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An efficient risk based multi objective project selection approach considering environmental issues

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C H R O N I C L E

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A B S T R A C T

There are many researches on project selection field, but few of them have considered environmental criteria in their studies. Moreover, there are many articles in evaluating risk but there is no article that considers value at risk concept to evaluate the amount of risk in multi project selection. We propose a multi objective mathematical model to address a situation in which several projects are candidate to be invested completely or partially. Three objective functions are considered in this paper. The first objective maximizes sum of the net present value of pure cash flow obtained from selected projects. In this objective, we consider the factor of time and its impact on value of money. In addition, we use the concept of value at risk (VAR) as the present value for the first time in project selection problems. Although green projects are more interesting, there are few articles, which address environmental issues. Hence, we consider the objective, which are related to environmental issues as the final criterion. Multi-Objective Differential Evolution algorithm (MODE) algorithm is applied to solve a problem, which is known as robust and efficient algorithm. Then computational results are compared with solutions obtained by NSGA-II algorithm which is well-known algorithm in this field with respect to seven comparison metrics.

1. Introduction

There are literally many surveys on project selection but none of them considers net present value, present expected value at risk and green consideration, simultaneously. In this paper, a new mathematical model by considering several candidate projects to invest completely or partially is presented. We consider three objectives; first maximize sum of net present value of pure cash flow received from selected projects with the consideration of time impact on value of money. In addition, the most value which can be lost on each investment is important, so we use the concept of value at risk (VAR) as a factor of evaluating the amount of risk in present value. We also consider the green management objective introduced by Prato (2007) and develop it by using coefficient costs determined

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by default government as the final criterion. It is assumed that, government determines special penalties at the end of projects according to the type of projects and their damages on environmental. Furthermore, a new constraint is presented to control risk, which cannot exceed a special confidence level. For the proposed problem defined, it is worthwhile to take a look at articles which have been devoted to various aspects of project selection problem or taking into account the risk concept for portfolio or financial problems.

Chen and Askin (2009) tried to formulate and analyze the joint problem of project selection and task scheduling, under the condition that project returns are function of project completion time and the limitation of renewable resources was considered in their paper. Mathematical formulation aimed to maximize present worth of profit. An implicit enumeration procedure was also developed and tested to provide good solutions based on project ordering and a prioritization rule for resource allocation. This research also demonstrated the importance of integrating the impact of resource constraints into the selection of projects. In a paper proposed by Medeglia et al. (2008), the authors proposed a mixed integer programming (MIP) model for projects selection from a bank of projects which are capable for investment. They also considered the timing of the selected projects. Their proposed model maximizes the weighted sum of normalized economic and financial net present value and a social impact index while satisfying the precedence relations among the projects, the earliest and latest starting times of the projects, budget limits and endogenous project cash flow generation at the same time. Sun and Ma (2005) recorded the development and application of a heuristic packing-multiple-boxes model, which can be used for both selecting and scheduling candidate R&D projects. The proposed model was initialized at the request of a case company that conducts up to 20 large R&D projects, simultaneously. The example of using this model at the case company for a five-year planning period was provided.

Ghorbani and Rabbani (2009) presented a multi-objective algorithm, for the problem of project selection, which are maximizing total expected benefit of selected projects and minimizing the summation of the absolute variation of allotted resource between each successive periods. The research presents some test problems for comparing the proposed genetic algorithm with other competing methods, and they concluded that the proposed multi-objective meta-heuristic was an effective algorithm for their proposed problem. Gabriel et al. (2006) presented a multi-objective integer-constraint model for the aim of project selection using probability distributions to describe cost. The objectives correspond to important project criteria, such as rank, managerial labor needed, and average cost. Padhy and Sahu (2011) proposed a two-stage methodology based on (1) Real Option Analysis for evaluating the value of the project to improve the managerial flexibility (2) a zero-one integer linear programming model for selecting and scheduling an optimal project portfolio. This study contributes to managerial practices by identifying a new way of valuating the six-sigma projects through real option analysis by considering various kinds of risks. Carazo et al. (2010) proposed a multi objective binary programming model that facilitates both obtaining efficient portfolio in conjunction with the set of objectives pursued by the organization as well as their scheduling regarding the optimum time to launch each project within the portfolio without the need for a priori information on the decision-maker`s preference. Tian et al. (2005) introduced the R&D project selection as a complicated multi-stage decision-making process, which involves groups of decision makers. They proposed organizational aspects of the decision making process and then proposed a Decision Support System (DSS) for R&D project selection. An Object-Oriented method was also used to design the architecture of the DSS.

Dey (2006) proposed a decision support system, which analyzes projects with respect to market, technicalities, and social and environmental impacts in an integrated framework using analytic hierarchy process (AHP), a multiple-attribute decision making technique which not only reduces duration of project evaluation and selection, but also help to select optimal project for the organization for sustainable development. Oral et al. (2001) discussed a project evaluation and selection methodology based on multi-criteria dis-aggregative approach used as an instrument rather than as a descriptive tool in an organization which has more than a dozen country members in order to maximize the level of consensus among the member countries subject to some certain budgetary constraints and resentment-avoiding principles. Prato (2007) proposed a conceptual framework which consists of two elements: (1) a priori optimization model for selecting projects that minimizes present value loss in ecosystem services with respect to a budget constrain; and (2) a model determines which implemented projects have decreased ecosystem losses. An optimization model has been formulated in three cases which includes knowing for sure that how the projects expenditures influence on losses in ecosystem service (certainty case), not knowing how projects expenditures influence on losses in ecosystem service (risk case), (3) Uncertain knowing how projects expenditures influence losses in ecosystem service (uncertainty case).

