A Binary Cuckoo Search Algorithm for Solving Project Portfolio Problem with Synergy Considerations

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Abstract: Many companies are moving toward a project-oriented way of managing their businesses while considering the risk of losing the limited available resources because of selecting incorrect projects to be executed. With a number of candidate projects larger than those which can be funded, organizations aim to select projects that maximize benefit and enhance their competitive advantages. These reasons force organizations to search for more effective techniques to improve their decision with project selection. The consideration of synergy between projects is not addressed much in literature. This paper proposes new meta-heuristic technique which is Cuckoo Search Algorithm to solve Project Portfolio Selection problem with synergy among various projects is considered. Four scenarios are experimented on 0 – 1 optimization problem contains two constraints budget and segmentation to show performance algorithm through iterations with changing scenarios in addition to the effect of synergy on projects selection and total benefit for the organization.

1 INTRODUCTION

An organization decision whether to select a project for implementation or not is a crucial decision. Such a decision has a high impact on the organization resources and its benefit. On one hand the organization loses resources which are used in unsuitable projects and, on the other hand, it loses benefit of more suitable projects that could have been implemented instead, to achieve more benefit for organization (Shakhsi-Niaei et al., 2011). This kind of decisions is called Project Portfolio Selection (PPS) in which a set of proposed or candidate projects compete for scarce resources to be implemented and satisfy all constraints. Project Portfolio Selection (PPS) is choosing a group of candidate projects to maximize benefit of organization (Archer and Ghasemzadeh, 1999). Research efforts were exerted in this direction to develop and design models that represent the nature of the PPS problem and to solve it using either simulation techniques or optimization techniques.

PPS problem is classified as complex decision making process due to many factors affecting the decision such as: determining weights of different criteria, performance value for each project in addition to, other qualitative and quantitative factors should be considered in decision making (Güngör and Can, 2011). Careful attention should be given when selecting the set of projects to be implemented, as every organization tries to achieve its conflicting organizational objectives while having a limited amount of resources (Ahn et al., 2010). One of the factors affecting the decision making process concerning the PPS problem is the high level of risk due to uncertainty or incompleteness of information about the problem.

A recent stream of research was proposed to deal with uncertainty in portfolio selection decision. Studies such as (Shakhsi-Niaei et al, 2011) and (George et al., 2013) proposed a two-stage techniques that mainly depend on using Monte Carlo simulation and considering the output of the first stage as input for the second.

Several Evolutionary Algorithms (EA) were used to solve the PPS problem since it is classified as NP-hard and it is difficult to use exact algorithms to solve it. Some of the EA used to solve this kind of problem are Scatter Search Algorithm, Genetic Algorithm (GA), Ant Colony Optimization (ACO) and Cuckoo Search Algorithm (CS). Scatter Search algorithm was introduced in (Carazo et al., 2010) to aid decision maker to select optimal project

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portfolio. The model takes into account interdependencies between projects which are assessed in groups, also the model takes into consideration multiple objectives without taking preferences from decision maker.

Doerner (2004) deployed Ant Colony Optimization to solve multi-objective PPS with limited resources. A modified Pareto Ant Colony Optimization algorithm was introduced by (Tofighian and Naderi, 2015) in order to solve a PPS mixed integer linear programming model to maximize total benefit.

A binary Cuckoo Search Algorithm to solve PPS was proposed by (El-kholany and Abdelsalam, 2015), it considered two types of constraints budget and segmentation constraints. The algorithm results showed that Cuckoo Search was an efficient choice to solve this type of problem compared to Lingo software results. Cuckoo Search Algorithm is new meta-heuristic technique proposed by (Yang and Deb, 2009) to solve combinatorial and NP-Hard problems. This algorithm proved its efficiency for getting solutions better than other heuristics such as Genetic Algorithm and Particle Swarm Optimization (Roy and Sinha Chaudhuri, 2013).

