Project Portfolio Selection Considering Return-risk Evaluation and Multiple-Criteria Decision Analysis

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Abstract: Companies often face a challenge when they need to select their projects for execution because the resources are not enough for all of them. For supporting decision, they need to employ some form of selecting the best portfolio to run. There are several proposals in the literature, many allowing an evaluation of efficiency between expected return and risk. However, these proposals indicate a list of efficient portfolios, but not the one best suited for execution. On the other hand, multi-criteria analysis methods allow a more specific indication, but they are difficult to be executed when the number of projects increases. This work seeks to cover this gap by proposing a selection method that combines the return-risk assessment using mean-Gini approach, complemented by the application of the multi-criteria decision method PROMETHEE II. The result is the objective indication of the best project portfolio to be executed by the company.

1 INTRODUCTION

Frequently, companies have a list of projects to be executed. But, due to resource constraints, they are forced to select a subset of them (Abbassi et al., 2014). This need for decision has been one of the critical problems of project management (Jafarzadeh et al., 2015). Decision makers need to prioritize projects and define the best subset to be executed (Perez and Gomez, 2014). The subset of projects can be viewed as a portfolio.

Portfolio analysis may manage the risk in a set of assets to establish which one offers the greatest return for a certain level of risk or the lowest risk for a defined level of return. These portfolios are called efficients. Project portfolios can be evaluated in the same way of asset portfolios (Eilat et al., 2006).

Markowitz (1952) was a pioneer in proposing an optimum strategy for maximizing return and minimizing risk of portfolios candidates for selection. Based on his work, an efficient frontier of portfolios can be found by comparing expected return mean and the correspondent variance for each portfolio (MV portfolio). However, MV portfolio has reliable results only when return are normally distributed or decision maker utility function are quadratic (Feldstein, 1969). In this way, while MV portfolio has been well explored by works as Levy and Levy (2014); Zopounidis et al. (2014), other ones propose alternatives.

The work of Shalit and Yitzhaki (1984) presented an alternative for portfolio selection by comparing return mean and Gini coefficient of portfolios under evaluation (MG portfolio). Its application is less restrictive than MV. Investment portfolio selection using MG can de viewed in Alessandra Cillo (2014). The same approach applied to project portfolio selection was used in the works of Ringuest et al. (2004) and Gemici-Ozkan et al. (2010).

Resources scarcity is a reality in companies (Perez and Gomez, 2014). In the same sense, Dutra et al. (2014) state that, in general, there is no enough resource for all projects. It highlights the importance of selecting the best set of projects (portfolio) to be executed.

Projects selection must be done, naturally, before knowing their returns. Decision makers decide based on estimations, which leads to uncertainty, even if good tools are applied (Kitchenham and Linkman, 1997). In this case, it is important to consider uncertainty in project portfolio selection (Marcondes et al., 2017).

Project Management Body of Knowledge Guide (PMBOK®) from *Project Management Institute* recommends triangular distribution for dealing with uncertainty in projects (PMI, 2013). It allows considering worst-case, most-likely and best-case estimation for projects, using a range of value in evaluations (instead of point values). Still in PMI (2013),

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Monte Carlo simulation is indicated as a tool for uncertainty evaluation, which is usually used when mathematical model is difficult (or impossible) to be treated (Bertrand and Fransoo, 2002; Better and Glover, 2006).

In despite of return estimation based methods for project portfolio selection, as in MV and MG portfolios, in general, there are several conflicted criteria to be evaluated. For supporting this kind of decision, the literature offers the Multi-Criteria Decision Making (MCDM) approaches (Behzadian et al., 2010). Preference ranking organization method for enrichment evaluation (PROMETHEE) is an MCDM method for ranking finite set of options under evaluation, among conflicted criteria. Its application is increasing, based on the number of published papers in literature (Behzadian et al., 2010).

As PROMETHEE application compares, in all criteria, options pair-by-pair, it can be cumbersome, depending on the number of projects to be evaluated. For instance, if one evaluates ten projects, there are 1,023 possible portfolios (not considering the option of no project selected). If twenty projects, the number of portfolios is 2,047.

Based on it, this work proposes a new method for selecting a project portfolio to be executed. It applies first MG portfolio to reach an efficient portfolio list (the ones which are in MG efficient frontier), considering uncertainty of estimations by Monte Carlo simulation (implemented by Python language). For indicating the best option, over the efficient portfolios, PROMETHEE II is applied. At the end, decision maker has a ranking of portfolios, indicating from the best to the worst, for choosing.