Some articles have considered the problem of project and portfolio selection while considering the risk concept in the process of selection. Drake and Kuhlmeyer (2010) investigated the effect of past project performance history and bonus incentive pay schemes on managers` propensity to select more or less risky projects. Two types of bonus incentive pay schemes were employed in this study. Their findings are based on prospect theory predicting that prior bad outcomes motivate greater risk-taking than prior good outcomes. Strong et al. (2009) addressed the fundamental principles of financial risk assessment and compared alternative investment using simulation approach. They introduced net present value, premium risk, mean and standard deviation and coefficient of variation of the Rate of Return (ROR) as the key metrics for evaluating performance of investment, then they examined the following applications: (1) stand-alone risk assessment for a capital-budgeting problem; (2) comparison of risk-free and risky investment strategies designed merely to keep up with the cost of living; (3) value-at-risk (VAR) analysis for a single-stock investment; (4) VAR analyses for two-asset portfolios consisting of stock and either call or put options. Caron et al. (2007) considered the portfolio management for an engineering and contracting company and the distribution of net present value along the project lifecycle, in a similar way as the distribution of return for a portfolio of financial assets over a specified time horizon, in order to define a synthetic measure of risk for an engineering and contracting project. They measured the risk based on the Value at Risk concept in order to obtain a better balancing of overall portfolio of projects. The proposed framework was tested as a decision support tool on a power plant project. Juuso Liesiö and Ahti Salo (2012) propounded scenario based portfolio selection of investment projects with incomplete probability and utility information. The proposed methodology extends scenario based project appraisal to select project portfolios in the presence of incomplete information about scenario probabilities and risk preferences. According to the literature, it can be found that there are a few surveys on project selection considering environmental issues (Prato, 2007). This fact motivates us to develop green objective by using cost coefficients which are determined by Iran government. Furthermore, it is interesting topic to know the maximum amount of money, which can be lost during an investment. To response this question, we use the concept of value at risk for the first time in multiple project selection.

This paper is organized as follows: our proposed model is presented in section 2. Section 3 discusses about our solution method, while section 4 represents our test problems and solution results. In section 5, conclusions remarks is provided.

2. Problem formulation

2.1 Notations

R	interested rate
X_j	fraction of project j should be selected
d_{ij}	duration of activity i in project j
Q_j	total activities durations for project j

D_{ij}	cumulative activities durations from first activity *i* to activity *j*
A	confidence level
$E(d_{ij})$	mean of duration activity *i* in project *j*
$\sigma^2(d_{ij})$	variance of duration activity *i* in project *j*
L_j	coefficient of costs in project *j*
q_{ij}	penalty for delay from mean activity *i* in project *j*
VAR_j	value at risk of project *j*
σ_j	standard deviation of project *j*
b_{ij}	benefit of project *j* comes from activity *i*
C_{ij}	cost needed at the beginning of activity *i* in project *j*

The following model is presented when we have several candidate projects which can be invested completely or partially. We consider three objectives in this paper. The first objective function maximizes sum of the net present value of pure cash flow received from the selected projects. In this objective, we consider the factor of time and its impact on value of money. In addition, the most value which can be lost on this investment, is as important factor as the amount of money which is expected to comeback, hence we use concept of value at risk (VAR) as the present value and propose the second objective function for the first time in project selection problems. Although green projects are more interesting than others, there are few surveys, which address environmental issues. In the last objective function, we consider the objective proposed by Prato (2007) and develop it by using coefficient costs determined by Iran government. In this survey, it is assumed that government determines special penalties at the end of each project according to the type of projects and their damages on environmental.

$$\max \sum_j \sum_i \left(b_{ij} - C_{i+1j}\right) Q_j (1+r)^{-E(D_{ij})} \tag{1}$$

$$\min \sum_j VAR_j X_j (1+r)^{E(Q_j)+Z_a\sqrt{\sum_i \sigma^2(d_{ij})}} \tag{2}$$

$$\min \sum_j X_j L_j (F/P,\ r\%,\ Q_j) \tag{3}$$

subject to

$$\sigma_j{}^2 = \sum_i \sigma^2(d_{ij}).q_{ij}^2 \tag{4}$$

$$VAR_j = Z_a.\sigma_j \tag{5}$$

$$\frac{VAR_j(1+r)^{-E(Q_j)-Z_a\sqrt{\sum_i \sigma^2(d_{ij})}}}{\sum_i \left(b_{ij} - C_{i+1j}\right) X_j (1+r)^{-E(D_{ij})}} \le b \tag{6}$$

$$D_{kj} = \sum_{i=1}^{k} d_{ij} \tag{7}$$

$$0 \le X_j \le 1 \tag{8}$$

In real world, each project (j) includes several activities (i) with different durations (d_{ij}) which are not deterministic. We assume that d_{ij} has normal distribution ($d_{ij} \sim N(\mu_i, \sigma_i)$) and consider q_{ij} as penalty of delay in each activity (i) from each project (j) which is obtained at the end of each project. Eqs. (1-3) are the objective functions which attempt to maximize net present value, minimize value at risk and minimize penalties of environmental damages, respectively. Eq. (4) calculates variances of penalties and Eq. (5) calculates value at risk of each project under specific confidence level. We use value at risk concept adapted from Markowitz (1952) with some modifications. Since projects with different expected NPV have various values at risk, we introduce a way enabling us to compare the mentioned situations. A new concept is proposed in this paper which evaluates the percent of maximum probabilistic lost in each unit of NPV in a special confidence level. Constraint 6 is a new constraint used for the first time. In this constraint, we attempt to control this proportion to be less than a special value dependent on investor. Constraint (7) calculates finish time of each project under uncertainty and constraint (8) declares that we can select part or all of each projects.