A main factor that affects the Project Portfolio Selection problem is whether or not there is synergy between the projects. Synergy can be defined as the complement between two or more projects that generate additional benefit besides projects' own benefit if executed separately. Synergy is powerful phenomenon to execute projects together to increase benefit with consuming the fewest available resources. A framework of IT portfolio selection was proposed by (Cho and Shaw, 2009) to examine the importance effect of IT synergy. IT synergy was classified into three types several sub additive cost, two-way super-additive and one-way super additive that used index c, tv & ov respectively and effects of different types were examined and concluded that firms with high tolerance and moderate are more likely to obtain IT portfolio than firms with low tolerance. In (Almeida and Duarte, 2011) a binary non-linear decision model was proposed to study the effect of synergy on the PPS decision. ACO is used to solve PPS problem considering synergy and one of its special cases where two or more projects cannot be financially supported in the same time in (Rivera et al., 2013). A framework considering synergy between IT projects on the risk and return of portfolio was proposed in (Cho and Shaw, 2013).

The main focus of this paper is to propose a cuckoo search algorithm to study the effect of synergy between projects on project portfolio selection; considering segmentation and budget constraints. The data used to perform the study and test the algorithm was extracted from (Shakhsi-Niaei et al., 2011) in the case of no synergy used. For synergy case, the interdependencies data matrix was generated hypothetically to study the impact of considering synergy while selecting projects to be implemented.

Following the introduction, the rest of the paper is organized as follows. Section 2 covers the problem formulation as a mathematical model. Followed by the proposed solution algorithm in Section 3. While Section 4 provides the results and numerical analysis of the problem. Finally, conclusions are given in Section 5.

2 PROBLEM DEFINITION AND MATHEMATICAL MODEL

The problem considered here is one of the main problems found in project based organizations. The problem lies in that there is a set of candidate projects that the organization should choose from -to implement- in order to maximize its benefit without violating any constraints. Two main cases are going to be covered of this problem, the first is the effect of executing each project alone on the company's total benefit and other is the synergy effect.

2.1 Project Evaluation

The project evaluation consists of two parts, benefit for each project separately and the second is synergy evaluation were proposed by (Almeida and Duarte, 2011).

Let's assume m candidate projects to be implemented and the evaluation will be based on n criteria. Each project has performance value for each criterion where each project is represented by an array Z_i where each value in the array for example Z_{12}, represents the performance value for project 1 in criterion 2.

$$Z_i = [z_{i1}, z_{i2} \dots z_{in,}] \; \forall \; i = 1,2, \dots m. \quad (1)$$

Performance value for all projects can be represented by Matrix Z, where each row represents project i and each column represents criterion j and Z_{ij} is performance value for project i in criterion j.

$$Z = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \cdots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix} \quad (2)$$

Each criterion is assigned a weight where the summation of these weights should equal to one Equation 3.

$$w = [w_1, w_2, \dots, w_n], where \sum_{i=1}^{n} w_i = 1 \quad (3)$$

For each project, benefit is evaluated by multiplying each criterion with performance value represented by equation (4)

$$b_i = \sum_{j=1}^{n} w_j z_{ij} \; \forall i = 1,2, \dots \dots, m \quad (4)$$

2.2 Synergy Evaluation

To establish measurement for synergy between projects, decision maker determines added value percentage to each project by his experience by joining other projects in the portfolio. Synergy can be evaluated by answering two questions (Damodaran, 2005): (1) what is the form of synergy expected to take? For example, in economic scale, will the synergy reduce cost and increase profit? Or market power, will it increase further growth?
; and (2) when will the synergy effect start?

There are 3 steps to estimate synergy: (1) benefit for each project is estimated separately; (2) the value of the combined projects are evaluated, without synergy by adding values that obtained in first step; and (3) by expecting rate of growth, combined projects with synergy is evaluated and the difference between the value of combined projects without synergy and value of combined projects with synergy provides value of synergy.