The research approach was based on simulation with a real set of project. Mäkinen and Vilkko (2014) and Marcondes et al. (2018) applied simulation as a tool for portfolio selection.

The remainder of this paper is organized as follows. Section 2 presents MG portfolio selection and PROMETHEE II method. Section 3 explains how to use triangular distribution for considering uncertainty in selection. Proposed method is presented in Section 4 and its application using a real projects dataset in Section 5. Finally, Section 6 concludes this work.

2 PROJECT PORTFOLIO SELECTION

2.1 Mean-Gini

Mean-Gini portfolio selection considers estimation of portfolio return for indicating an efficient frontier. Based on return distribution, one can calculate its mean, indicating expected return, and Gini coefficient, indicating risk.

Expected return of a portfolio depends on expected return of each project included in it. Project expected return is the expected value of its return random variable. Portfolio expected return (R_P) (or portfolio mean), can be found by Equation (1).

$$R_P = \sum_{j=1}^{N} w_j r_{p_j} \tag{1}$$

where:

- r_{p_j} is the expected return of project j;
- $w_j \in \{0,1\}$ represents the decision of exclude or include project j in portfolio, respectively.

Gini coefficient is a statistical dispersion measure. In general, it is largely applied to measure inequality in income distribution for nation's residents. Shalit and Yitzhaki (1984), although its original purpose, presented an application of Gini coefficient for portfolio risk analysis. Their application is an alternative of variance application. Ringuest et al. (2004) state Gini coefficient is a simple measure and easy to be applied in decision making process.

Gini coefficient can be calculate by (Shalit and Yitzhaki, 1984):

$$\Gamma = 2\text{cov}\left[R, F\left(R\right)\right] \tag{2}$$

where:

- R is the portfolio return random variable;
- $F\left(R\right)$ is its cumulative probability distribution.

R_{P_i} and Γ_{P_i} denote the return mean and Gini coefficient, respectively, for portfolio i, in MG sense, a portfolio II is dominated by a portfolio I, if and only if (Ringuest et al., 2004):

$$R_{P_I} \geqslant R_{P_{II}} \tag{3a}$$

and

$$\Gamma_{P_I} \leqslant \Gamma_{P_{II}} \tag{3b}$$

where at least one of these two conditions (3a) or (3b) must be satisfied as inequality.

Non-dominated portfolios are kept in efficient evaluation, and dominated ones discarded (not efficient, compare to any other portfolio). Non-dominated portfolios are considered efficient. They compose the efficient frontier.

2.2 MCD PROMETHEE

Often, decision makers must select among options based on several criteria that can be conflicting. For this situation, literature offers the Multi-Criteria Decision Making (MCDM) approaches (Behzadian et al., 2010). Preference ranking organization method for enrichment evaluation (PROMETHEE) is an MCDM outranking method when evaluating, among conflicted criteria, a finite set of alternatives.

There are some PROMETHEE options. PROMETHEE II is the chosen one when complete ranking of alternatives is needed. It can offer a final list of alternatives, ranked from the best to the worst, based on the defined criteria and weights assigned to them. The comparison for each criterion must be made pair by pair, starting by calculating the deviation (difference between their values). The difference of each criterion must be applied to a preference function (there are six basic types to be chosen, depending on the kind of comparison is done).

PROMETHEE II considers:

- A a set of n alternatives to be compared in j different criteria ($j = 1, ..., k$);
- $g_j(a)$ the evaluation (value) of alternative a ($a \in A$) in criterion j;
- $d_j(a,b)$ the difference between alternatives a and b ($a,b \in A$) in criterion j;
- $F_j[d_j(a,b)]$ the result of preference function applied to $d_j(a,b)$;
- w_j the weight of criterion j.

It is based on five steps, as following (Behzadian et al., 2010):

1. Calculate the deviations between a pair of criteria (pair by pair):

$$d_j(a,b) = g_j(a) - g_j(b) \tag{4}$$

2. Apply the preference function:

$$P_j(a,b) = F_j[d_j(a,b)] \text{ for } j = 1, ..., k \tag{5}$$

3. Calculate the global preference index (π):

$$\forall a,b \in A \Rightarrow \pi(a,b) = \sum_{j=1}^{k} w_j P_j(a,b) \tag{6}$$

4. Calculate the outranking flows (positive ϕ^+ and negative ϕ^-) for each alternative:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A}^{k} \pi(a,x) \tag{7}$$

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A}^{k} \pi(x,a) \tag{8}$$

5. Calculate the net outranking flows for each alternative:

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{9}$$

After all steps, $\phi(a)$ for each alternative can be compared. The higher the value of $\phi(a)$, the better the alternative. At the end, the evaluation results in the ranking among alternatives, facilitating the choice for the decision maker.

