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Developing and Solving an One-Zero Non-Linear Goal Programming Model to R and D Portfolio Project Selection with Interactions Between Projects

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Abstract: Because of limited resources, organizations, often have to make crucial decisions regarding selection and scheduling of a project portfolio among the candidate projects. A poor decision might affect the organization in two ways: first, by wasting the organization's resources (monetary cost), investing them in weak and non-strategic projects and second, by losing the opportunity to invest the resources in more profitable projects (opportunity cost). Hence, selecting a rich portfolio has been always an important role of project managers. In portfolio selection, the impact of one project selection on another projects selection is not studied widely. In this research the project portfolio selection was studied from a system perspective. In a system perspective, as a result of interactions between the components in the system, the whole is not necessarily equal to the sum of its parts. In this study, the project portfolio selection and scheduling are integrated in one model and formulated as a bi-objective non-linear problem. A goal programming technique is proposed to solve this model and find the optimal portfolio together with the scheduling of selected projects. Some limitations such as budget, resources and scheduling constraints have been considered in this case also the projects may have strengthening and weakening effects on the profit, risk and costs of other projects that is considered in this study.

Key words: Project portfolio, research and development projects, goal programming, interactive effects, interdependency

INTRODUCTION

Since scientific introduction of capital and investment in profit and risk analysis of investors, the most significant concern and question on their behalf was that how certain resources of funding can be allocated among the various options so that the maximum profit with the minimum risk be held on the investor. The first scientific approach to select the optimal portfolio was known as mean-variance model presented by Markowitz (1952) which could play a key role in portfolio selection theory and also brought about a Noble prize on economic for its designer. Markowitz's modern theory of portfolio provided the investors with new paradigm to select a portfolio with the highest rate of return in determined or minimum level of risk in a given level of expected return (Markowitz, 1952, 1959). Prior to his theory, the published theory about investment was a traditional one. Although, the concept of portfolio selection, based on Markowitz theory was initially introduced for selecting stock portfolio but later developed to other areas one of which is projects portfolio selection. One of the differences between project portfolio selection and stock portfolio selection is that in the former if a project is selected and then is started there is no other opportunity to sell or remove it, while in the later it is provided to sell the stock whenever possible. For this reason project portfolio selection is more sensitive than stock portfolio selection to the wrong decision. Stock portfolio selection and project portfolio selection are same in objects and different in constraints and variables. Variables in Stock portfolio selection are continuous and in project portfolio selection are discrete. Also there may be interdependency among the different projects which cause inequality of profit (cost) earned by various projects with total profit (cost) earned by individual project.

Regarding to the resource restrictions, the project portfolio selection is defined as "projects selection and optimal resources allocation to them during the studied period so that return rate and the all other intended functions would be optimized (Kraslawski, 2006; Solak *et al*., 2010).

Review of literature: Markowitz (1952) published his first study which was really the basis for modern portfolio analysis. In the last 5 decades, Mean-variance model

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served as basis for development of modern financial theory. Establishing the Risk-return framework for investors' decisions is the most significant role supposed for the theory. Previously, investors were informed about the necessity of considering risk along with efficiency but it was Markowitz who tried for the first time to formulate the portfolio selection theory under the uncertain conditions in the form of mathematical model. Most attempts developed by experts in this field were carried out to solve and develop Markowitz theory. According to the real market limitations, the attempts are intended to make the model more applicable. Totally, the research carried out about portfolio selection can be broken down into two general categories:

- The studies which select their own intended portfolio based on MADM (Multi Attribute Decision Making) methods
- The studies which select their own intended portfolio based on the MODM (Multi Objective Decision Making) methods

Studies on the first category: Kumar (2004) and Dey (2006) applied AHP method to evaluate the project portfolio. Huang *et al*. (2008) applied Fuzzy AHP to select R and D projects. Tiryaki and Ahlatcioglu (2009) applied Fuzzy AHP method to assess portfolio project and Feng *et al*. (2010) applied AHP method to assess collaborative R&D projects. Promethee methodology was implemented by Rudolf and colleagues for assessing project portfolio.