Relationships between projects can be changed by changing strategy of company. For example, organization changed its strategy from increasing profit to applying legal projects. Legal Projects can coordinate interactions more effectively than others that increase profit (Cho and Shaw, 2013) as a result of this decision maker increases value percentage for legal projects. Synergy is important feature differs because from other criteria which involves interrelated groups of projects, when whole synergetic group is supported the benefit are bigger than the same group will be applied separately (Rivera et al., 2013). Synergy matrix was developed in matrix (5) to represent synergy between projects.

$$S_{ij} = \begin{bmatrix} s_{11} & \cdots & s_{1m} \\ \vdots & \cdots & \vdots \\ s_{m1} & \cdots & s_{mm} \end{bmatrix} \quad (5)$$

Where s_{ij} is degree of contribution of project j to project i, in percentage value of project i.

2.3 Objective Function

Objective function is to maximize fitness which evaluated by aggregating benefit and synergy evaluation in equation (6).

$$Max\ f = \sum_{i=1}^{m} b_i x_i + \sum_{i=1}^{m} b_i x_i \sum_{j=1}^{m} x_j s_{ij} \quad (6)$$

$$\text{D.V} x_i = \begin{cases} 1 & project\ i\ selected \\ 0 & otherwise \end{cases} \quad (7)$$

2.4 Constraints

There are two types of constraints as mentioned in (Shakhsi-Niaei et al., 2011). The first is budget constraint equation (8), where the implementation cost of all the selected projects cannot exceed the available organizational budget.

$$\sum_{i=1}^{m} c_i x_i \le budget \quad (8)$$

Where c_i is cost of project i to be carried out and budget is total available budget for organization.

The second type of constraints is segmentation constraint, where all the projects are classified into three general categories A, B and C. Each category must achieve specific percentage from all selected projects. Equations (9-11) will represent segmentation constraints.

$$\sum_{Type\ A} x_i \le r1 \sum_{i=1}^{m} x_i \quad (9)$$

$$\sum_{Type\ B} x_i \le r2 \sum_{i=1}^{m} x_i \quad (10)$$

$$\sum_{Type\ C} x_i \le r3 \sum_{i=1}^{m} x_i \quad (11)$$

$r1$,$r2$ and $r3$ are percentage of candidate projects to be achieved for each type.

3 PROPOSED SOLUTION ALGORITHM

3.1 Cuckoo Search Algorithm

Cuckoo Search is new meta-heuristic technique which simulates behaviour of cuckoo bird which is laying its eggs on nest for host bird. Cuckoo Female special way in mimicry colour and pattern of the egg in order to decrease probability of eggs being abandoned and increase reproductively. Cuckoo has skill in the timing of laying eggs by selecting host bird's nest just laid its eggs so, cuckoo eggs hatch earlier than host eggs. Once first child cuckoo is hatched, it moves randomly and throws other eggs for host bird which increases probability of cuckoo to share food with host bird. There are rules applied in algorithm

- Each Cuckoo lays one egg at time and chosen nest to dump its egg randomly.
- Nest with best quality will be remained to next generation.
- Number of nests is fixed, probability of discovering host bird cuckoo egg Pa∈[0,1].

The quality of nests is determined by value of objective function. For maximization problems, nest that achieves maximum value for given objective function will be the best and will continue for next generation. Figure 1 provides pseudo code for Cuckoo Search Algorithm.

3.2 Implementation Step

3.2.1 Solution Representation

Cuckoo Search is a multi solution algorithm, each solution is represented by nest. For the problem at hand, the solution is represented by length M which is total number of candidate projects. Available values for each cell either zero or one. If cell number i assigned to 1 so project i will be selected otherwise project i will not be selected.