PROMETHEE II is easy to be applied for ranking projects criteria and its application is increasing, based on the number of published papers in literature (Behzadian et al., 2010). Based on it, it was chosen for this work.

3 UNCERTAINTY ON PROJECTS

As Eilat et al. (2006), when proceeding portfolio selection, uncertainty must be considered. A bad performance on selection can occur due to parameters uncertainty, mainly if it is considered that return estimation is difficult (DeMiguel and Nogales, 2009). In fact, the impact of estimation error in choosing the optimal portfolio was discussed in several works, showing it represents an important role in project selection (Lim et al., 2011; Marcondes et al., 2017).

Three point estimation is recommended by PMI (2013). For it, instead of estimating only one value, they are three: worst-case (a), most-likely (b), and best-case (c) outcomes. With them, one can construct a triangular distribution, as presented in Figure 1, as frequently applied in projects uncertainty evaluation (Marcondes et al., 2018).

4 PROPOSED METHOD

The method proposed in this paper is based on MG portfolio selection and PROMETHEE II. The purpose is to indicate a portfolio to be executed by the company. There are some steps, as presented in Figure 2, detailed described as following.

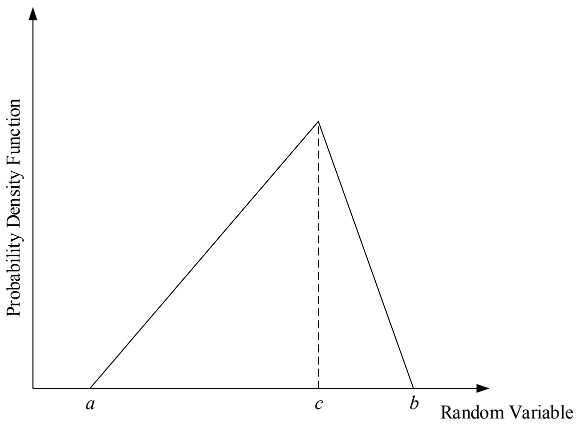

Figure 1: Triangular distribution based on three point estimation.

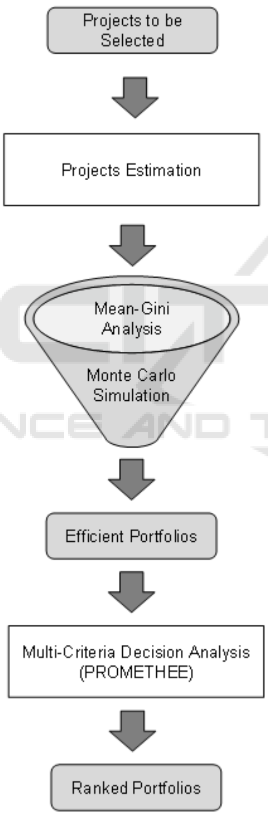

Figure 2: Proposed Method.

1. **Projects Estimation**
   Specialists use three-point estimation for estimating projects parameters and define worst-case, most-likely, and best-case outcomes for return. After that, for each project a triangular distribution is obtained.

   They must also estimate information for PROMETHEE II application, classifying the projects in criteria as, for instance, strategic importance, market position, innovation, and so on.

2. **Mean-Gini Analysis**
   All portfolio possibilities are identified and mean-Gini comparison is started. Portfolios return mean and Gini coefficient are calculated and compared, using Monte Carlo simulation. If a portfolio is identified as dominated (not efficient), it is discarded for future comparisons.

   At the end of this step, there will be a list of efficient portfolios.

3. **Multi-Criteria Decision Analysis**
   Over the list of efficient portfolios, PROMETHE II is applied. $\phi(a)$ is calculated for each project, and after that, for each efficient portfolio (by summing up all $\phi(a)$ of each project constituting it). Then, the list is ranked (from the highest to the lowest value of $\phi(a)$) and the decision maker can choose portfolio to be executed.

After mean-Gini evaluation, decision maker has a list of efficient portfolio. However she/he must decide for just one portfolio to be executed. Several criteria must be consider for this decision. In the proposed method, considering all criteria established by the company, multi-criteria decision is applied for ranking the portfolios. After these steps, decision maker has a ranking for choosing the portfolio to be executed.