Studies on second category: In fact, later studies carried out on portfolio selection are intended to develop Markowitz theory. Initial model introduced by Markowitz (1952) was intended to maximize the profit gained by portfolio and to minimize the risk of selected portfolio. His definition of risk was a kind of deviation from expected mean called variance. After that lots of models have been introduced by others. The models introduced by Zhang *et al*. (2006) and Ma (2011) for portfolio selection were intended to minimize the portfolio's average risk so that the average portfolio profit is at least equal to M. In these studies, the concept of variance has been used for measuring risk. Joro and Na (2006) presented a model for portfolio selection which aims three goals: maximizing average profit, maximizing traction and minimizing risk. Rabbani *et al*. (2006) presented one-zero goal programming model for portfolio selection. In addition to selection, the model is able to schedule the projects. Minimizing sum of weighted deviations from expected mean, deviation from expected mean and deviation from intended resources are the objective functions of the present study and limitation related to project scheduling (prerequisite, ...) are of the model restrictions (Rabbani *et al*., 2012). Christer Carlsson et al., 2007 applied Fuzzy approach for R and D project portfolio selection. In this paper, trapezoidal Fuzzy numbers were applied to forecast future cash flow (Christer *et al*., 2007). Fang *et al*. (2008) investigated a compound portfolio. The portfolio was combination of R&D projects and securities. Zero-one and continuous programming have been used for modeling the projects and securities, respectively. Jana *et al*. (2007) introduced a MVS three-objective model for portfolio selection. Jafarizadeh and Khorshid-Doust (2008) applied the concept Semi variance for measuring risk. They believed that not all the deviations apart from mean are desirable and every result or consequence better than goal are not subjected to risk and are even desirable. Chen and Askin (2009) tried to maximize final portfolio profit using zero-one programming but the point here is that the profit from each project is dependent on the termination time. In the other word, the profit is depended on time. In the study, the limitations are in terms of scheduling and resources. It means that portfolio selection is performed simultaneously with scheduling. Here, risk is not taken into account. Carazo *et al*. (2010) presented zero-one programming model in order to maximize portfolio's profit in which the scheduling is performed simultaneously with the portfolio selection. Chang and Lee (2012) introduced a DEA (Data Envelopment Analysis) model for portfolio selection.

The conclusions of the studies conducted: Reviewing previous studies and literature on solving the problems related to portfolio selection, the results are supposed as: despite the long-lasting introduction of optimal portfolio project in the literature, the studies conducted indicate that the most significant concern of investors is making decision about investment. Despite passing more than half a century of Markowitz efficient theory, in addition to all the development implemented on it during the times, the model is accompanied with some assumptions (for example, independency of projects). Markowitz model and the studies carried out indicate that mostly, variance is considered as indicator of risk but it is not the case that all the deviations are always undesirable. Here, positive deviations or the values more than the predicted efficiency rate is not only considered as risk but also considered as mean for increasing profit. Therefore, Semi-variance has been presented in risk calculation that takes only into account the negative and undesirable deviations of return's rate. The most studies on portfolio selection, either those studies which select the portfolio based on the multi-criteria decision making or the studies which were intended to solve the portfolio selection problems based on multi-objective decision making and Markowitz model development, supposed that the options and criteria in the first and second categories are independent options. A limited number of studies which investigated options' dependency (projects) are only concentrated on time dependency of the options.

MATERIALS AND METHODS

Suppose there is an n-project proposal for an organization which is intended to select the best portfolio among a set of objectives and limitations. Assuming that the planning time horizon is divided into T periods in which the decision variable of the problem would be as follow:

$$x_{it} = \begin{cases} 1 & \text{If ith project started at tth period} \\ 0 & \text{otherwise} \end{cases}$$

So, the response vector x = ($x_{11}, x_{12}, ..., x_{21}, x_{22},..., x_{2T},..., x_{n1}, x_{n2},..., x_{nT}$) is a binary vector T×n which is an indicator for optimal portfolio. If ith project started at tth period and it takes d_i period to be finished then at the kth period of planning horizon: the ith project is in k-t+1th years of its implementation. If k-t+1 ≤0 then it means that the project is not started and if k-t+1>d_i then it means that the project is terminated. The condition according to which the ith project should be in progress at kth period is that:

$$\sum_{t=k-d_i+1}^{k} x_{it} = 1$$

Where:

- x_{ij} = Decision variable
- $x_{ij} = 1$ = If ith project being selected in optimal portfolio and started at jth period
- $x_{ij} = 0$ = If ith project is not started at jth period
- n = No. of proposed project
- b_i = The expected profit or income for i^{th} project
- d_i = Duration of project i
- c_i = The cost necessary for ith project implementation
- r_i = The ith project risk and likely that profit from anticipated ith project is less than b_i
- m_i = The resources necessary for implementing the ith project
- M = Available resources
- B_k = The budget available at kth period
- B = The total available budget for planning horizon
- IB = Ideal profit level
- IR = Acceptable risk level

Objective functions: In the present study, the proposed model is intended to optimize two objectives in which the first objective is to maximize profit as follow:

$$\max Z_1 = \sum_{i=1}^{n} b_i \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} b_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} b_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + ... \quad (1)$$

The total benefit from the projects will be obtained by considering the sum of individual benefits and additional benefit due to benefit interdependency. Second object is to minimize risk and is modeled as follow:

$$\min Z_2 = \sum_{i=1}^{n} r_i \sum_{t=1}^{T} x_{it} + \left[\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} r_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} r_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + ...\right] \quad (2)$$

In two these models, the parameter b_{ij} is amount of additional profit which is achieved due to selection of two I and j projects simultaneously and the same is true about r_{ij} which is additional risk level. The b_{ijk} and r_{ijk} are amount of additional profit and risk which are achieved due to selection of i, j and k projects simultaneously which are obtained from Eq. 3.

$$\begin{aligned} b_{ij} &= b(i,j) - b_i - b_j \\ b_{ijk} &= b(i,j,k) - b_i - b_j - b_k - b_{ij} - b_{ik} - b_{jk} \end{aligned} \quad (3)$$

where, b(i,j) is total benefit acquired due to selection of projects i and j. It is worth to say that b_{ij} and r_{ij} can be positive, negative or zero (provided that the projects have strengthening and weakening impact on each other or is independent). Marichal and Roubens (2000); Kojadinovic, 2004, 2005).

Restrictions of the model: The first restriction on the proposed model is budget limitation. If we take the highest level of budget determined by organization in the kth period as B_k, it can be presented as follow:

$$C_k(x) = \sum_{i=1}^{n}\sum_{t=1}^{k} c_{i,k-t+1} x_{it} - \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k} c_{i,j,k-t+1} x_{it} x_{jt} - \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k} c_{i,j,z,k-t+1} x_{it} x_{jt} x_{zt} - ... \le B_k + (B_{k-1} - \sum_{i=1}^{n}\sum_{t=1}^{k-1} c_{i,k-t} x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k-1} c_{i,j,k-t} x_{it} x_{jt} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k-1} c_{i,j,z,k-t} x_{it} x_{jt} x_{zt} + ...(1+i) \quad (4)$$

This expression means that the part of remained budget from previous period which is not allocated, is saved in a bank with interest rate i and it can be used in the next period. So the point here is that the total cost spent for a given period should not be more than total budget of current period plus additional budget allocated for previous period. Another limitation supposed here is related to technical human resource which includes:

$$\sum_{i=1}^{n}\sum_{t=1}^{k} m_{i,u,k-t+1}x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k} m_{i,j,u,k-t+1}x_{it}x_{jt} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k} m_{i,j,z,u,k-t+1}x_{it}x_{jt}x_{zt} + \ldots \leq M_u \quad (5)$$

Human resource used during the total programming period is defined as total human resource used in each project plus additional required human resource or minus reduced human resource because of the project interdependency. Another limitation considered here is scheduling. Each project shouldn't be performed more than one time during total programming period. Thus, it is formulated as follow:

$$\sum_{t=1}^{T} x_{it} \leq 1 \qquad \forall i \quad (6)$$

In the other hand, if ith project is as prerequisite for jth project, the later should be postponed till the termination of former. The jth project shouldn't be performed if ith project is not started. This restriction is defined as follow:

$$\sum_{l=1}^{T} l x_{jl} \geq \sum_{l=1}^{T} (l + d_i) x_{il} \quad , \quad \sum_{l=1}^{T} x_{il} \geq \sum_{l=1}^{T} x_{jl} \quad (7)$$