3.3 Binary Cuckoo Search

Cuckoo Search is meta-heuristic technique designed to handle continuous variables which are generated between upper and lower bound however, more researcher modified it to handle discrete and binary problems. An improved Cuckoo Search was proposed in (Feng et al., 2014) for solving knapsack problem by converting continuous numbers to binary using sigmoid function as shown in equation 12.

$$y_i = \begin{cases} 1 \; if \; sig(x_i) \geq 0.5 \\ 0 \quad otherwise \end{cases} \tag{12}$$

Where x_i is real nest number i , y_i is binary nest

$$sig(x) = \frac{1}{(1 + e^{-x})}$$

3.4 Handling Constraints

The problem on hand has two types of constraints: budget and segmentation constraints. Two methods were applied to handle these kinds of constraints. Greedy Transform Method (GTM) was proposed to handle the budget constraint as applied in (Feng et al., 2014), this function depends on calculating efficiency for each decision variables by dividing benefit by cost and select most efficient decision variable as long as constraint is satisfied. Segmentation handling was proposed by (El-kholany and Abdelsalam, 2015) to handle second type of constraints.

3.5 Generation New Solution and Stopping Criteria

Two ways are applied to generate new solution. Lévy flight distribution represented in equation 13 is used to generate new solution. The other way was proposed by (Feng et al., 2014) and replaced by function of discovering host bird for cuckoo eggs in its own nest. Algorithm stopped when it reaches to predefined maximum number of iterations.

begin
objective function $f(x) = (x_1, x_2, \ldots\ldots\ldots, x_d)^T$
Generate initial population of n host nests $x_i = (i = 1, 2, \ldots\ldots\ldots, n)$
while(t ≤ MaxGeneration) or (stopping criterion)
  Get a cuckoo randomly by Levy flights its quality/fitness
  $x_i^{(t+1)} = x_i^t + \alpha \oplus levy(\lambda)$
  choose a nest among n (say, j) randomly
  if($F_i \geq F_j$)
    replace j by the new solution;
  end if
  A fraction (p_a) of worse nests are abandoned and new ones are built;
  Keep the best solutions (or nests with quality solutions);
  Rank the solutins and find the current best
  t = t + 1
end
end

Figure 1: Cuckoo Search Algorithm.

$$x_i^{(t+1)} = x_i^t + \alpha \oplus l\acute{e}vy(\lambda) \quad (13)$$

Where

$x_i^{(t+1)}$ is solution for next generation

$x_i^{(t)}$ is solution in current generation

α is transition probability where α>0

lévy (λ) is random walk based on lévy flights.

4 NUMERICAL ANALYSIS

4.1 Case and Data

Data taken from (Shakhsi-Niaei et al., 2011) was used to test the proposed algorithm. The data used as it is in case of no synergy between projects. The data used was deterministic data in the purpose of simplicity. While for synergy case, the interdependencies data matrix was generated hypothetically to study the impact of considering synergy while selecting projects to be implemented. The extracted data covers information about 20 candidate projects in R&D department, only a set of them should be chosen based on 5 different criteria as follows:

1. Cost: Total cost is required to complete selected project.
2. Proposed Methodology: efficiency level of project planning and discipline.
3. Abilities of personnel: level of experience for project team that is assigned for proposed project.
4. Scientific and actual capability: level of education and scientific degree for team and scientific degree.
5. Technical capability: ability for providing technical facilities.

As mentioned in equations (9-11) Basic, Developing and Applied are three categories represented in case of research centre in Iran, total available budget is 6000 $ r1, r2 and r3 equal 10%, 30% and 60% respectively and project types have been mentioned in (14-16). For example, Project 2, 5 and 1 are of Basic, Developing and Applied.

$$x_2 + x_7 + x_9 + x_{12} + x_{13} + x_{14} + x_{17} \leq 0.1 \sum_{i=1}^{m} x_i \quad (14)$$

$$x_5 + x_8 + x_{15} + x_{19} \leq 0.3 \sum_{i=1}^{m} x_i \quad (15)$$

$$x_1 + x_3 + x_4 + x_6 + x_{10} + x_{11} + x_{16} + x_{18} + x_{20} \leq 0.6 \sum_{i=1}^{m} x_i \quad (16)$$

Table 1: Synergy Matrix for Scenario 2.

