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Project portfolio selection problem with exponential synergistic effects

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A B S T R A C T

Project portfolio selection is a major issue in organizations, which involves a complex process from the first step to the end step of project selection. In order to pursue the organizations' financial and physical constraints, choosing the most suitable portfolio of projects is necessary. Organizations have a number of constraints to select a portfolio of projects that must be considered. Different interactions are considered between the proposed projects. For example, resource constraints, the possibility of transferring liquidity resources that are not consumed over a period to the next, the interdependence between projects, and the synergistic impact of the projects are important. In this paper, an exponential function is considered for synergistic impact of the projects that make the problem more similar to the real-world problems. An illustrative example is used to demonstrate the appropriate application of the proposed model.

1. Introduction

A project is a complex effort and a project has to be completed in less than three years. Accomplishment of any project is involved various tasks by different organizations (Archer & Ghasemzadeh, 1999). The portfolio is a collection of projects that either simultaneously or consistently must be considered during a period of time (Schaeffer & Cruz-Reyes, 2016). Companies are dealing with optimization and changes in projects need to have a lucidity to use the project portfolio management (Martinsuo, 2013). The most important factor that companies are competing strongly are the development of a new product, so companies should select the best project portfolio to generate the potential revenue and competitive edge (Wei & Chang, 2011). Usually decision makers select the project baskets with limited information about projects and portfolios (Bastiani, 2013). Primarily portfolio optimization problem was introduced in financial area by Markowitz (1952), which has been the most influence for the majority of financial models designed to provide a solution to the portfolio selection problem (Markowitz, 1952). Nowadays financial portfolio optimization and selection problems are developed increasingly (Mohammadi & Mohammadi, 2018).

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Selecting the best portfolio of the projects is a vital issue among managers and they have to regularly pursue multiple objectives (Doerner, 2004). Every organization needs to decide to select project portfolios through existing projects (Carazo, 2010). Projects in the portfolios must compete through the sponsor for scarce resources such as personnel, finance, time, etc. because there are usually insufficient resources for the proposed project that meet the minimum requirements for certain criteria such as profitability (Rădulescu & Rădulescu, 2001). Many organizations try to choose a set of proposed projects that can meet maximum performance and resource constraints (Roland et al., 2016). The synergy of a project portfolio addresses the benefits from the gains in which are generated when two or more similar projects coexist in the project portfolio. There are two kinds of usual synergies. First is when required facilities are shared among different projects, although these projects might be independent and with their own facilities, but they can be brought together in a project portfolio that lead to synergistic effects. The second kind of synergy is achieving economies of scale by developing two or more projects together.

The problem that arises in the selection and optimization of the project portfolio is that projects may have limited resources and they want additional resources to be transferred over a period of time to the next period and there is interdependence among different projects (Carazo, 2010). In organizations, selecting a subset of projects that satisfies a set of constraints and represents a compromise among various groups of experts plays an important role for the success of the projects (Roland et al., 2016). Effective project selection and employee allocation strategies directly affect organizational profitability (Liu & Liu, 2017). In optimizing portfolio issues, the effects of dependent investment projects are considered in many studies (Rudenko, 2016). In the project portfolios when projects have joint constraints, there are new resources or capacities that go beyond the accumulation of those resources or the capacity that we perceive as synergistic in projects. If we consider the issue of selecting and planning a project portfolio, the resource constraints, interdependence between projects, transferring additional resources from one period to the next, the synergy between projects, the impact of these issues on organizations will be investigated.

2. Modeling the problem

Assume that an organization should choose the best project portfolio from the set of projects. The organization also determines that each project will start on a given planning horizon that is divided into *T* periods.

