social and economic benefits of infrastructure projects. Systems. 2017; 5(2): 29.

[40]Jia, S. Economic, environmental, social, and health benefits of urban traffic emission reduction management strategies: case study of Beijing, China. Sustain Cities Soc. 2021; 67: 102737.

[41]Tang, L. , Y. Yue , X. Xiahou, et al. Research on performance measurement and simulation of civil air defense PPP projects using system dynamics. J Civ Eng Manag. 2021; 27(5): 316-330.

[42]Meng, H. , X. Liu , J. Xing, et al. A method for economic evaluation of predictive maintenance technologies by integrating system dynamics and evolutionary game modelling. Reliab Eng Syst Safe. 2022; 222: 108424.

[43]Wang, Y. F. , B. Li , T. Qin, et al. Probability prediction and cost benefit analysis based on system dynamics. Process Saf Environ. 2018; 114: 271-278.

[44]Martins, J. H. , A. S. Camanho , M. M. Oliveira, et al. A system dynamics model to support the management of artisanal dredge fisheries in the south coast of Portugal. Int T Oper Res. 2015; 22(4): 611-634.

[45]Chaudhary, K. , P. Vrat. Circular economy model of gold recovery from cell phones using system dynamics approach: a case study of India. Environ Dev Sustain. 2018; 22(1): 173-200.

[46]Li, J. , V. Nian , J. Jiao. Diffusion and benefits evaluation of electric vehicles under policy interventions based on a multiagent system dynamics model. Appl Energy. 2022; 309.

[47]Torres, J. P. , M. Kunc , F. O'Brien. Supporting strategy using system dynamics. Eur J Oper Res. 2017; 260(3): 1081-1094.

[48]Kunc, M. H. , J. Morecroft. Resource-Based Strategies and Problem Structuring: Using Resource Maps to Manage Resource Systems. J Oper Rec Soc. 2009; 60(2): 191-199.

[49]Wang, L. , M. Kunc , S.-j. Bai. Realizing value from project implementation under uncertainty: an exploratory study using system dynamics. Int J Proj Manag. 2017; 35(3): 341-352.

[50]Yan, W. , L. Cao. Evaluation of economic benefits of highway PPP projects based on system dynamics. J Civ Eng Manag. 2021; 38(3): 8-14.

[51]Byers, C. , A. Botterud. Additional capacity value from synergy of variable renewable energy and energy storage. IEEE T Sustain Energ. 2019; 11(2): 1106-1109.

[52]Kock, A. , H. G. Gemünden. Project lineage management and project portfolio success. Proj Manag J. 2019; 50(5): 587-601.

[53]Meskendahl, S. The influence of business strategy on project portfolio management and its success — A conceptual framework. Int J Proj Manag. 2010; 28(8): 807-817.

[54]Bilgin, G. , G. Eken , B. Ozyurt, et al. Handling project dependencies in portfolio management; International Conference on Enterprise Information Systems; 2017.

[55]Zhao, J. , P. Guo , W. Zheng, et al. A nonlinear model for portfolio scale decision-making considering project interdependences; IEEE International Conference on Systems, Man and Cybernetics; 2019.

[56]Pianka, E. R. The structure of lizard communities. Annu Rev Ecol Syst. 1973; 4: 53-74.

[57]WIPO. IPC - Technology Concordance Table: Concept of a Technology Classification for Country Comparisons; 2008.

[58]Kádárová, J. , M. Durkáčová , L. Kalafusová. Balanced scorecard as an issue taught in the field of industrial engineering. Proc Soc Behav Sci. 2014; 143: 174-179.

[59]Kaplan, R. , D. Norton. The balanced scorecard: translating strategy into action: Harvard Business School Press; 1996.

[60]Bai, L. , X. Qu , J. Liu, et al. Analysis of factors influencing project portfolio benefits with synergy considerations. Eng Constr Archit Ma. 2022.

[61]Van Wijk, R. , A. Nadolska. Making more of alliance portfolios: The role of alliance portfolio coordination. Eur Manag J. 2020; 38(3): 388-399.

[62]PMI. The standard for portfolio management; 2019.

[63]Saiz, M. , M. A. Lostumbo , A. A. Juan, et al. A clustering - based review on project portfolio optimization methods. Int T Oper Res. 2021; 29(1): 172-199.

[64]Jonas, D. Empowering project portfolio managers: how management involvement impacts project portfolio management performance. Int J Proj Manag. 2010; 28(8): 818-831.

[65]Zarei, E. , N. Khakzad , V. Cozzani, et al. Safety analysis of process systems using Fuzzy Bayesian Network (FBN). J Loss Prevent Proc. 2019; 57: 7-16.

[66]Coroianu, L. Trapezoidal approximations of fuzzy numbers using quadratic programs. Fuzzy Set Syst. 2021; 417: 71-92.

[67]Qi, Z. Y. An Improved Similarity Measure for Generalized Trapezoidal Fuzzy Numbers and Its Application in the Classification of EEG Signals. Int J Fuzzy Syst. 2021; 23(3): 890-905.