Projects	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		0.0129	0.0047	0.0182	0.02	0	0.004	0	0.0082	0.0171	0.003	0.011	0	0.0142	0.009	0.001	0.0033	0	0.014	0.003
2			0	0.016	0.0171	0.0029	0.0014	0.0182	0	0.0084	0.0023	0.01	0.0071	0.005	0.0012	0.0213	0.007	0.0017	0	0
3				0.0124	0.0143	0	0.0092	0	0	0.0114	0.0023	0.01	0.0092	0.0045	0.0011	0.0033	0.0029	0.0045	0.022	0.011
4					0.014	0.0061	0.0005	0.0037	0	0.0042	0.0071	0.005	0.0029	0	0.006	0.0291	0.0173	0.003	0	0.0198
5						0.0058	0.0092	0.0058	0	0.0171	0.0419	0.0582	0	0.0044	0.0017	0	0.0631	0.0592	0.0193	0.0839
6							0	0	0.0066	0.0075	0	0.0391	0.0637	0.0039	0	0.0553	0.0794	0.0502	0.0836	0
7								0.0197	0	0	0.0374	0	0.0485	0.031	0.0847	0.045	0	0.0379	0.0883	0.008
8									0.0067	0.0187	0.0384	0.0182	0	0.01	0.0375	0.0274	0.0172	0	0	0.0374
9										0.0182	0	0.0379	0.0576	0.0937	0.0465	0	0.0917	0.0178	0.0112	0.0435
10											0.0176	0.0735	0	0.0818	0	0.0716	0.0183	0.0993	0	0.0375
11												0.0485	0	0.0373	0.0222	0.0188	0	0.0991	0.0737	0.0736
12													0.0118	0.0775	0	0.0884	0.0223	0	0.0919	0.0636
13														0.0226	0	0	0.0732	0.0335	0	0
14															0.0885	0.05	0	0.0449	0.0782	0
15																0	29	0	0.0924	0.0394
16																	0.0592	0	0.734	0
17																		0.304	0	0.055
18																			0.0088	0
19																				0.0021
20																				

Four different scenarios were applied to test how synergy affects project selection and the company total benefit:

- Scenario 1 is characterized based on absence of synergy between projects.

Scenario 2 is applied based on synergy between all projects together that shown in

- Table 1which assigned based on experts.
- Scenario 3 only project 4 receives synergistically from other projects.
- Project 18 only contributes synergistically for all other projects in scenario 4.

4.2 Numerical Results

In Table 2 represents the results of applying the proposed cuckoo search on the extracted data for the previously mentioned scenarios. The first column of the table is the scenario number; the second is the set of projects selected, while the third represents the total benefit from implementing the selected portfolio. The fourth column shows the synergy gained which was calculated by equation 17 and finally the total cost of the selected portfolio in the fifth column.

$$SG = \frac{\sum_{i=1}^{m}\left(b_i x_i \sum_{j=1}^{m} x_j s_{ij}\right)}{\sum_{i=1}^{m}\left(x_i \sum_{j=1}^{n} w_j z_{ij}\right)} \quad (17)$$

In the first scenario, it is observed that the projects selected are those with greatest overall evaluations where synergy between projects wasn't taken into consideration. However, when synergy was considered in scenario 2, project 11 and project 12 is more attractive than projects 3 and13 respectively, because synergy gain provided by project 11 is 0.2993 that's greater than synergy gain provided by project 3 0.0603, on the other hand project 12 is more attractive than project 13. In scenario 3 synergy between projects are cancelled but only project 4 receives synergistically from all projects which it makes it more attractive project to be selected than project 20 which are in type C.

