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Multi-criteria approach to project portfolio selection considering structural hardness and correlations between projects

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Abstract

Project portfolio selection is one of the important subjects for decision-makers' in project-based organizations. As financing projects with low benefit is just wasting the valuable resources, the best assignment of resources to the most appropriate projects is a necessary target for all project-based organizations. However, existing project selection models pay not much attention the structure and special features of projects as a selection criterion, while their hardness may prolong the project duration and even result in stopping the project. Furthermore, the models don't consider the correlations between projects which may affect the results. In this paper, a model is proposed to measure the structural hardness of projects. Then, a project portfolio selection model is proposed considering hardness and correlations between projects. A case study is presented to test the performance of the model in real world problems. At the end, some large-sized numerical example has been solved. The results show the capability of the model to solve large-sized problems in a suitable time. The important roles of structural hardness in project selection are discussed and sensitivity analysis has been done.

Keywords: Project portfolio, structural hardness, correlation, project-based organization, decision makers

1- Introduction

In today's competitive environment, the major effort of organizations is to produce products with a lower cost and a better quality. In order to do so, organizations should find projects to reduce their cost, improve their quality and so on. In this way, project portfolio selection is to select a suitable set of projects among other available projects and assign the limited resources of organization such as human resource, time, budget and equipment to these projects (Shakhsi-Niae et al., 2014)

Project portfolio selection has received ever-growing attention in recent years and plays an important role for project-based organizations such as public construction projects or private sector projects. In the other words, project selection is one of the most important tasks of managers in project-based organizations.

According to the literature review, discussed in Section 2, there are many models for modeling and solving the project selection problem. The main research gaps can be summarized as below:

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- There may be some correlations between some of projects and selecting two projects concurrently may affect positive or negatively to others. This phenomenon was neglected in most of the related papers.
- Projects have various level of structural hardness and this can affect the implementation of projects. In the other words, most of the papers just paid attention to financial matters in project portfolio selection and neglected structural hardness of projects in portfolio selection.
- There are some constraints in real-world that has been neglected in many literature researches including segmentation and budgetary constraints. Ignoring these constraints may decrease the quality of the model for using in real-world problems.

In this paper, we aim to propose a model which considers projects correlations, structural hardness of projects and also some real-life constraints in order to help Decision Makers (DMs) to select the best portfolio of projects considering their organization's objectives.

Briefly, the main contributions of the paper can be summarized as follows:

- Considering the correlations between projects by a practical formulation
- Defining "structural hardness of projects" as a new concept in projects
- Proposing a project portfolio selection model considering structural hardness
- Considering real world constraints such as segmentations and budgetary constraints
- Proposing an approach for solving multi-objective project selection model
- Demonstrating the usefulness and feasibility of the approach in large-scale (real-world) problems.

In order to do so, the rest of the paper is organized as follows. Section 2 is literature review. Section 3 discusses the correlations between projects. Section 4 presents definition of structural hardness of project and propose the process to measure this factor. Part 5 describes notations, basic model and also some constraints of practical real-world constraints. An approach for solving the multi-objective model using augmented e-constraint method and also a case study is described and solved in part 6. Computational burden and sensitivity analysis is presented in part 7 and finally, part 8 concludes the paper.

2-Literature review

Project portfolio selection is a very important task of managers especially in project-based organizations. Project selection has been a hard and strategic decision for organizations since it has been always faced some problems like variable criteria which may be in conflict with each other. DMs should select some of the most profitable projects between the alternatives considering some features of the project's efficiency (Mavrotas et al., 2008).Project selection process assigns limited resources to a set of projects considering the goals of the organization (Medaglia et al., 2007).Inappropriate decisions in project selection can bring harmful results for the organization. First, resources are used on unsuitable projects and the organization loses the benefits it could gain if these resources had been spent on more suitable projects (Martino, 1995). Since project selection has been a challenging topic for the DMs, many methods and criteria have been presented for selecting the best portfolio of projects (Iamratanakul et al., 2008).

Sefair et al. (2017) proposed a linear solution schemes for mean-semi variance project portfolio selection problem and applied the model in the oil and gas industry. Fliender and Liesio (2016) presented an adjustable robustness for multi-attribute project portfolio selection. The approach accounts for dependencies among project scores and uncertainty in portfolio constraint. They applied the proposed approach to supply chain management in the semiconductor industry. Namazian and Haji Yakhchali (2016) modeled and solved project portfolio and contractor selection problem based on project scheduling under uncertainty. They tested the model and solving approach by some numerical examples and the results showed the validity of the proposed model. Nasr Esfahani et al. (2016) presented a project portfolio selection model using the problem by Harmony search algorithm and modern portfolio theory. Results showed that the proposed algorithm solves the hard problem to nearly optimality faster and more robust than the exact algorithms. Tavana et al. (2015) presented a fuzzy hybrid project portfolio selection method using data envelopment analysis, TOPSIS and integer programming. They proposed a three-stage hybrid method to select an optimal combination of projects. Data envelopment analysis was used to screen the available projects, TOPSIS was used to rank the potentially promising projects and linear integer programming was used to select the most suitable project portfolio. Arraita et al. (2016) proposed a static R&D project portfolio selection in public organizations. They proposed a multi-objective model framework where projects are sets of tasks and the model framework includes synergies between tasks or projects. Yang et al. (2011) have defined 32 criteria in order to analyzing all alternative projects. He classified these criteria into three major factors including critical, quantitative and qualitative factors and weighted them based on the importance of each factor. Badri Masood et al. (2001) proposed a binary goal programming models for project selection. They considered some factors that influence the decision to select a project. These factors were DMs' preferences and priorities, risks, costs and the availability of other resources. Rabbani et al. (2010) present a multi-objective model with three objectives: minimizing the total risk, maximizing the total benefit and minimizing the total cost. They propose a new approach for solving this multi-objective problem. Liesio and salo (2012) present a model for a condition that the DM has some barriers to gather the information about risks or scenario probabilities and they also consider the effect of exogenous uncertainties factors such as rate of industry growth on the project selection. Ghapanchi et al. (2012) consider project interdependencies as fuzzy variables, and model the interdependencies among projects by linguistic variables. Then they use data envelopment analysis to select portfolio of projects. Han et al. (2004) proposed a multi criteria financial portfolio risk management for international projects. They focused on financial portfolio risk management for international projects to integrate the risk hierarchy of each project and also and also at the corporate level.