[68]Delgado, M. , F. Herrera , E. Herrera-Viedma, et al. Combining numerical and linguistic information in group decision making. Inform Sciences. 1998; 107(1-4): 177-194.

[69]Pagoni, E. G. , G. Patroklos. A system dynamics model for the assessment of national public–private partnership programmes' sustainable performance. Simul Model Pract Th. 2019; 97: 101949.

[70]Magoua, J. J. , F. Wang , N. Li. High level architecture-based framework for modeling interdependent critical infrastructure systems. Simul Model Pract Th. 2022; 118: 102529.

[71]Ecem Yildiz, A. , I. Dikmen , M. Talat Birgonul. Using system dynamics for strategic performance management in construction. J Manage Eng. 2020; 36(2): 04019051.

[72]Barlas, Y. Multiple tests for validation of system dynamics type of simulation models. Eur J Oper Res. 1989; 42(1): 59-87.

[73]Qudrat-Ullah, H. , B. S. Seong. How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. Energ Policy. 2010; 38(5): 2216-2224.

[74]Forrester, J. W. , P. M. Senge. Vol. 14 of Tests for building confidence in system dynamics models: TIMS studies in the management sciences: Amsterdam, Netherlands: North- Holland Publishing Company; 1980.

[75]Jeong, H. , J. Adamowski. A system dynamics based socio-hydrological model for agricultural wastewater reuse at the watershed scale. Agr Water Manage. 2016; 171(Jun): 89-107.

[76]Bai, L. , H. Chen , Q. Gao, et al. Project portfolio selection based on synergy degree of composite system. Soft Comput. 2018; 22(16): 5535-5545.

Technology dimension	Sub indicators
I Electrical engineering	Electrical machinery, apparatus, energy
	Audio-visual technology
	Telecommunications
	Digital communication
	Basic communication processes
	Computer technology
	IT methods for management
	Semiconductors
II Instruments	Optics
	Measurement
	Analysis of biological materials
	Control
	Medical technology
III Chemistry	Organic fine chemistry
	Biotechnology
	Pharmaceuticals
	Macromolecular chemistry, polymers
	Food chemistry
	Basic materials chemistry
	Materials, metallurgy
	Surface technology, coating
	Micro-structure and nano-technology
	Chemical engineering
	Environmental technology
IV Mechanical engineering	Handling
	Machine tools
	Engines, pumps, turbines
	Textile and paper machines
	Other special machines
	Thermal processes and apparatus
	Mechanical elements
	Transport
V Other fields	Furniture, games
	Other consumer goods
	Civil engineering

Appendix B The measurement criteria of project portfolio synergy benefits

Subsystems	Weights	Second indicators	Weights	Third indicators	Weights
Financial benefit	0.31	Profitability	0.75	Portfolio cost	0.5
				Portfolio revenue	0.5
		Solvency	0.25	Total liabilities	0.5
				Total assets	0.5
Stakeholders benefit	0.1	PP customers	0.62	Customer satisfaction	0.32
				Ability to attract and retain customers	0.12
				Quality of product or service	0.56
		PP suppliers	0.14	Supplier delivery rate	0.75
				Supplier renewal rate	0.25
		Government and public	0.24	Response to local policy	0.75
				Attention to public health and safety	0.25
Learning and growth benefit	0.41	Employee professional skills	0.75	Employee training times	0.67
				Employee training rate	0.33
		Process data	0.25	Data preservation integrity	0.67
				Historical experience learning	0.33
Internal process benefit	0.18	Technological factors	0.32	Application of new technologies	0.33
				Technical maturity	0.67
		Tangible resources	0.12	Efficiency of resources utilization	0.67
				Resource productivity	0.33
		Human capital	0.56	Proportion of core talents	0.75
				Employee satisfaction	0.25

Appendix C Synergy degree calculation results

Time	Synergy				
	Type	Projects	$p_{in_{ka}}$	w_{ij}	Degree
1-8	Resource（human）	1	1/(1+1.5-0.3)=0.45	0.93	S_R=0.8
		2	1.5/2.2=0.68		
	Resource（Material）	1	1.5/(1+1.5-0.3)=0.68	0.94	
		2	1/2.2=0.45		
9-11	Technology（Type2）	2	1	1	S_T=0.6
		4	1		
	Technology（Type4）	2	1	1	
		4	0.5		
9-19	Knowledge（Overt）	1	1	1	S_K=0.6
		4	0.3		
	Knowledge（Recessive）	1	0.4	1	
		4	1		
12-24	Outcome（R T）	2	1	0.8	S_O=0.5
		3	0.62		
13-24	Resource（human）	3	1/(1+1.2-0.3)=0.53	0.8	S_R=0.7
		5	1.2/1.9=0.63		
	Resource（Material）	3	1/(1+1.67-0.25)=0.41	0.93	
		5	1.67/2.42=0.69		