Total benefit increases to 634.298 with increase of 7%. In scenario 4, project 18 contributes synergistically for all other projects, it entered to portfolio instead of project 20 which are in type C and total benefit increased to 652.423 with 5.8%.

As shown figures 2 – 4 show solution progress through 100 iterations for scenarios 2 – 4 and observed that in scenario 2, algorithm got total benefit 820.01 which is highest value reached at iteration number 25. On the other hand, scenario 3 takes more time to find maximum solution reached -Iteration number 41-. Finally, scenario 4 got value of objective function 652.423 at iteration 65.

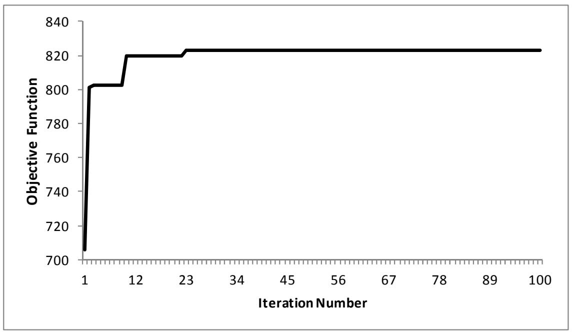

Figure 2: Solution Improvement with iteration - Scenario 2.

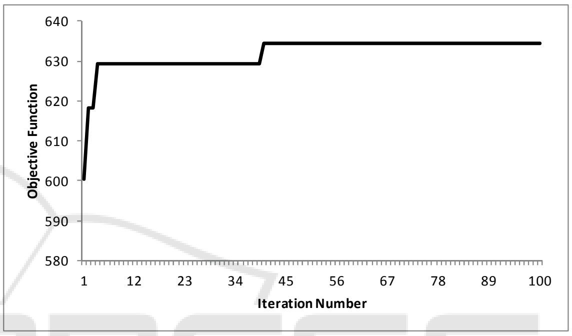

Figure 3: Solution Improvement with iteration - Scenario 3.

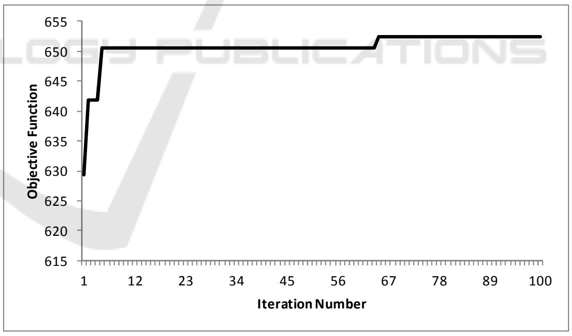

Figure 4:Solution Improvement with iteration - Scenario 4.

5 CONCLUSIONS

The model developed studied the synergy between projects and provides multi criteria approach for project portfolio selection. Cuckoo Search algorithm was proposed to solve the problem considering synergy relations between projects which were represented by a matrix. This matrix should be

Table 2: Scenario Results.

Scenario	Portfolio Selected	Total Benefit	Synergy Gain	Total Cost
1	P1 P3 P5 P6 P10 P13 P15 P16 P19 P20	629.28	0	2928
2	P1 P5 P6 P10 P11 P12 P15 P16 P19 P20	820.01	38. 65 %	2896.5
3	P1 P3 P4 P5 P6 P8 P13 P15 P16 P18	634.29	7 %	2947.5
4	P1 P3 P5 P6 P10 P13 P15 P16 P18 P19	652.42	5. 87 %	2949.5

supported by experts or decision makers in order to be accurate. The solved problem had two types of constraints: budget and segmentation that were handled using GTM and Segmentation handling respectively. Results obtained illustrate the importance of applying synergy between projects on the company's total benefit and the portfolio selection process. There are several ways to extend our work is to deal with synergy between groups of projects in addition to, investigating other types of Objective functions that also calculate synergy and considering synergy with multi-objective problems.

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