In literature, many project selection methods concentrated on quantitative and financial tools such as NPV, discounted cash flow, rate of return or payback period (Liberatore, 1987). Since these approaches ignore some crucial factors that may influence the portfolio selection and don't prepare a useful approach to mix all relevant criteria into a unique model, they can't be an ideal solution for project selection problems (Brewer et al., 1993). So, multi-criteria ranking methods are employed widely to enhance project selection. These methods are used to rank projects considering to each of the objectives. Each objective has a weight and each project is scored with respect to the objectives.

As a summary, there have been some approaches and models for project selection. Benefit measurement approaches including comparative models (Ghorbal-Blal, 2011), scoring models (Nelson, 1986) and AHP models (Anagnostopoulos and Petalas, 2011). Another approach is mathematical programming such as robust multi-objective optimization (Hassanzadeh et al., 2014), constraint programming (Liu and Wang, 2011), Linrae and nonlinear programming models (Asher, 1962; Blanning, 1981), Integer and Goal programming models (Paolini and Glaser, 1977; Winkofsky et al., 1981), Dynamic programming models (Souder and Mandakovic, 1986), and Fuzzy mathematical models (Weber et al., 1990). Cognitive emulation is another common approach in literature that includes some models such as Decision-tree models (Martino, 1995), Game-theorical (Grossman and Shapiro, 1987), Group decision making techniques (Khorramshahgol et al., 1988) and Expert systems (Liberatore and Stylianou, 1993). Simulation and Heuristics are other common approaches for project selection. Monte Carlo simulation (Shakhsi-Niaei et al., 2011), System dynamic simulation (Fox and Baker, 1985) and conceptual mixed methods are some of models of simulation and heuristics approach. Another approach used in literature is real options analysis that includes active decision making considering uncertainty (Luehrman, 1998) and case-based reasoning (Mousavi, 2013).

To the best of our knowledge, until now, there hasn't any research that considered structural hardness of projects as a criterion in the project selection process. In this paper, we propose a multi-objective model which considers structural hardness of projects and also correlations between projects as two important factors in project portfolio selection. In order to do so, the main objectives and novelties of the paper are to:

1. Defining structural hardness of projects,
2. Specifying the elements and dimensions of structural hardness of projects,
3. Proposing a mathematical model for measuring structural hardness and,
4. Proposing a new portfolio selection model considering structural hardness, correlations between projects and some new real-world constraints.

3- Problem statement

In each planning horizon, project-based organizations may offered many alternative projects in order to select between them. Each organization has limited resources and it should allocate its resources to the best portfolio of projects which maximize its benefits. In order to select the best project portfolio selection, many mathematical models have been proposed in the literature which paid attention to the problem from a specific view. However, there are some important factors that may affect the portfolio selection and ignoring these factors may decrease the quality of the proposed model.

One of those most important factors is correlations and synergies between projects which can crucially affect the success of a project. In the other words, here may be some correlations between some of the projects and concurrent selection of those projects may have a negative or positive effect on the performance of projects.

One of the other important factors in project portfolio selection is structural hardness of projects which can affect the implementation of projects. Structural hardness can make the progress of a project with a lot of unpredictable boundaries and it should be measured and exactly planned before the start of a project.

In the following sections of the paper, the definition of correlations between projects is defined clearly and then we define the phenomenon of structural hardness of projects and the present a mathematical formulation for measuring structural hardness of projects. Finally, a new project portfolio selection model considering correlations and structural hardness of projects is proposed. After proposing the model, an approach is proposed for solving this multi-objective problem and then shows the feasibility of the model and approach by solving numerical examples.

4- Correlations between projects

In most of the literature researches in portfolio selection, set of projects selected as portfolio considered being static. In the other words, they seemed to have no correlations or interactive between projects of portfolio. But it is clear that projects are not a rigid phenomenon and there may be some correlations between projects. For example, two (or more) projects may have the same preliminary studies and researches for a project can be used for other projects (positive correlation). Another positive correlation which mentioned by Shakhsi-Niaei et al. (2014) is the case of ISO. In implementing ISO 9001 and ISO1 4001 systems at the same time, since the determining and the mapping processes of the organization are the same, the total efforts will be decreased and there will be a reduction in the time and cost. On the other hand, there may be a negative interactive between projects. For example, if two (or more) projects which are alternatives for selecting as portfolio of projects and needs the same resources which is limited, selection of these projects simultaneously may have negative effects on the total risk, time, cost and other features of projects.