In which i is prerequisite for j. Of course, if ith project is coordinated for jth project, so It means either both project or none of them should be implemented. This limitation is indicated as follow:

$$\sum_{l=1}^{T} l x_{jl} = \sum_{l=1}^{T} l x_{il} \quad (8)$$

And if there are some projects which need to be implemented, they should be selected in this model. This restriction is formulated as follow:

$$\sum_{t=1}^{T} x_{it} = 1 \qquad \forall i \text{ that i is mandatory} \quad (9)$$

However, incompatible project shouldn't be selected together. This restriction is formulated as follow:

$$\sum_{t=1}^{T} x_{it} + \sum_{t=1}^{T} x_{jt} + \sum_{t=1}^{T} x_{kt} + \ldots \leq 1 \quad (10)$$
$$\forall i, j, k, \ldots \text{that i, j, k,... are incopmatible}$$

Solving the model: The goal programming method is used to solve the proposed model. First, in the method a goal is determined for each objective. The goal here is to minimize the weighted undesirable deviations of goal in each of the objectives. Therefore, according to the predefined objectives in the previous section, the final objective in goal programming is as follow:

$$\min Z = w_1 \times d_1^+ + w_2 \times d_2^- \quad (11)$$

In the above equation, d_1^+ is defined as the degree of positive deviation (unwanted) from the first objective function named profit and d_2^- is defined as degree of negative deviation (unwanted) from objective function named risk, w_1 and w_2 are weights of each deviation determined by decision makers. Both w_1 and w_2 are equal or greater than zero. The greater the w_i the more important the object i. It is not necessary $w_1+w_2 = 1$.

The IB is the goal for benefit, clearly if benefit acquired from portfolio be greater than IB, it is desirable. d_1^- is desirable deviation from IB. but it is unwanted that total benefit be less than IB, d_1^- is desirable deviation. IR is acceptable risk for portfolio clearly if total risk acquired from portfolio be less than IR, it is desirable. The d_2^+ is desirable deviation from IR. but it is unwanted that total risk be greater than IR, d_2^- is unwanted deviation. In the other hand, according to the goal programming method, primary objective functions are presented in the form of goal (ideal) restrictions. The two new restrictions added to the previous restriction are as follow:

$$\sum_{i=1}^{n} b_i \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} b_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} b_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + \ldots + d_1^+ - d_1^- = IB \quad (12)$$

$$\sum_{i=1}^{n} r_i \sum_{t=1}^{T} x_{it} + \left[\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} r_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} r_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + \ldots \right] + d_2^+ - d_2^- = IR \quad (13)$$

Given this description, the final model problem which is a one-zero nonlinear goal programming model is as follow:

$$\min Z = w_1 \times d_1^+ + w_2 \times d_2^- \quad (14)$$

$$\sum_{i=1}^{n}\sum_{t=1}^{k} c_{i,k-t+1}x_{it} - \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k} c_{i,j,k-t+1}x_{it}x_{jt}$$
$$-\sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k} c_{i,j,z,k-t+1}x_{it}x_{jt}x_{zt} - \ldots \le$$
$$B_k + (B_{k-1} - \sum_{i=1}^{n}\sum_{t=1}^{k-1} c_{i,k-t}x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k-1} c_{i,j,k-t}x_{it}x_{jt}$$
$$+\sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k-1} c_{i,j,z,k-t}x_{it}x_{jt}x_{zt} + \ldots)(1+i)$$

$$\sum_{i=1}^{n}\sum_{t=1}^{k} m_{i,u,k-t+1}x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{t=1}^{k} m_{i,j,u,k-t+1}x_{it}x_{jt}$$
$$+\sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{z=j+1}^{n}\sum_{t=1}^{k} m_{i,j,z,u,k-t+1}x_{it}x_{jt}x_{zt} + \ldots \le M_u$$

$$\sum_{t=1}^{T} x_{it} \le 1 \qquad \forall i$$

$$\sum_{l=1}^{T} l x_{jl} \ge \sum_{l=1}^{T}(1+d_i)x_{il} \quad , \quad \sum_{l=1}^{T} x_{il} \ge \sum_{l=1}^{T} x_{jl}$$
$\forall i, j$ which i is Prerequisite for j

$$\sum_{l=1}^{T} l x_{jl} = \sum_{l=1}^{T} l x_{il}$$
$\forall i, j$ which i, j are coordinated