3. Methodology

This section discusses about the methodologies, which we used in solving the proposed model. As the number of the projects increases, the complexity of the proposed multi-objective model increases, hence, we have to use appropriate meta-heuristic approaches for the reason that the problem is NP-hard (Carazo et al., 2010). One of the popular algorithms for solving multi-objective problems is MODE (Multi-Objective Differential Evolution algorithm). This algorithm applies Differential Evolution (DE), which has been successfully applied to selected real world problems in this field. It should be noted that, Differential Evolution (DE), is simple, robust and faster in optimization among the population based search algorithms that are stochastic in nature (Gujarathi & Babu, 2009). On the other hand, MODE algorithm is equipped with non-dominated population selection combined with basic DE algorithm (Gujarathi & Babu, 2009). Now, we utilize the research executed by Gujarathi and Babu (2009), which described MODE as a multi-population, multi-objective DE approach. The algorithm can be summarized as follows:

An initial population is generated randomly. All dominated solutions are eliminated from the population using the non-dominated sorting approach. The remaining non-dominated solutions are retained for recombination. Three parents are selected, randomly. A child is generated from these three parents and this child is placed into the population, if it dominates the first selected parent; otherwise, a new selection process takes place.

Of course, to validate the performance of the algorithm another algorithm is needed; hence, we used another multi-objective meta-heuristic algorithm called non-dominated sorting genetic algorithm (NSGA-II), which is one of the most efficient multi-objective evolutionary algorithms using elitist approach. Its particular fitness assignment scheme consists of sorting the population in different fronts using the non-domination order relation. Then, to form the next generation, the algorithm combines the current population and its offsprings generated with the standard bimodal crossover and polynomial operators. Finally, the best individuals in terms of non-dominance and diversity are chosen. This new version of NSGA has a low time complexity of O ($N \log N$), where N is the population size.

As it mentioned before to estimate two suggested algorithms and conclude the most appropriate algorithm for the problem, we compare the performance of two described algorithm with respect to seven metrics in 20 test problems in the next section.

4. Numerical results

We solve 20 sets of test problems including 8 small-size, 6 medium-size, and 6 large-size problems, which have been represented according to Tables A.1 to A.3 in Appendix section. To solve each test problem, both proposed algorithms are used and the obtained results have been compared with each other regarding comparison metrics. For this purpose, each test problem shown in Table 1 is solved 10 times and the average of 10 runs for each output has been reported in Table 1. For better comparing the performance of two proposed algorithms, we plot charts in which two algorithms have been compared as we see in Figs. 1-21. We have compared our algorithms, by metrics of: objective functions, computational time, number of Pareto solutions, diversity, and spacing metrics. As aforementioned, the first objective aims to maximize net present value. Fig.1 shows that, MODE has better solutions for all small, medium and large size test problems. Also, Figs. 2-3 are related to objectives 2 and 3; hence we are interested in least values. As Figs. 2-3 show, MODE has better solutions in all small, medium and big size test problems.

Table 1
Results of running each test problem by NSGA II and MODE algorithm

Test problem	NCGA-II							MODE						
	Best objective 1	Best objective 2	Best objective 3	Run Time	Number of Pareto	diversity	spacing	Best objective 1	Best objective 2	Best objective 3	Run Time	Number of Pareto	diversity	spacing
1	13.9	0	0	1.12	14	48	1.19	14.6	0	0	16.99	11	39	1.01
2	40.36	0	0	2.16	38	154	0.96	40.53	0	0	13	110	260	1.07
3	34.36	7.21	6.93	2.15	125	403.56	1.57	60.76	0	0	21.47	150	453.8	1.1
4	50.15	19.85	3.93	1.14	81	166.70	1.12	57.61	0	0	23.94	150	241.92	0.97
5	82.14	0	0	4	62	136	1.61	86.54	0	0	18.15	150	206	1.31
6	70.01	0	0	7.77	125	166	1.57	73.21	0	0	20	150	177	1.21
7	29.89	25.2	14.45	5.03	112	478.98	1.11	38.38	0	0	30.5	150	605.81	0.88
8	14.18	39.56	29.03	7.78	109	387.21	1.03	17.23	31.41	21.41	35.11	150	218	0.48
9	52.85	0	0	14.56	140	477	1.34	57.52	0	0	25	150	517	0.87
10	68	0	0	11.65	119	175	1.17	71.7	0	0	25.93	150	214	0.88
11	55.11	0	0	16.92	162	195	1.17	58.6	0	0	23.58	150	276	0.53
12	68.12	0	0	7.12	82	178	0.85	71.7	0.46	0.17	26.91	150	243	0.711
13	212.07	0.66	0.1	4	57	227	1.31	236.67	0	0	31.73	150	404	1.12
14	119	47	1.2	8.45	82	365	1.24	123	40	3	26	150	501	0.89
15	94	7.89	0.88	12.92	121	366	1.36	99	7.39	0.63	27.62	150	468	1.01
16	107	13.4	1.7	11	117	410	1.54	114	13.21	1.53	33	150	524	0.97
17	27.25	18.90	14.91	8.12	108	650.34	1.17	32.95	15.53	2.49	31.83	150	812.49	0.55
18	37.17	12.45	8.34	8.56	112	703.51	0.98	41.23	13.76	3.78	39.23	147	810.32	0.57
19	55.67	18	2.04	8.39	99	260	1.27	59.51	17.3	1.94	24.69	150	335	0.94
20	73	14.77	0.53	9.16	90	296	0.59	77.25	11	0.37	33.01	150	370	1.14

4.1. Net present value

The first objective tries to estimate net present value (NPV) in the beginning year of the investment. NPV is one of engineering economic method to compare real benefits of each investment. Often previous researches consider this criterion as a major factor to recognize which project or combination of projects is more profitable. However, in the real world in many cases, activities duration would not occur just in estimated time; hence, we calculate NPV based on expected duration times.