As a summary, if performing a project has a negative or positive effect on other projects, there is a correlation between these projects. These effects may include the correlation on resources, time, quality, risk and so on. In this way, correlations and coefficients between alternative projects which may be selected as portfolio of projects should be determined before deciding on selection of projects.

Yu et al. (2010) defined correlation effects as a function of the number of selected projects. In this way, they defined $d_j\ (S_k)$ as additional effects if the portfolio of projects contains a combination of at least k projects. The multiplication index of $\prod_{i=1}^{L} x_i$ is set from 1 to L for all various correlation sets, S_k. In this way, the correlation effect $d_j\ (S_k)$ is applied when all projects 1 to L are selected in portfolio of projects, which is not logical (Shakhsi-Niaei et al., 2014). For example, consider the portfolio set include all projects 2 to N. If project 1 is not selected, no interactive effect will be incorporated, although N-1 projects are selected. This way of modeling correlations is not logical in practical cases, since the correlations usually happens when a set of projects are selected at the same time, not when the number of selected projects increase. In this paper, we define the correlation effects as a parameter, $\mathrm{d_{ikj}}$. In this way, $\mathrm{d_{ikj}}$ refer to Positive or negative interactive effect on factor j if projects i and k are both selected $(y_i = 1, y_k = 1)$.So correlations between projects in portfolio selection are considered in objective function as: $Min\ Z = \sum_{i=1}^{n} \sum_{k \neq i}^{n} \sum_{j=1}^{n} W_j\, \mathrm{d}_{ikj} y_i y_k$.

5- Structural hardness of project

In this paper, structural hardness of project is considered as an important factor in project portfolio selection. In order to propose a model for measuring the structural hardness, a comprehensive understanding of this concept should be presented. Structural hardness of project is" The properties, features and elements of project that makes its implementation difficult and faces the project building process with hardness". The main fact here is the difficulty of implementation of project. Now, the question here is that what cause this difficulty and hardness? In the other words, what are the factors that make the implementation of projects hard? To answer to these questions, factors and sub-factors of structural hardness of project should be determined.

After researches in books, papers, projects and consultation with some of experts in project management, we conclude a unique definition. In this way, we define structural hardness of projects can be defined as below:

If a project contains multiple and various elements which are dependent to each other and cannot be easily separated, the structure of the project is hard to be implemented.

Based on this definition, it can be concerned that structural hardness is something more than risks, uncertainties or multiplicity of projects. Structural hardness of project is related to 3 principal factors: multiplicity of elements, variety of elements and interdependencies between elements of projects. Multiplicity refers to a property of a project that contains many elements and parameters. Variety means that a project has elements that are various and are not the same and homogenous. Inter-dependency refers to a property of project that the elements of it are dependent to each other and cannot be implement separately.

Figure 1 shows the factors effective on structural hardness of projects.

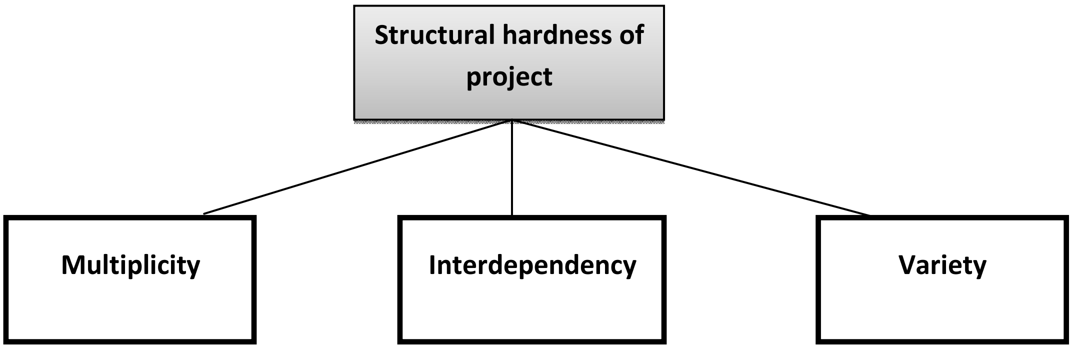

Figure 1. Factors effective on structural hardness of project

5-1- Steps to present a model for measuring structural hardness of project

Now that a comprehensive definition of structural hardness of project is presented, we aim to present a model for measuring this important phenomenon. In order to do so, the following steps show the process to find this model.

5-1-1- Determining the most important factors and their weights

This step has been done via the following sub-steps:

a) Identifying the factors that affect the structural hardness of projects

In order to determine the factors that are related to various complexity features, a complete and comprehensive study on related papers, documents of several projects and also a survey among different experts in the field of project management has been done. After the great studies, a comprehensive list including 44 factors is extracted. As shown in table 1, among this list, 22 factors are related to multiplicity, 9 related to variety, and 13 related to interdependency.