2.1. Problem Symbols

Sets	
$\boldsymbol{j}$	The proposed project set $1, \mathbf{2}, \dots, \mathbf{J}$.
$\boldsymbol{k}$	Number of available periods
$\boldsymbol{t}$	The time periods $\mathbf{1}, \mathbf{2}, \dots, \mathbf{T}$.
$\boldsymbol{u}$	Number of required resources
$\boldsymbol{n}$	The number of selected project set $\mathbf{1}, \mathbf{2}, \dots, \mathbf{q}$.
$\boldsymbol{w}$	Weights which enable the aggregation of time-related information
Parameters	
$\boldsymbol{m_n}$	The minimum number of active projects for synergy
$\boldsymbol{M_n}$	The maximum number of active projects for synergy
$\boldsymbol{d_j}$	Project duration $\boldsymbol{j}$
$\boldsymbol{bz_k}$	Lower bound for the number of active projects of each period $\boldsymbol{k}$
$\boldsymbol{bb_k}$	Upper bound for the number of active projects of each period $\boldsymbol{k}$
$\boldsymbol{CB_k}$	Coefficient for the number of active projects of each period $\boldsymbol{k}$
$\boldsymbol{\beta z_j}$	Lower bound for the start of the project $\boldsymbol{j}$
$\boldsymbol{\beta b_j}$	Upper bound for the start of the project $\boldsymbol{j}$
$\boldsymbol{v_{j,t}}$	The value coefficient is equal to the amount of the project j for periods $\boldsymbol{t}$
$\boldsymbol{a_{nk}}$	Synergy coefficient to n project set in period $\boldsymbol{k}$

$\boldsymbol{tr_{uk}}$	The transfer rate of the resources to the next period k for the Resources category $\boldsymbol{u}$
$\boldsymbol{SR_{uk}}$	The maximum amount of resources the organization can spend in the $\boldsymbol{k}$ period
$\boldsymbol{r_{j,u,t}}$	The amount of resources $\boldsymbol{u}$ required for Project $\boldsymbol{j}$ for periods $\boldsymbol{k}$
$\boldsymbol{g_{nuk}}$	The resources generated by the synergy set $\boldsymbol{n}$ for resources u in period $\boldsymbol{k}$

Binary variable	
$\boldsymbol{x_{jt}}$	If project $\boldsymbol{j}$ starts at t, 1 otherwise 0
$\boldsymbol{S_k^n(x)}$	If the number of active projects of the set n in period k is between $\boldsymbol{m_n}$ and $\boldsymbol{M_n}$ 1, otherwise 0
$\boldsymbol{S_k^{nm}(x)}$	If the number of active projects in period $\boldsymbol{k}$ is greater than $\boldsymbol{m_n}$ 1, otherwise 0
$\boldsymbol{S_k^{nM}(x)}$	If the number of active projects in period $\boldsymbol{k}$ is lesser than $\boldsymbol{M_n}$ 1 otherwise 0

2.2. Objective function

The organization should evaluate the proposed projects in accordance with a set of features in each period k from the planning horizon; therefore, the objective function is defined as follows:

$$\max \quad \sum_{k=1}^{T} \frac{\left(\sum_{j=1}^{J}\sum_{t=1}^{k} v_{j,k+1-t} \cdot x_{jt} + \sum_{n=1}^{q} S_k^n(x).(a_{nk})^2\right)}{(1+w)^k} \tag{1}$$

The objective function is to maximize the value of the project j at the time t and the synergy between projects n in period k. When we say that synergy is created, it means that several sources or capacities are put together and a new resource or capacity is created that goes beyond the sum of resources or capacities that are extensively $(a_{nk})^2$ considered.

2.3 Constraints

These constraints limit the amount of any kind of resources spent at any point in time. For this purpose, it is essential to know the exact amount of resources needed for each project at any time.

$$\sum_{j=1}^{J}\sum_{t=1}^{k} r_{j,u,k+1-t} . x_{jt} \le SR_{uk} \ , \qquad u \in \{1,2,\dots,U\}, k \in \{1,2,\dots,T\} \tag{2}$$

The amount of resources u that is used for each period k can have a maximum value.

$$\sum_{j=1}^{J}\sum_{t=1}^{k} r_{j,u,k+1-t} . x_{jt} \le SR_{uk} + (1+tr_{uk}).\left(SR_{u,k-1} - \sum_{j=1}^{J}\sum_{t=1}^{k-1} r_{j,u,k-t} . x_{jt}\right) \tag{3}$$

$$u \in \{1,2,\dots,U\}, k \in \{1,2,\dots,T\}$$

Some resources may not be fully utilized during a course and organizations are interested in transferring them to the next period using the relevant transfer rate which is defined as follows:

$$\sum_{j=1}^{J}\left(\sum_{t=1}^{k-1}\left(r_{j,u,k+1-t} + (1+tr_{uk}).r_{i,u,k-t}\right).x_{jt} + r_{j,u,1}.x_{jk} + \sum_{n=q+1}^{\hat{q}} S_k^n(x).g_{nuk} + (1+tr_{uk}).\sum_{j=q+1}^{\hat{q}} S_{k-1}^n(x).g_{n,u,k-1}\right) \le SR_{uk} + (1+tr_{uk}).SR_{u,k-1} \tag{4}$$

$$u \in \{1,2,\dots,U\}, k \in \{1,2,\dots,T\}$$

Moreover, if the synergy between projects is considered, these resources may be affected. For example, this synergy can show that if projects are run simultaneously, several projects may share a specific resource; therefore, a set of independent projects j is created in which the decision maker has a minimum (m_n) and a maximum (M_n) of the project that determines what should be selected for active synergies which is defined as follows:

$$S_k^n(x) = S_k^{nm}(x).S_k^{nM}(x) \tag{5}$$

$$\left(\sum_{J\epsilon A_i}\sum_{t=k-d_j+1}^{k} x_{jt}\right) - m_n + 1 \leq J.S_k^{nm}(x) \leq \left(\sum_{j\epsilon A_i}\sum_{t=k-d_j+1}^{k} x_{jt}\right) - m_n + J \tag{6}$$

$$n = 1,2,\dots,\hat{q}$$

$$M_n - \left(\sum_{j\epsilon A_i}\sum_{t=k-d_j+1}^{k} x_{jt}\right) + 1 \leq J.S_k^{nM}(x) \leq M_n - \left(\sum_{j\epsilon A_i}\sum_{t=k-d_j+1}^{k} x_{jt}\right) + J \tag{7}$$

$$n = 1,2,\dots,\hat{q}$$

These constraints ensure that functions $S_k^n(x)$ can only take the value of 1 if synergy activated between projects. The decision maker may include some of the limitations of active projects in the portfolio for the period k, which is not dependent on their execution time. They are listed in constraint 8:

$$bz_k \leq CB_k.\begin{pmatrix} \sum_{t=k-d_1+1}^{k} x_{1t} \\ \vdots \\ \sum_{t=k-d_J+1}^{k} x_{Jt} \end{pmatrix} \leq bb_k \tag{8}$$

$$k = 1,2,\dots,T$$

This constraint is similar to constraint (8), but not related to that period that is defined as follows:

$$\underline{b} \leq B.\begin{pmatrix} \sum_{t=1}^{T} x_{1t} \\ \vdots \\ \sum_{t=1}^{T} x_{Jt} \end{pmatrix} \leq \overline{b} \tag{9}$$

These constraints ensure that each project only starts once which is defined as follows:

$$\sum_{t=1}^{T} x_{jt} \leq 1. \qquad j = 1,2,\dots,J \tag{10}$$

With regard to the subset F of all projects, these constraints can select certain projects, in selected periods by decision makers which are as follows:

$$\beta z_j.\sum_{t=1}^{T} x_{jt} \leq \sum_{t=1}^{T} t.x_{jt} \leq \beta b_j \qquad j\epsilon F \tag{11}$$

Given a set P_l of past projects for Project l, these constraints ensure that project l cannot be selected if it is not selected in its previous projects which is defined as follows:

$$\sum_{t=1}^{T} x_{it} \geq \sum_{t=1}^{T} x_{lt} \qquad i\epsilon p_l \tag{12}$$

3. Illustrative example

Assume that the organization needs to choose from 10 proposed projects for which they have invested over the past 3 years. The organization's goal is to maximize its expected benefits. Assume that an organization needs 3 types of resources, employee recruitment, advertising, and equipment. If the resources that are used in each course are considered maximal and the resources used in each course are not fully utilized, they will be transferred to a later period with a transitional rate. Let's suppose there are synergies among the proposed projects in the following projects. The value coefficient of project j for period t is shown in Table 1. The number of resources generated by the synergy set n for resources u in period k is shown in Table 2. Table 3 presents the amount of resources u required for Project j for period k. The rate of transfers for the next period k for the resources category u is shown in Table 4. Table 5 demonstrates the number of synergy coefficient to n project set in period k. The minimum and maximum number of active projects n for synergy are shown in Table 6 and finally, the number of weights which enable the aggregation of time-related information are shown in Table 7.