We have solved the test problems for small, medium and large sizes using both NSGA-II and MODE algorithms. Figs. 1-3 show that MODE algorithm clearly causes to make solutions with higher NPV in small size problems. Though NSGA-II shows better the first objective function in medium and large size problems rather than small size ones, but MODE in medium and large size problems also derives better solutions according to this objective.

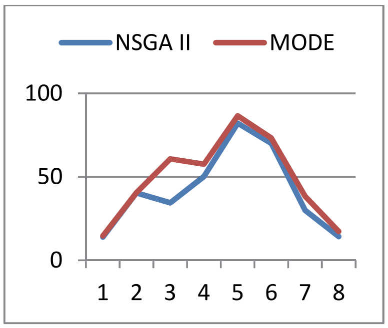

Fig. 1. Small sized test problems results related NPV

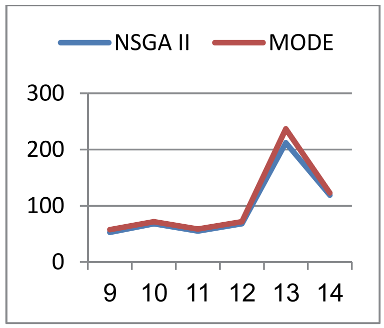

Fig. 2. Medium sized test problems results related NPV

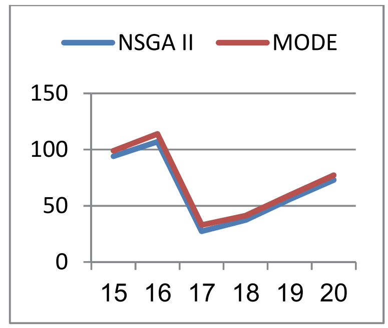

Fig. 3. Large sized test problems results related NPV

4.2. Value at risk

Under nondeterministic conditions, some estimated earnings may increase or even decrease. For example, completion time of each project variable or activities' durations cause different net present values. Many investors are interested in knowing the amount of maximum value which is at risk of lost in a specific confidence level. In this article, the amount of value at risk related to each combination of projects is calculated based on the expected duration times and net present value of them. We assume that durations of activities follow normal distribution which is common assumption in this field. As Figs. 4-5 show MODE algorithm generates solutions with lower amount of value at risk in small and medium sizes test problems and could outperform NSGA-II solutions. Although there are few cases in large test problems that NSGAII solutions induce lower amount of value at risk, yet in most tests MODE solutions transcend NSGAII solutions in large sizes.

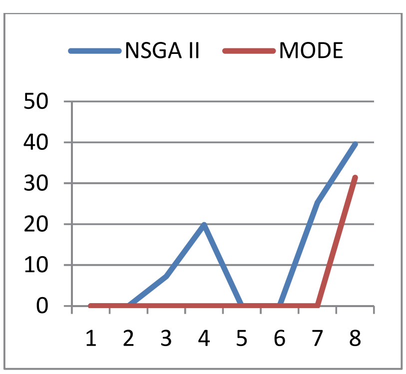

Fig. 4. Small sized test problems results related value at risk

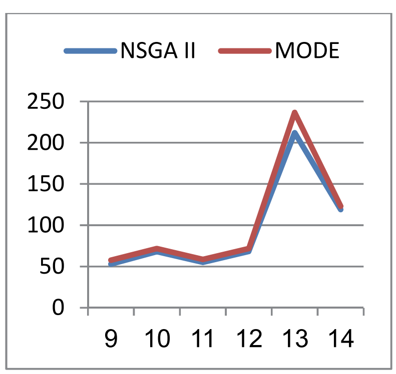

Fig. 5. Medium sized test problems results related value at risk

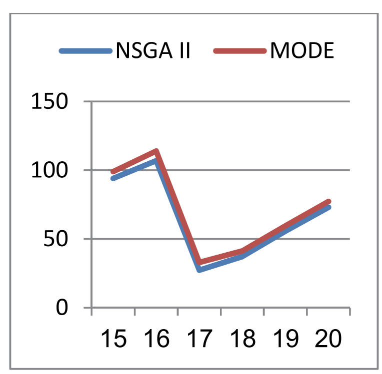

Fig. 6. Large sized test problems results related value at risk

4.3. Green considerations

Today, one of the most important factors to select and implement projects is green considerations. There are many industrial or projects with little or irreparable damage to environmental. For example, cement factory make that plants which are close to factory cannot grow for many years, so it may be considered as a lost cost. Hence, in many countries, governments determine heavy penalties to protect environment, they get some money as penalty depends on the type of project.

Sometimes penalties are too heavy which means this project is not economic to select. In this article, penalties of environmental damages should be paid at the end of project, and then it is calculated as the present value. Obviously, it is desirable to have the least penalties. As Figs. 7-9 indicate MODE solutions completely provide the lower amount of penalties than NSGA-II solutions for small and medium and large size problems.