Also there may be some additional factors related to structural hardness of projects, we try to gather the maximum factors which was possible and are the most important. Also it should be mentioned that the factors list should be shortened for 2 reasons: 1. A model with at least 44 parameters and also some constraints and variables is very hard to solve, 2. Data gathering would be very difficult. In this way, some additional works is necessary in order to decrease these factors and determine the most important factors and related weights.

b) Identifying the factors with the most effect on structural hardness and their weight

In order to shorten the list of structural hardness factors, a survey via a questionnaire has been done. Questionnaire is one of the most relevant methods of survey and research that can be used in different methods. Although the questionnaire methods and the selected sample sizes are different in the literature; a group of 9 to 18 experts is recommended (Sackman, 1974). Okoli and Pawlowski (2004) recommended that an expert classification should be done before sending the questionnaires to them. Skulmoski et al. (2007) recommended different features for the participants selected in the survey such as:

- Be expert in the field of issue (at least 10 years useful work in the related field),
- Have sufficient time, capacity and enthusiasm to practice,
- Have good communication skills.

In our study, 5 academic and 5 professional experts who have managed many projects during their profession have participated. First, a brief definition of the topic was presented to them and then, they were asked to answer two questions about each factor: 1. Is the factor important on project structural hardness, and 2. Assign a number between "0 to 10" to each factor as its importance score.

After the arranged time, the questionnaire sheets were gathered from experts and were carefully analyzed with SPSS software. In order to have good results, reliability and validity of questionnaire should be analyzed. In order to test the reliability of the questionnaire, two approaches were used: Split-half method and internal consistency. In split-half method, correlations between scores of two tests were 0.735. Therefore, reliability of the questionnaire can be calculated as follow: 2*0.765/ (1+0.765) = 0.867. On the other hands, for reliability test by internal consistency method, we consider three subsets of questions and calculate the variances related to each subset and the total questionnaires. After all, Cronbach's alpha of the questionnaire was 0.943. Using these two reliability factors, the reliability of the questionnaire is proved. For validity of the questionnaire, three factors of multiplicity, variety and inter-dependencies qualified a high amount of total variance and therefore are three important and effective factors. In analyzing content validity, validity coefficient factor was 0.918. As a summary, reliability and validity of the questionnaire are logical and at a standard level. So, we can rely on results came out from the questionnaire.

After all, 10 factors which had the highest scores of experts are selected. Table 1 shows the final 10 factors mostly effective on structural hardness of projects and their weights. Between these 10 factors, 4 factors are related to inter-dependency, 5 for multiplicity and 1 related to variety.

Note 1. In column 3 of the below table, we used numbers 1, 2, 3 for showing multiplicity, variety and interdependency factors respectively.

Note 2. In column 5 of the below table, the weights of each factor on structural hardness of project is shown. Just 10 factors have considerable importance and for the other factors which have little weights, we use – (means 0) as weight.

Table1. The most important factors and their weights

Row	Factor	Type	Total score	Weight
1	Team cooperation and communication between staffs	3	77	0.111
2	Number of decision makers	1	74	0.106
3	Number of Projects should share with them	1	72	0.104
4	Number of activities for projects	1	71.5	0.103
5	Variety of technologies	2	70	0.100
6	Access to human and resources	3	70	0.100
7	Interdependencies with other projects of organization	3	68	0.098
8	Interdependencies with environment	3	66	0.095
9	Number of components	1	64	0.092
10	Interdependencies between activities	1	62.5	0.091
11	Number of beneficiaries and influential	1	55	-
12	Dependencies between managers	3	55	-
13	Number of groups in project	1	54.5	-
14	Number of departments involved	1	53.5	-
15	Interdependencies with suppliers	3	53	-
16	Number of managers	1	52	-
17	Variety of projects doing in organization	2	51	-
18	Variety of skills needed	2	51	-
19	Number of deliveries	1	50	-
20	Number of goals of project	1	49.5	-
21	Number of information systems	1	49	-
22	Number of suppliers	1	49	-
23	Number of hierarchical levels in organization	1	49	-
24	Feedback loops in project graph	1	48.5	-
25	Interdependencies between phases of projects	3	48	-
26	Organizational depend	3	48	-
27	Variety of components	3	46	-
28	Amount of resources used in project	1	46	-
29	Time duration of the project	1	45	-
30	Number of staffs	1	44.5	-
31	Number of phases of the project	1	44	-
32	Number of decisions should make	1	43.5	-
33	Number of skills needed	1	43	-
34	Variety of information systems	2	42.5	-
35	Dependencies between goals	3	42.5	-
36	Variety of financial resources	2	41	-
37	Dependencies between information systems	3	38.5	-
38	Number of investors	1	38.2	-
39	Largeness of investment	1	37	-
40	Dependencies between staffs	3	35	-
41	Variety of interests of investors	2	30	-
42	Number of stakeholders	1	28	-
43	Variety of project management tools	2	27.5	-
44	Variety of staff nationality	2	26.5	-

5-1-2- Defining measurement scales for the selected factors

Now that the most important factors effective on structural hardness of projects and also their weight are determined, a measurement scale should be designed for different levels of each factor. In order to do so, some meetings were held with five leading project management experts who had at least 10 years of international experience. Each expert had good communication skills, great executive experiences, academic backward in project management and also enthusiasm for academic researches. Table 2 shows the defined scales for each of 10 factors.