$$\sum_{t=1}^{T} x_{it} = 1$$
$\forall i$ which i is mandatory

$$\sum_{t=1}^{T} x_{it} + \sum_{t=1}^{T} x_{jt} + \sum_{t=1}^{T} x_{kt} + \ldots \le 1$$
$\forall i, j, k, \ldots$ that $i, j, k, \ldots$ are incopmatible

$$\sum_{i=1}^{n} b_i \sum_{t=1}^{T} x_{it} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} b_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} +$$
$$\sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} b_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + \ldots + d_1^+ - d_1^- = IB$$

$$\sum_{i=1}^{n} r_i \sum_{t=1}^{T} x_{it} + \begin{bmatrix} \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} r_{ij} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} + \\ \sum_{i=1}^{n-2}\sum_{j=i+1}^{n-1}\sum_{k=j+1}^{n} r_{ijk} \sum_{t=1}^{T} x_{jt} \sum_{t=1}^{T} x_{it} \sum_{t=1}^{T} x_{kt} + \ldots \end{bmatrix}$$
$$+d_2^+ - d_2^- = IR$$
$$x_{ij} = 0 \text{ or } 1 \qquad \forall i, j$$

RESULTS AND DISCUSSION

Numerical example: The data presented by 6 other projects have been considered to evaluate the performance of the proposed model. The data are presented in Table 1. In the other hand, data related to the project interdependency are presented in Table 2. The resulted model is solved using Lingo 13 software and the optimized portfolio is as follow:

$$0\left[x_{ij}\right] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

In the above optimized response, first project, third project and fifth and sixth ones should be implemented in first, third and second period of programming schedule, respectively. Second and fourth project are not considered in optimal portfolio. Scheduling of the selected portfolio is presented in Fig. 1.

Table 1: Project information

					Necessary resources	
Project	Profit	Risk	Duration (year)	Necessary funding	Other	Human
P1	17.00	0.55	2	3.75 (3.75)	9	30
P2	7.250	0.46	2	5.0 (1.25)	10	12
P3	5.500	0.65	2	1.4 (1.2)	27	18
P4	1.500	0.50	2	1.1 (1.0)	17	17
P5	11.50	0.45	2	5.0 (2.2)	6	10
P6	11.25	0.65	2	5.0 (1.5)	12	10

Table 2: Project interdependency on profit, cost, risk and human resource

Profit	Value	Cost	Value	Risk	Value	Human resource	Value
P1, 6	0.03	P1, 2	0.18	P1, 2	0.10	P1, 6	5
P2, 3	0.05	P3, 5	0.30	P1, 3	0.05	P3, 4	3
P2, 6	0.65	P3, 6	0.05	P1, 4	0.15	P3, 5	2
P3, 5	2	P4, 6	0.5	P1, 6	0.12	P3, 4, 5	7
P1, 3, 5	3.75	P2, 5, 6	0.17	P4, 5	0.20		
		P1, 3, 5	0.40	P4, 6	0.35		
		P2, 4, 6	0.006	P2, 3	0.12		
				P2, 4	0.46		
				P3, 4	0.28		
				P3, 5, 6	0.32		

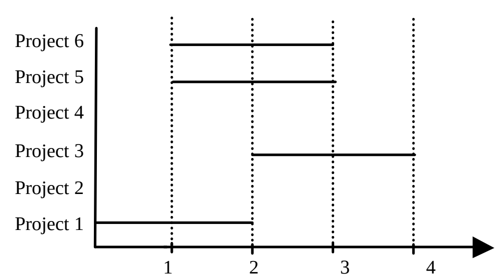

Fig. 1: Project portfolio scheduling

CONCLUSION

One of the major activities performed by organizations' managers particularly in R and D is project selection. Strengthening and weakening affects among the projects in terms of cost, profit and risk, are issues that have been given less attention in the literature. In this study, one-zero non-linear goal programming model has been introduced for selecting and scheduling R and D projects. Final objective function in the proposed model is defined as minimizing total weighted unwanted deviations from the ideals (goals) which are considered for two primary objective functions namely maximizing profits and minimizing risks. The model restrictions are also included: first category is consisted of the systematic restrictions including budget restriction, human resource and scheduling and second category is consisted of goal restrictions which are indicators of the ideals (goals) determined by decision makers for two main objective functions. The results obtained by solving the proposed model based on numerical sample are shown.

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