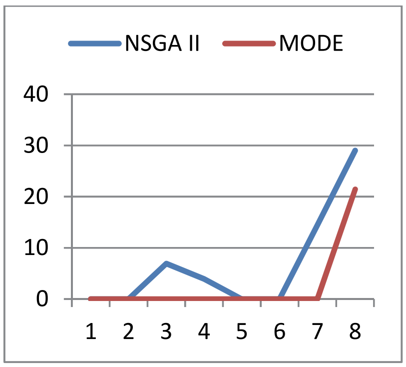

Fig. 7. Small sized test problems results related green penalties

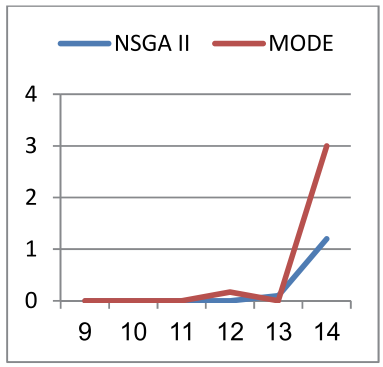

Fig. 8. Medium sized test problems results related green penalties

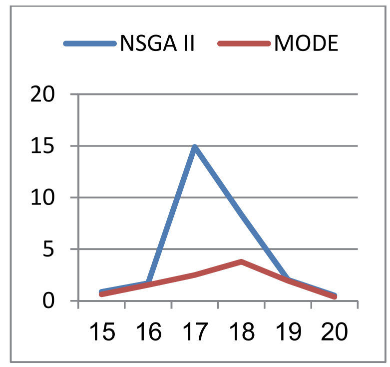

Fig. 9. Large sized test problems results related green penalties

4.4. Computational time

Required computational time for each algorithm to obtain solution displays efficiency of each algorithm. It is more desirable that an algorithm finds good solutions in less amount of time. Running time could be considered as an interesting criterion to compare the performance of different algorithms. Figs. 10-12 declare that NSGA-II needs less time to reach solutions than MODE in all small, medium and large scales of test problems.

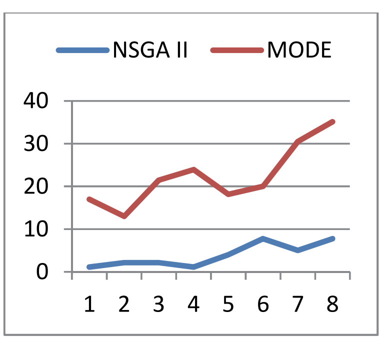

Fig. 10. Small sized test problems results related run times

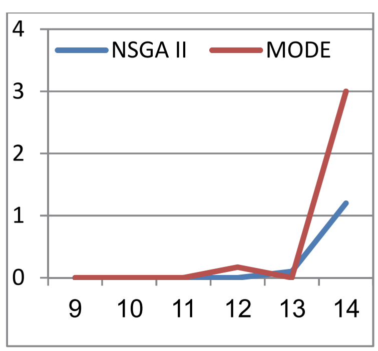

Fig. 11. Medium sized test problems results related run time

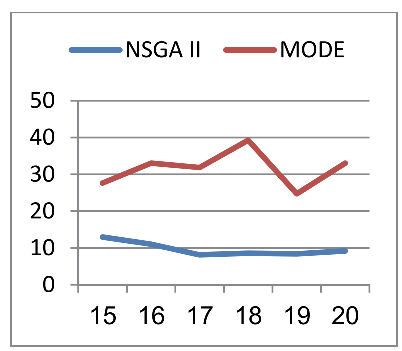

Fig. 12. Large sized test problems results related run times

4.5. Number of Pareto solutions

When there are multi objectives instead of single objective, we may find the number of solutions instead of an optimum solution called Pareto solutions. It could be interesting to have more Pareto solutions because they make more decision items suitable under different circumstances. Figs. (13-15) illustrate that the number of generated Pareto solutions from MODE is more than NSGA-II for test problems with small and large size. Also Fig. 14 indicates usually number of Pareto solutions got from MODE is more than NSGA-II in medium size, hence it could be claimed MODE often makes more Pareto solutions than NSGA-II for this problem.

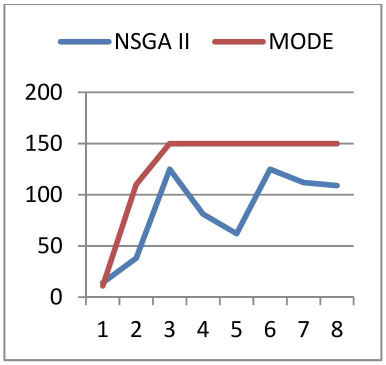

Fig. 13. Small sized test problems related to number of Pareto solutions

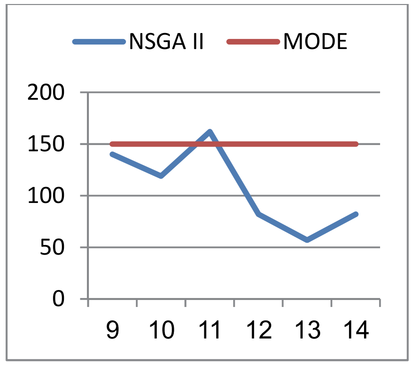

Fig. 14. Medium sized test problems related to number of Pareto solutions

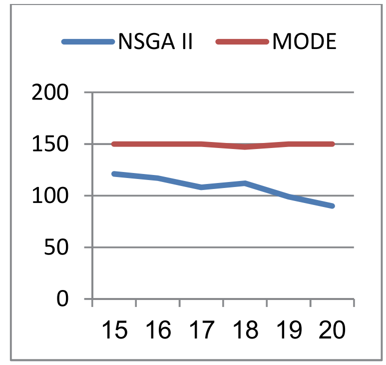

Fig. 15. Large sized test problems related to number of Pareto solutions

4.6. Spacing metric

This metric has been initially proposed by Scott (1995) and evaluates the degree of even distribution of the points in approximation Pareto set of the objective space. The formulation of this proposed metric has been presented as below by Rabbani et al. (2016):

$$\Delta = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\bar{d}-d_i)^2}$$

where ; $d_i = \min_j \left(\left| f_1^i(\vec{x}) - f_1^j(\vec{x}) \right| + \left| f_2^i(\vec{x}) - f_2^j(\vec{x}) \right| \right)$, $i,j = 1,2, \ldots n$.