Table2. Scales for measuring project structural hardness factors

Factor	Scales		
	0	0.5	1
1. Team cooperation and communication between staffs	Good	Medium	Low
2. Number of decision makers	Not greater than 3	4 or 5	More than 5
3. Number of projects should share with	Not greater than 5	6to10	More than 10
4. Number of activities for project	Less than 100	Between 100 and 200	More than 200
5. Variety of technologies	Less than 10	Between 10 and 20	More than 20
6. Access to human and resources	High access	Medium	Low access
7. Interdependencies with other projects of organization	Low	Medium	High
8. Interdependencies with environment	There is no or very low interdependencies	Partial dependencies	Total interdependencies
9. Number of components	Less than 50	Between 50 and 200	More than 200
10. Dependencies between activities	There is no or very low interdependencies	Partial dependencies	Total interdependencies

6- Portfolio selection considering correlations and structural hardness

Indexes, parameters and also variables used in the model are as follow:

Indexes:

i,k: Projects

j: Factors

Parameters:

W_j: Weight of factor j

NPV_i: Net present value of project i

d_{ikj}: Positive or negative interactive effect on factor j if projects i and k are both selected

C_i: Budget needed for project i

S_{ij}: Score of project i in factor j

B: Total budget of organization

BR: Minimum preferred rate of budget consumption

Variables:

y_i: binary variable representing selection/not selection of project i

yy_{ik}: binary variable representing selection/not selection of projects i and k simultaneously

z_1: Net present value of the selected projects

z_2: Total structural hardness of the selected projects

The primary portfolio selection model considering structural hardness and correlations between projects is formulated as follows.

$$Max\ z_1 = \sum_{i=1}^{n} y_i\ NPV_i \tag{1}$$

$$Min\ z_2 = \sum_{i=1}^{n}\sum_{j=1}^{m} W_j\, S_{ij} y_i + \sum_{i=1}^{n}\sum_{k\neq i}^{n}\sum_{j=1}^{m} W_j\, d_{ikj} y_i y_k \tag{2}$$

Subject to:

$$\sum_{i=1}^{n} y_i\, C_i \ \leq B \tag{3}$$

$$\sum_{i=1}^{n} y_i\, C_i \ \geq B.BR \tag{4}$$

$$y_i, y_k \in [0, 1] \tag{5}$$

Objective function (1) maximizes total NPV returned by total projects selected as portfolio. Objective function (2) minimizes total structural hardness of projects and also negative correlations between projects of portfolio. Equation (3) restricts the expenditures to the determined budget. In many organizations, there is an implicit rule which the organization should spend at least a specific percent of its current budget in order to receive the same amount in the next year from the related ministry. Or in another way, there is a force for organizations to complete a specific percent of project construction during a period. In this way, equation (4) enforces that *BR* percent of the budget should be spent for the projects. The multiplication of y_i and y_k, as two variables, makes the model non-linear which may result in non-optimal solutions. So, the model is mapped into a linear model via defining a new variable yy_{ik} which is equal to 1 if both projects i and k are selected, 0 otherwise. In addition to the mentioned variable exchange, equations (6)-(8) should be added to the model in order to formulate the structural relation between the exchanged variables.

$$yy_{ik} \leq \ y_i\,, \forall i, k \tag{6}$$

$$yy_{ik} \leq \ y_k\,, \quad \forall i, k \tag{7}$$

$$yy_{ik} \geq y_i \ + y_k \ - 1\,,\ \forall i, k \tag{8}$$

It should be mentioned that if there is interactive between three or even more number of projects, the positive or negative correlations can be considered easily by adding one or more index(s) to parameter d_{ikj}. Moreover, the equations (6-8) should be changed in order to cover the new index.

7-Case study

In order to show the mechanism and application of the proposed model, a case study related to a project-based organization is presented here. The organization is worked on research-based projects and has a good experience in doing national and international projects. The organization is expert in three types of research-based projects: X, Y, and Z. once, the organization was provided several projects by a ministry and should decide to select some of the alternative projects between 50 of the proposed projects. In this way, the organization invited some experts to choose the best portfolio of projects considering structural hardness of projects.

The organization has an annual budget of 10000 million Toomans (Iranian monetary unit) and the organization cannot spend more than this amount on the projects. Based on decision of management and experts' comments, the total selected projects from segment X should not be greater than 0.2 of all selected projects. Also more than 0.3 of projects should not be selected from Y sets and the projects of segment Z should not be more than 0.5 of all selected projects. In order to maintain the amount of budget assigned to organization, it should spend at least 0.85 of its allocated budget. So, based on these limitations, constraints (9) - (13) can be presented as follow:

$$\sum_{i=1}^{n} y_i\, C_i \ \leq 10000 \tag{9}$$

$$y_2 + y_7 + y_9 + y_{12} + y_{13} + y_{14} + y_{17} + y_{22} + y_{23} + y_{26} + y_{28} + y_{37} + y_{38} + y_{39} + y_{41} + y_{43} + y_{47} \leq 0.2 \sum_{i=1}^{n} y_i \tag{10}$$

$$y_5 + y_8 + y_{15} + y_{19} + y_{29} + y_{34} + y_{40} + y_{42} + y_{44} + y_{45} \leq 0.3 \sum_{i=1}^{n} y_i \tag{11}$$

$$y_1 + y_3 + y_4 + y_6 + y_{10} + y_{11} + y_{16} + y_{18} + y_{20} + y_{21} + y_{24} + y_{25} + y_{27} + y_{30} + y_{31} + y_{32} + y_{33} + y_{35} + y_{36} + y_{46} + y_{48} + y_{49} + y_{50} \le 0.5\sum_{i=1}^{n} y_i \qquad (12)$$

$$\sum_{i=1}^{n} y_i\, C_i \ge 8500 \qquad (13)$$

Other information about the projects is shown in table 3.