5 APPLICATION IN REAL PROJECTS

The method proposed in this paper was applied in a real set of software development projects, from a service provider company. The estimation process involved three software engineers (specialists) with more than 10 years of experience on software development working as software architects and developers. Table 1 presents return three-point estimation for eight projects.

For proceeding PROMETHEE II evaluation, the following characteristics were defined, and a weight distribution established:

- **Competitiveness Improvement (weight - 0,5):** considering the capacity of project for improving company competitiveness (from 1 - low to 4 - high);
- **Market Potential (weight - 0,3):** considering the capacity of project for improving market share or market penetration (from 1 - low to 4 - high);

Table 1: Projects Return Information.

	Return		
Project	Worst-Case	Most Likely	Best-Case
A	-19,830	10,420	20,760
B	-20,540	5,170	9,930
C	4,990	31,080	59,870
D	-20,510	10,120	19,490
E	9,920	30,260	49,790
F	-3,120	10,480	30,750
G	0	20,000	40,000
H	9,950	29,680	49,640

- **Degree of Innovation (weight - 0,2):** considering how innovative the project is (from 1 - low to 4 - high).

Table 2 summarizes the specialists evaluation for each project characteristics.

Table 2: Projects Characteristcs.

	Characteristics		
Project	Comp. Imp.	Market Pot.	Innovation
A	1	1	4
B	1	3	2
C	4	2	3
D	1	1	1
E	2	4	3
F	4	2	3
G	2	3	2
H	3	2	1

Based on Tables 1 and 2 informations, the simulation was run. From a total of 255 portfolios, it was selected 15 efficient portfolios. Figure 3 presents a graphical with these partial result: all inefficient portfolios in black circles, efficient portfolios in red squares and efficient frontier in dashed line.

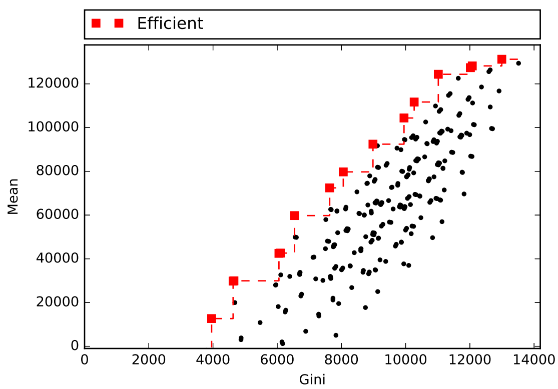

Figure 3: Efficient Frontier.

In the sequence, over these 15 efficient portfolios PROMETHEE II was run. For each project, $\phi(a)$ was:

Table 3: Projects Characteristcs.

Project	$\phi(a)$
A	-1.800
B	-1.267
C	2.467
D	-3.400
E	1.400
F	2.467
G	0.067
H	0.067

The final ranking of portfolio was (the sequence of letters indicates which projects are included in the portfolio):

1	CEFGH	9	FH
2	CEFH	10	F
3	ACEFGH	11	EGH
4	EFGH	12	EH
5	CEGH	13	E
6	EFH	14	ACDEFGH
7	EF	15	H
8	CDEFGH		

The ranking indicates that portfolio CEFGH is the best option for being executed. It is efficient (for its level of return mean, there is no one with lower risk; for its risk level, there is no one with higher return mean) and it has the highest $\phi(a)$ value. Complimentary, this portfolio has the fourth highest return mean value and the best return/risk ratio.

6 CONCLUSIONS

Presently, define the project portfolio to be executed is a challenge for companies. In general, they don't have enough resources to execute all projects.

Several project portfolio selection method are proposed in literature. The ones based on efficient frontier evaluation compares return and risk. Indicating a list of efficient portfolios.

However, over this list, decision makers need to choose only one. Several criteria must be applied (highest return, best relation return/risk, strategic results, and so on). When several criteria must be considered at the same time, it is important to use a suitable tool for this.

Based on this, this work proposes a method for project portfolio selection combining efficiency (return and risk) evaluation and multi-criteria decision PROMETHEE II in a sequence. The first one works as a pre-selection for applying the second one. The result is an objective ranked list of portfolios to be selected. Supporting decision maker in her/his decision.

For future works, the author has the following list:

- Before applying PROMETHEE II, over efficient portfolios some filters can be used: minimum expected return, minimum return/risk rate, or other;
- Additionally to return and risk information, some constraints must be considered: people limit, time limit, equipment (or other resources) limit, and so on;
- Survey with some companies about the use of this method in project portfolio selection.

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