For the proposed formulation, $\bar{d}$, is the mean of all d_i, and *n* is the size of known Pareto front. This metric has a very low computational overhead, and also, can be used in the case of more than two objective function algorithms (Grosan & Oltean, 2003). According to the above definition, this metric is better to have lower values. Fig. 17 demonstrates NSGA-II causes results with higher spacing than MODE in test problems with medium size. In Figs. (16-18) there are few results with NSGA-II superior performance, nevertheless it sounds MODE has more efficient than NSGA-II for small and large sizes.

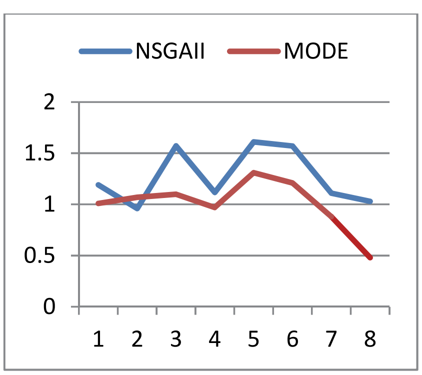

Fig. 16. Small sized test problems comparison of spacing

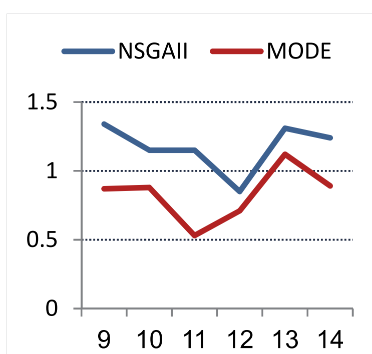

Fig. 17. Medium sized test problems comparison of spacing

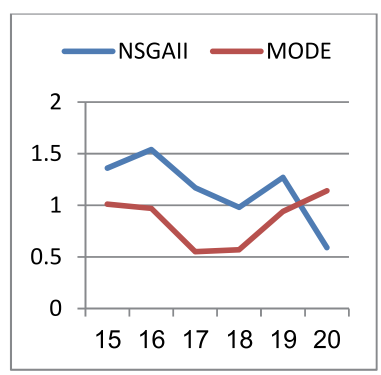

Fig. 18. Large sized test problems comparison of spacing

4.7. Diversity metric

In diversity metric, the obtained non-dominated points at each generation are projected on a suitable hyper plan. The plan is divided into a number of small grids. The diversity metrics is defined to be dependent on whether each grid contains an obtained non-dominated point or not. The best possible result is obtained if all grids are represented with at least one point. If some grids are not represented by a non-dominated point the diversity is poor. Hence, the diversity metric is better to take higher values . As mentioned before it is better to have solutions with high diversity. Figs. 20-21 show that for the test problems with medium and large size, MODE has produced solutions with more diversity compared with NSGA-II. Also, it is found from Fig. 19 that in problem with small size usually MODE induces more diversity than NSGA-II, hence MODE causes better effects than NSGA-II according to diversity metric.

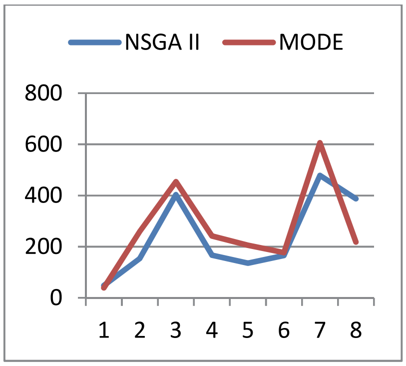

Fig. 19. Small sized test problems comparison of diversity

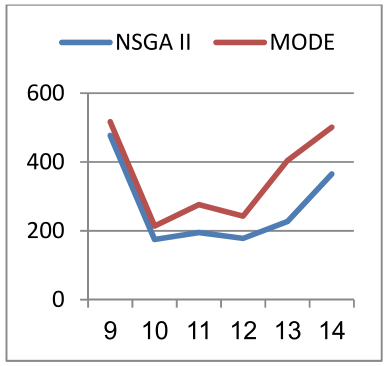

Fig. 20. Medium sized test problems comparison of diversity

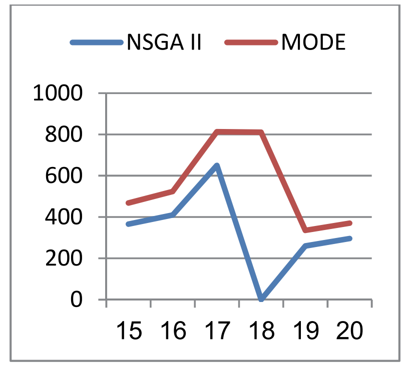

Fig. 21. Large sized test problems comparison of diversity

5. Conclusion

In this research, we have proposed a multi-objective project selection problem, which uses the concept of Value at risk to select combination of total or parts of projects for the first time. Moreover, our proposed model determines an amount of risk that the investor considers as a threshold in a specific confidence level. As the proposed model is an NP-hard problem, we have employed two multi-objective algorithms. One of them is NSGA-II, which is known as a robust multi-objective algorithm, and the other one is MODE, which is well applicable for real world problems. The performance of two proposed algorithm were compared with respect to seven comparison metrics. The results have shown the dominancy of MODE algorithm for almost all of the proposed metrics for all sizes of test problems.