Table 3. Data set of alternative projects in the case study

Project	Segment	Cost (million Toomans)	NPV (million Toomans)
Project 1	Z	406	132
Project 2	X	41.5	22
Project 3	Z	414	141
Project 4	Z	432	185
Project 5	Y	163	21
Project 6	Z	416	135
Project 7	X	46	21
Project 8	Y	153	56
Project 9	X	46	25
Project 10	Z	435	184
Project 11	Z	382	24
Project 12	X	47	21
Project 13	X	52	27
Project 14	X	51	29
Project 15	Y	174	31
Project 16	Z	441.6	133
Project 17	X	43	28
Project 18	Z	402	147
Project 19	Y	152.3	46
Project 20	Z	376	97
Project 21	Z	373.5	117
Project 22	X	51.2	36
Project 23	X	49	27
Project 24	Z	411.5	69
Project 25	Z	385	96
Project 26	X	49.5	26
Project 27	Z	398.5	25
Project 28	X	45.5	24
Project 29	Y	157.5	76
Project 30	Z	409.5	86
Project 31	Z	431.5	101
Project 32	Z	403.5	24
Project 33	Z	359	84
Project 34	Y	145	45
Project 35	Z	413	43
Project 36	Z	435	32
Project 37	X	52.5	23
Project 38	X	44.5	17
Project 39	X	46.5	23
Project 40	Y	160	41
Project 41	X	212	26
Project 42	Y	186	35
Project 43	X	63	29
Project 44	Y	388.5	86
Project 45	Y	196	73
Project 46	Z	528.5	111
Project 47	X	423	95
Project 48	Z	453.5	38
Project 49	Z	462	76
Project 50	Z	451	42

The first and may be the most important step to solve the problem is to obtain the measurements of each factor of structural hardness (S_{ij}). There are 50 alternatives projects and 10 structural hardness factors. Therefore, 500 S_{ij} should be determined. In order to obtain the score of each project in each of factors, a meeting between experts and managers of organization with experts and related managers of ministry was held and in the meeting, these scores was discussed and concluded to the scores of each project in each factor. The second step is to determine the potential correlations between pair of projects (d_{ikj}) . There are some pairs of projects that have correlations with the following effects (Table 4).

Table 4. Correlations between projects of the case study

Parameters	value
$d_{2,7,7}$	0.2
$d_{8,13,4}$	-0.1
$d_{3,22,4}$	0.2
$d_{11,16,7}$	-0.3
$d_{17,19,2}$	0.3
$d_{14,42,10}$	-0.2
$d_{26,45,3}$	-0.2
$d_{21,48,3}$	0.1

For example, by performing projects 2 and 7 at the same time, some problems related to the resources and experts needed for both projects may occur. This negative correlations is evaluated by $d_{2,7,7}$= 0.2. As another example, if project 26 is performed, a part of supervisions necessary for project 45 is also done. So, the supervision team of project 45 will be shrunk. This positive correlation is evaluated with$d_{26,45,3} = -0.2$. It should be mentioned that evaluating correlations between projects in some factors is based on the comments of decision makers of the organization and it may be imprecise since there is not an exact method to measure detailed correlations between projects and we should rely on the comments of experts of the organization.

Now we have all the parameters needed to solve the model. In order to solve the model, we aim at using augmented ε-constrained method for finding efficient frontier. Since the method may be unfamiliar for the readers, it is briefly described here.

7-1- Solving the case study using augmented ε-constrained method

There are many methods for solving such multi-objective problems (See Mavrotaset et al., 2005). Between all the approaches, ε- constrained method seems to be the most common method (Chankong and Haimes, 1983).Altering one parameter in the right hand side of the constrained objective functions; several efficient solutions of the problem are obtained. A famous version of ε-constrained method is augmented ε-constrained method (AUGMECON) proposed by Mavrotas (2009). The interested readers may refer to (Mavrotas, 2009) for further information about the AUGMECON method.

The final result of the model is a set of solutions called Pareto set. Since managers have different risk-taker levels, the convenient portfolio can be widely varied for different managers. Classical project portfolio selection models have been little attention to this important issue. In the proposed model, the manager can increase the probability of having higher return by taking more level of complexity, and vice versa. Based on different levels of complexity, the efficient frontier is classified and efficient solutions are obtained. In an efficient solution, it is impossible to make any better objective function value without making at least another objective function worse.

The pay-off table is determined in the case study by calculating the range of objective functions. In this way,z_1 is optimizedasz_1^* and thevalue of z_2 is calculated based on this solution which is not requisitely optimized. Then, z_2 is optimizedasz_2^* and the related value of z_1 is calculated then. The resulted payoff table is shown in table 5.