Table 1
Value coefficient project j for period t

$v_{j,t}$		j									
		1	2	3	4	5	6	7	8	9	10
t	1	3	2	2	4	2	3	2	2	3	4
	2	4	2	2	2	3	2	4	3	2	2
	3	4	3	2	4	3	3	3	3	4	2

Table 2
Synergy set n for resources u in period k

g_{nuk}		(n,u)											
		(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	(4,1)	(4,2)	(4,3)
k	1	1	1	2	2	1	1	1	2	2	2	2	2
	2	2	1	2	2	2	2	4	2	0	0	2	2
	3	2	2	2	2	1	2	1	2	2	2	2	2

Table 3
Amount of resources u required for Project j for period k

$r_{j,u,t}$		(j,u)									
		(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	(4,1)
t	1	1	1	2	2	1	2	1	1	1	1
	2	1	1	2	2	1	2	2	2	2	1
	3	2	2	2	2	2	2	1	2	2	1
$r_{j,u,t}$		(j,u)									
		(4,2)	(4,3)	(5,1)	(5,2)	(5,3)	(6,1)	(6,2)	(6,3)	(7,1)	(7,2)
t	1	2	2	2	2	1	1	2	1	1	1
	2	2	1	2	2	2	2	2	2	1	2
	3	1	2	2	2	1	2	1	2	2	1
$r_{j,u,t}$		(j,u)									
		(7,3)	(8,1)	(8,2)	(8,3)	(9,1)	(9,2)	(9,3)	(10,1)	(10,2)	(10,3)
t	1	2	2	1	1	1	2	1	2	1	2
	2	1	2	2	1	2	2	1	1	2	2
	3	2	1	2	2	2	2	2	2	1	1

Table 4
Transfer rate of the resources

tr_{uk}		u		
		1	2	3
k	1	0.991	0.240	0.630
	2	0.111	0.990	0.083
	3	0.047	0.586	0.974

Table 5
Synergy coefficient to n project set in period k

a_{nk}		n			
		1	2	3	4
k	1	2	1	2	1
	2	2	1	1	2
	3	2	1	1	2

Table 6
Min and max number of active projects n for synergy

		$\boldsymbol{n}$			
		1	2	3	4
	M	3	2	3	3
	m	2	2	2	2

Table 7
Weights enabling the aggregation of time-related information

	k		
	1	2	3
w	0.392	0.787	0.761

According to the data presented in Tables 1 to 7, after solving the model with the software Gams, we conclude that starts in the first period of projects 1 and 9, in the second period of projects 2, 4, 5, 7, 10 and in the third period of projects 3, 6 and 8. In addition, of the four project under synergy in the first period of projects 1 and 2, in the second period of projects 1, 3 and 4, in the third period of projects 1, 3 and 4, are between m_n and M_n. By solving the problem, the value of the objective function is equal to 115.21. Table 8 and Table 9 demonstrate the results in detail.

Table 8
The number of active projects of the set j in period k is between m_n and M_n

$\boldsymbol{S_k^n(x)}$		n			
		1	2	3	4
k	1	1	1	0	0
	2	1	0	1	1
	3	1	0	1	1

Table 9
Project j starts at t

$\boldsymbol{x_{jt}}$		$\boldsymbol{j}$									
		1	2	3	4	5	6	7	8	9	10
$\boldsymbol{t}$	1	1	0	0	0	0	0	0	0	1	0
	2	0	1	0	1	1	0	1	0	0	1
	3	0	0	1	0	0	1	0	1	0	0

The results of the exponential synergistic effects in the project portfolio selection problem are such that the objective function shows a better value. This issue is solved regardless of the exponential synergistic effect, and compared with the results of this paper, it is concluded that when the synergy effect is exponentially considered, the value of the objective function increases and better results are obtained.

4. Results and conclusion

Decision makers usually face resource and budget constraints to achieve expected profits, so they have to decide which projects to consider. The purpose of this article was to help decision makers in selecting and planning the project portfolio. In this paper, the selection and planning of the project portfolio, resource constraints, interdependencies between projects, the transfer of additional resources over a period to the next, and the synergy between the projects has been considered. The synergy between projects is that if there is a common constraint between the two projects, this synergy increases exponentially. By solving the model in software Gams, we have concluded that the amount of objective function and interest would be increased. Considering the exponential synergistic effects on the project portfolio selection issues increases the profit of the organization.

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