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Appendix

Table A.1

Small sized test problems

test problem:1	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	60	0	46	56		60	0	0		4	6	5		0.09	0.021	0.01		3	1	4		50
project 2	87	34	45	181		50	71	0		3	4	7		0.5	0.1	1.07		2	6	5		20
test problem: 2	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	54	23	47	67		54	3	1		9	6	6		0.08	0.32	0.081		5	3	7		40
project 2	60	34	46	45		60	10	3		2	4	1		0.01	0	0.05		1	1	2		45
test problem: 3	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	120	80	150	119		100	140	80		2	1.7	3		1	0.07	0.2		11	13	15		120
project 2	120	90	50	150		90	80	100		3	2	1		0.04	0.01	0.05		10	14	9		250
project 3	110	100	150			95	130			2	3			0.09				10	10			100
test problem: 4	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	125	119	132	108		100	125	101		2	1.5	3		0.62	0.22	0.09		10	8	12		200
project 2	100	108	160	64	91	96	150	60	80	1.75	0.8	2	0.5	0.09	0.04	0.06	0.01	7	9	11	10	100
project 3	150	118	91	170		99	80	160		1.5	2	3		0.02	0.01	0.02		5	6	4		300
test problem: 5	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	12	10	20	30		12	8	7		3	2	6		0.001	0.05	0.03		1	3	1		80
project 2	15	28	13	33		15	25	4		4	3	5		0.1	0.4	0.2		2	1	1		20
project 3	10	30	23	31		10	11	7		2	7	3		1	0.9	0.5		2.5	2	3		60
project 4	56	28	17	104		54	30	2		3	2	1		0.5	0.01	0.09		1.5	1.3	1.2		43
test problem: 6	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	37	20	40	69		28	29	12		3	2	1		1	0.9	1.5		3	2	2		60
project 2	40	10	90			40	10			4	1			1.5	1.4			1	2			55
project 3	30	24	32	22		30	1	1		3	3	2		2	3	1		2	3	1		40
project 4	10	18	45	21		10	10	10		1.5	2	1.9		0.9	1.2	0.09		1	1.5	1		69
test problem: 7	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	90	80	20			90	0			5	4			0.03	0.08			10	5			210
project 2	100	110	80			100	50			4.5	4.3			2	1			7	9			120
project 3	100	80	100	150		90	110	115		4.4	5.5	4		0.01	0	0.02		8	1	5		180
project 4	100	120	110	110		100	100	110		5.7	5.5	3		2	0.01	0.03		4	5	9		200
project 5	80	90	80	120		80	90	80		2	2.3	3.4		1	5	3		6	3	4		77
test problem: 8	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	48	50	70			48	50			2	1			1	0.05			8	4			190
project 2	110	120	50	115		110	60	100		3	5	3		0.05	0.01	0.7		7	8	4		130
project 3	82	90	110			80	92			9	7			0.01	0.2			7	6			140
project 4	90	150	40			90	65			5	4			2	0			5	8			78
project 5	100	180				100				7				0.5				6				110

Table A.2
Medium sized test problems.

test problem:9	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	30	23	25			30	12			5	4			2	3			4	5			90
project 2	60	70				60				5				0.21				5				56
project 3	34	10	40			34	0			3	2			0.4	0.13			3	2			80
project 4	31	20	10	100		30	21	60		3	1	4		0.5	0.5	0.4		2	3	2		75
project 5	20	20	30	40	50	40	30	20	10	2	1	5	2	1	2	1	0.5	2	2	2	2	78
project 6	40	80				40				2				0				4				69
test problem:10	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	22	42				20				5				2				5				68
project 2	21	31	42			21	19			4	3			2	1			3	4			55
project 3	31	40				31				3				1.5				3				40
project 4	32	48	45	33		32	20	10		1	2	1		0.05	0.4	1		2	2	1		54
project 5	25	30				25				4				0				2				60
project 6	30	26	32			30	2			3	2			0.4	0.67			2	3			48
test problem: 11	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	20	34	44			20	32			3	2			0.4	1			2	1			52
project 2	18	45				27				3				4				3				49
project 3	42	32	22	12		42	10	5		4	3	5		1	2	1		3	2	1		44
project 4	32	44				32				3				1				3				37
project 5	44	50				44				2				0				5				65
project 6	20	32	35			20	12			1				2	2			3	1			70
project 7	22	42				22				2				0.05				2				55
test problem:12	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	40	52				40				4				2				5				68
project 2	31	31	42			31	19			2	3			1	3			3	3			59
project 3	31	40				31				3				1.5				3				40
project 4	32	48	45	33		32	20	10		1	2	1		0.05	0.4	1		2	2	1		54
project 5	25	30				25				4				0				2				60
project 6	30	26	32			30	2			3	2			0.4	0.67			2	3			48
project 7	29	51				29				5				3				5				42
test problem:13	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	10	12	21	29		10	10	2		2	2	3		0.02	0.05	0.03		2	3	1		77
project 2	15	20	13	33		15	2	3		2.9	3	5		0.1	0.4	0.2		2	1	1		42
project 3	12	32	24	29		12	15	3		2	3.4	2		1	1	0.5		3	1	2		62
project 4	30	28	16	99		30	21	2		3	2	1		0.5	0.01	0.08		2	1	1.2		55
project 5	36	21	37	66		28	7	13		3	2	3		1	3	1		5	6	3		57
project 6	30	11	90			30	9			1.4	2			1.4	2.8			2	1.9			65
project 7	30	24	32	22		30	1	7		3	3	2		2	3	1		2	3	3		55
project 8	33	18	45	21		33	6	5		1	2	2		0.03	0.4	0.9		2.5	2	2		68
test problem:14	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	70	80	40			70	10			2	1			0.66	0.4			4	3			42
project 2	41	29	70	20		40	30	10		2	3	3		0.3	0.3	0.33		5	4	3		55
project 3	60	85	65			60	30			4	3			1	0.7			8	7			70
project 4	75	88	93			75	55			3	2			0.3	0.4			4	4			70
project 5	84	79	130	100		84	69	88		9	2	2		0.3	0.4	0.5		4	4	5		66
project 6	60	56	60			60	10			4	3			0.3	1.01			3	3			72
project 7	110	135				110				3				0.5				4				70
project 8	90	100	95	60		90	80	50		3	5	3		0.4	0.6	0.8		4	7	1		76