Table5. Data set of alternative projects in the case study

Solution function	Z_1	Z_2
Z_1	2558 *	-15.658
Z_2	1936	-13.78*

The next step is to create new objective function and constraints based on the determined pay-off table. So, the new model is:

$$Max\ z_2 = -\left(\sum_{i=1}^{n}\sum_{j=1}^{m} W_j\, S_{ij} y_i + \sum_{i=1}^{n}\sum_{k\neq i}^{n}\sum_{j=1}^{m} W_j\, d_{ikj} yy_{ik}\right)$$

$$Subject\ to:$$

$$\sum_{i=1}^{n} y_i\ NPV_i \geq 1936 + \alpha\,(2558 - 1936) \tag{14}$$

$$\text{In addition to equations } (6-13)$$

$$y_i\ and\ yy_{ik} \in \{0,1\}$$

By solving the model with α from 0 to 1, the frontier of efficient solutions will be estimated. Table 6 shows the efficient solutions.

Table 6. Efficient solutions for objective functions

α	z_1	z_2
0	1936	-13.780
0.1	2037	-13.782
0.2	2085	-13.786
0.3	2152	-13.817
0.4	2189	-13.872
0.5	2248	-13.934
0.6	2327	-14.030
0.7	2373	-14.171
0.8	2438	-14.393
0.9	2504	-14.619
1	2558	-15.658

The pareto set is plotted in figure 2.

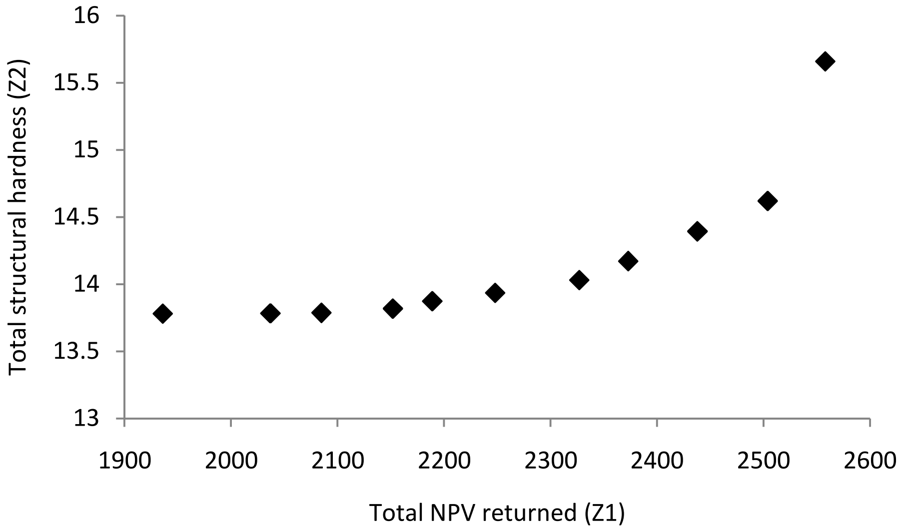

Figure 2. Efficient frontier of solutions

Now that the effective solutions (Pareto set) is defined, each of the solutions can be selected as the final solution according to the preferences of the decision makers and the amount of risk they can afford. For example, if a decision maker considers the same priority for two objective functions, α is considered equal to 0.5 and projects 1-5, 8, 10, 12, 15, 16, 18-22, 25, 26, 28-32, 34, 36, 42, 44, 45, 47, 48, 50 are selected as the portfolio of projects with total NPV of 2248.

8- Computational burden

In today's real world, project-based organizations are faced with much more projects comparing the size of our case study. In some situations, project-based organizations may have to select between 500 projects. So, there is a worry about the ability of the model to solve such problems with high dimension. In order to test the model from this feature, several numerical examples are created and solved using the proposed model. In order to do so, problems with 100, 200, 500, 1000, 2000, 3000, 4000 and 5000 projects are created and solved by GAMS 21.1.2 on a personal computer with a 2 GHz Pentium® Dual-Core CPU. Table 7 shows the computational time required for each problem. It is clear that the time needed to solve the problems even with high dimensions is logical. So, there is no need to implement any approximate and meta-heuristic approaches to solve the real-sized problems. Figure 3shows the relation between number of projects and computational time. As shown in Table 7 and Figure 3, as the number of projects goes higher significantly, the computational time increase slowly. For example, when the number of projects go from 100 to 5000 (50 times greater), computational time increases little than 7 times. In the other words, the increase in computational time is very much lower than the increase in number of alternative projects. In the other words, the speed of increasing computational time is very lower than the speed of increasing in number of projects and it shows the good performance of solution approach which can solve the large-scale problems in very little computational time.

Table 7. Computational time for different problem sizes

Number of projects	Computational time (minutes)
100	3.436
200	7.123
500	11.363
1000	15.632
2000	16.756
3000	17.423
4000	19.238
5000	21.367

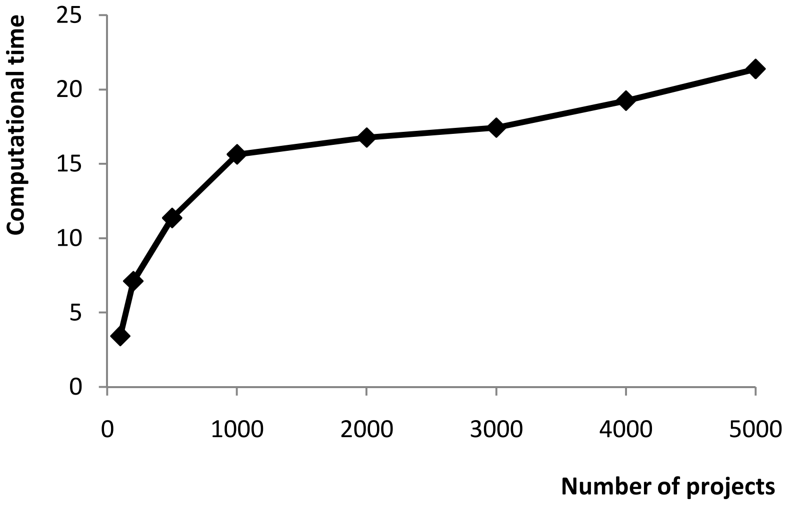

Figure 3. Relation between number of projects and computational time

8-1- Sensitivity analysis

In order to show the effect of change in some important parameters on the final results, some numerical analysis has been done and the results were extracted.

As mentioned before, each of the solutions on Pareto set can be selected as the final solution according to the parameter α which is selected according to the preferences of the decision maker(s) and the amount of risk they can afford. In the case study, based on different values of α, maximum changes in NPV and structural hardness of project objective functions are 622 and 1.878 units respectively. As shown in table 5, comparing the first point on the efficient frontier (1936, -13.78) with the last point (2558, -15.658), the first point has less structural hardness degree but also has the least return. On the other side, the last point has more structural hardness but a higher potential return. In this way, we can't suggest a special solution to the decision maker(s) and he (they) can select a solution from Pareto set based on his (their) preferences and amount of risk can afford.

One of the important parameters in the model is potential correlations between alternative projects (d_{ikj}). In order to analyze the importance of this factor, the proposed d_{ikj}values in the case study was changed to 0, 0.5, -0.5, -1 and 1. In this way, the results are shown in table 8 (α=0.5 for all the cases).

Table 8. Effect of change in d_{ikj} on final results

d_{ikj}	Z_1	Z_2	Projects selected
0	2274	-13.964	1-5, 8, 10, 12, 15, 16, 18-22, 26, 28-32, 34, 35, 42, 44-48, 50
0.5	2250	-14.025	1-5, 8, 10, 12, 15, 16, 18-20, 22, 25, 28-32, 34, 35, 39, 42, 44-48, 50
-0.5	2274	-13.808	1-5, 8, 10, 12, 15, 16, 18-22, 26, 28-32, 34, 35, 42, 44-48, 50
-1	2278	-13.642	1-5, 8, 10, 12, 15-22, 26, 29-32, 34, 35, 42, 44-48, 50
1	1924	-13.889	1-3, 5, 8, 12, 15, 18-20, 23-25, 28-36, 39,42, 44-48, 50

As shown in table 8, as negative correlations between alternative projects is greater, total structural hardness of projects is higher and as positive interactions between the potential projects is lower, the total structural hardness would be lower. On the other hands, when there is a great positive correlation between two projects, the possibility of selecting both of them in portfolio is high. But when there is a strong negative correlation between two projects (for example 0.9), the possibility of selecting both of them as portfolio is very little. In table 7, whend_{ikj} is 1(negative correlation), none of projects 2, 3, 7, 8, 11, 13, 14, 16, 17, 19, 21, 22, 26, 42, 45, 48 which have correlation is selected in portfolio of projects.

As mentioned in the introduction, one of the major shortages of most of the literature works on portfolio selection is that they just paid attention to quantitative and especially monetary issues as objective function. In order to show the superiority of this model trough other models, we deleted the second objective function and find the portfolio considering NPV solely. In this way, projects 1, 3, 4, 6, 8, 10, 13-25, 29-31, 33-35, 40, 42, 45-50 are selected with a total NPV of 2652. Comparing the results in table 5, total NPV with this single objective is greater than the NPV of multi-objective model. But the second model does not pay attention to structural hardness of the projects and just consider monetary issue.

In a summary, the proposed project portfolio selection model has the characteristics shown in table 9.

Table 9. Characteristics of the proposed model

Character	Convergense of solutions	Speed of convergence	Considering financial issue	Considering structure of projects	Easy to understand	Communicate with decision maker(s)	Reliablity
Degree	high	high	yes	yes	medium	medium	high

9- Conclusion

In this paper a definition of structural hardness of project was presented and criteria and sub-criteria of this important factor were determined and a model for calculating degree of hardness of projects was presented. Also, the structural hardness of project considered as a factor in selection of project portfolio selection. In the project selection model, two objectives including maximizing NPV and minimizing total hardness of projects of a portfolio is considered. The model also considered correlations between projects as a part of objective function. In order to show the mechanism and feasibility of the model, a case study was presented and analyzed. Since the model is multi-objective, a special version of ε-constrained method, AUGMECON, is used in order to obtain more accurate results. In order to show the ability of the model to solve real-world and large-sized problems, some numerical examples are randomly generated and solved. The results proved that the proposed model and the exact solution approach can solve these problems even with 5000 alternative projects. There are also several ways to extend this work. First, the definition of hardness may be used in other areas of industrial engineering such as production planning, supply chain management and so on. Preparing commercial software is another suggestion which is really beneficial for both academicians and practitioners.

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