Table A.3

Large sized test problems

test problem: 15	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	71	75	93			68	78			2	1			1	0.8			5	8			115
project 2	150	178				150				4				0.8				7				100
project 3	69	5	51	61		69	5	0		3	2	5		0.01	0.03	0.09		2	3	4		88
project 4	55	37	49	190		55	73	32		2	3	4		1	0.6	1.5		3	6	6		70
project 5	28	45				28				2				3				3				90
project 6	50	43	43			50	5			1	2			0.9	0.8			1	2			94
project 7	83	90				83				0.5				1				5				0
project 8	50	70	60	50		50	60	40		1	3	4		0.9	1	1.2		1	1	3		55
project 9	70	80				70				2				0				0				94
test problem: 16	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	178	230	200			178	190			1	2			1	1.02			5	4			230
project 2	70	240	96			250	70			1	1			0.09	0.05			2	2			220
project 3	80	100	120	125		80	110	122		0.5	2.5	1.5		0.4	0.04	1		4	3	3		189
project 4	80	105	100			80	80			2	3			0.8	1			1.4	1			200
project 5	60	100	89			60	50			1	2			1	2			0.2	0.5			210
project 6	49	50	40			26	29			3	2			0.4	1			1	2			209
project 7	90	100	80			90	90			9	5			2	0.9			0	0.4			225
project 8	67	88	78	92		67	50	70		4	1	7		0	0.02	0.09		1	0.4	0		217
project 9	78	170	115			78	77			7	1			0.9	1.2			1.4	2			206
test problem:17	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	110	100	90			110	70			5	8			0.7	0.3			13	5			35
project 2	70	80	90	115		70	80	100		3	4	3.5		0.2	0.3	0.4		4	5	14		65
project 3	70	85	65			70	70			4.5	4.5			0.2	0.7			7	12	7		75
project 4	93	90	103			80	89			2	2.4			0.2	0.1			4	5			95
project 5	85	80	73	105		85	70	90		10	3	3		0.3	0.4	0.6		3	5	7		100
project 6	140	160	140			140	132			5	3			0.2	1			4	3			105
project 7	110	120	100			110	95			6	6			0.1	0.2			7	6			110
project 8	95	100	120	111		95	110	99		4	5	4		0.7	0.8	0.9		5	8	1		115
project 9	75	80	90			70	75			6	5			1	0.01			4	7			120
project 10	160	180				160				5				0.9				6				125

Table A.3

Large sized test problems (Continued)

test problem:18	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	178	200	200			178	190			4	2			0.1	0.01			5	4			100
project 2	70	230	96			250	70			2	3			2	6			2	2			150
project 3	80	100	120	125		80	110	122		4	7	6		0.4	0.04	1		4	3	3		240
project 4	90	105	95			90	100			9	4			0.8	1			3	7			88
project 5	67	100	89			67	50			5	8			1	2			0.2	0.5			90
project 6	49	50	40			49	35			9	5			0.4	1			4	0.6			238
project 7	90	100	80			90	90			9	5			2	0.9			0	0.4			206
project 8	67	78	78	92		67	70	89		4	9	7		0.7	0.85	0.09		1	0.4	0		342
project 9	167	170	115			167	170			4	8			0.4	0.7			0.6	0.5			234
project 10	123	80	70			123	133			1	5			0.1	0.9			2	1			90
test problem:19	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	20	30	20			20	10			2	6			0.1	1			1	2			30
project 2	30	20	35			30	5			3	5			0.01	0.9			2	1			28
project 3	40	52				40				7				0.5				5				20
project 4	20	30	20	10		20	11	7		9	1	2		1	0.5	0.2		1	1	1		32
project 5	47	60				47				5				0.9				1				47
project 6	30	40	50	60		30	40	20		8	2	4		0.06	0.5	1		1	2	3		29
project 7	40	35	22	10		40	10	2		2	6	8		0.4	2	0		1	1	6		32
project 8	70	67	30			70	20			1	3			0.2	0.7			2	1			27
project 9	39	50				39				2				0.18				5				46
project 10	22	20	10			22	0			2	3			0.09	0.02			0	3			45
project 11	34	40				34				6				0.6				8				19
test problem: 20	R0	b11	b12	b13	b14	c11	c12	c13	c14	d11	d12	d13	d14	σ11	σ12	σ13	σ14	q11	q12	q13	q14	L
project 1	10	20				10				2				0.5				5				40
project 2	26	32				26				3				0.01				1				38
project 3	20	24	13			20	10			2	3			0.01	0.05			2	3			32
project 4	7	15				7				4				0				7				28
project 5	24	33	24	12		24	18	8		2	3	4		1	0.5	0.07		3	2	5		30
project 6	22	30				22				3				1				5				27
project 7	37	44	12			37	7			5	4			0.02	3	0.9		10	2	1		25
project 8	44	50				44				2				2				5				35
project 9	22	27	32	45		22	29	38		2	3	4		2	2	2		1	1	2		36
project 10	19	25				19				3				2				3				39
project 11	28	36				28				4				0.6				7				30