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NEUTROSOPHIC FUZZY QUADRATIC PROGRAMMING PROBLEM AS A LINEAR C COMPLEMENTARITY PROBLEM USING TAYLOR SERIES APPROACH

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Abstract

This paper presents a new approach to solve Neutrosophic Fuzzy Quadratic Programming Problem (FNQPP) using a Taylor Series. Moreover, the truth membership, indeterminacy membership and falsity membership associated with each objective of Neutrosophic Fuzzy Multi objective Quadratic Programming Problem are transformed to a single objective linear Complementarity problem by using a Taylor Series. The efficacy of the proposed method is illustrated by means of a numerical example.

1. Introduction

Fuzzy set (FS) is used to tackle the uncertainty using the membership grade, whereas neutrosophic set (NS) is used to tackle uncertainty using the truth, indeterminacy and falsity membership grades which are considered as

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independent. The concept of Neutrosophic set (NS) was first introduced by Smarandache [6, 7] which is a generalisation of classical sets, fuzzy set, intuitionistic fuzzy set etc. The linear complementarity problem (LCP) is a well-known problem in mathematical programming and it has been studied by many researchers in the past few decades. LCP is a general problem that unifies linear, quadratic programs and bimatrix games. In 1968, Lemke [10] proposed a complementary pivoting algorithm for solving linear complementarity problem and Katta G. Murthy [9] studied about linear and nonlinear programming problems. Fuzzy systems and Intuitionistic fuzzy systems cannot successfully deal with a situation where the conclusion is adequate, unacceptable and decision maker declaration is uncertain. The neutrosophic sets reflect on the truth membership, indeterminacy membership and falsity membership concurrently, which is more practical and adequate than fuzzy sets and intuitionistic fuzzy sets. Single valued neutrosophic sets are an extension of neutrosophic sets which were introduced by Wang et al. [8], This paper approach goes to M. Duran Toksari, [1], A. Nagoorgani [3], R. Irene Hepzibah [12] proposed multi objective quadratic programming problem using the Taylor series. Therefore, attempts were made to develop more general mathematical programming methods and many significant advances have been made in the area of multi-objective nonlinear programming. This paper is organized as follows. In Section 2, some basic concepts related with Neutrosophic sets and multi-objective quadratic programming problems are provided. Section 3 deals with an algorithm for solving a Neutrosophic fuzzy multi-objective quadratic programming problem. Section 4, deals with an algorithm for solving a neutrosophic fuzzy linear complementarity problem. Finally in Section 5, the effectiveness of the proposed method is illustrated by means of an example.

2. Preliminaries

Definition 2.1. Let E be a universe. A Neutrosophic set A over E is defined by $A = \{\langle x, (T_A(x), I_A(x), F_A(x))\rangle : x \in E\}$ Where $T_A(x), I_A(x)$, $F_A(x)$ are called the truth-membership function, indeterminacy membership function and falsity membership function respectively. They are respectively defined by $T_A : E \to \left]^{-}0, 1^{+}\right[$, $I_A : E \to \left]^{-}0, 1^{+}\right[$, $F_A : E \to \left]^{-}0, 1^{+}\right[$, such that $0^{-} \leq T_A(x) + I_A(x) + F_A(x) \leq 3^{+}$.

Definition 2.2. A single valued triangular neutrosophic number (SVTN) $\widetilde{A} = \langle (a, b, c); w_{\widetilde{a}}, u_{\widetilde{a}}, y_{\widetilde{a}} \rangle$ is a special neutrosophic set on the real number set R, whose truth-membership, indeterminacy-membership and a falsity membership are given as follows:

$$\mu_{\widetilde{a}}(x) = \begin{cases} \dfrac{(x-a)w_{\widetilde{a}}}{(b-a)}, & a \le x \le b \\ w_{\widetilde{a}}, & x = b \\ \dfrac{(c-x)w_{\widetilde{a}}}{(c-b)}, & b \le x \le c \\ 0, & \text{otherwise} \end{cases}, \quad v_{\widetilde{a}}(x) = \begin{cases} \dfrac{(b-x+u_{\widetilde{a}}(x-a))}{(b-a)}, & a \le x \le b \\ \mu_{\widetilde{a}}, & x = b \\ \dfrac{(x-b+u_{\widetilde{a}}(c-x))}{(c-b)}, & b \le x \le c \\ 0, & \text{otherwise} \end{cases},$$

$$\lambda_{\widetilde{a}}(x) = \begin{cases} \dfrac{(b-x+y_{\widetilde{a}}(x-a))}{(b-a)}, & a \le x \le b \\ y_{\widetilde{a}}, & x = b \\ \dfrac{(x-b+y_{\widetilde{a}}(c-x))}{(c-b)}, & b \le x \le c \\ 0, & \text{otherwise.} \end{cases}$$

2.3 Multi-objective quadratic programming problem

A multi-objective programming problem may be stated as:

Minimize $[z_1(x), z_2(x), \ldots, z_k(x)]$

Subject to, $Ax \overset{\le}{\underset{>}{=}} b$, $x \ge 0$, $x \in X$

where $z_j(x)$, $j = 1, 2, \ldots, n$ is an N vector of cost coefficients, A an $m \times N$ coefficients matrix of constraints and b an m vector of demand, the problem stated above is a multi objective quadratic programming problem subject to linear constraints.

3. Neutrosophic fuzzy multi-objective quadratic programming problem

A multi-objective programming problem may be stated as:

Minimize $[\widetilde{z}_1(x), \widetilde{z}_2(x), \ldots, \widetilde{z}_k(x)]$

Subject to, $\widetilde{A}x \overset{\le}{\underset{>}{=}} \widetilde{b}$, $x \ge 0$, $x \in X$

where $\tilde{z}_j(x),\ j = 1, 2, \ldots, n$ is an $\tilde{N}$ vector of cost coefficients, A an $\tilde{m} \times \tilde{N}$ coefficients matrix of constraints and b an m vector of demand, the problem stated above is a multi objective quadratic programming problem subject to linear constraints.

3.1 An algorithm for Neutrosophic fuzzy multi objective quadratic programming problem:

A Taylor series approach to Neutrosophic fuzzy multi-objective quadratic programming problem, truth–membership function, indeterminacy membership function and falsity membership function associated with each objective are transformed by using Taylor series at first and then a satisfactory value (s) for the variable (s) of the model is obtained by solving the neutrosophic fuzzy model, which has a single objective function. An algorithm for solving neutrosophic fuzzy multi-objective quadratic programming problem is developed here.

Step 1. Determine $x_i^* = (x_{i1}{}^*, x_{i2}{}^*, \ldots, x_{in}{}^*)$, that is used to maximize or minimize the i^{th} truth membership function $T_{\tilde{\imath}}(x)$, indeterminacy membership function $I_{\tilde{\imath}}(x)$ and falsity membership function $F_{\tilde{\imath}}(x)$ $(i = 1, 2, 3, \ldots, k)$ where n is the number of variables.

Step 2. Transform the truth-membership function, indeterminacy membership function and falsity membership function by using first order Taylor polynomial series

$$\hat{T}_{\tilde{\imath}}(x) \cong T_{\tilde{\imath}}(x_i^*)$$

$$+\left[(x_1 - x_{i1}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_1} + (x_2 - x_{i2}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_2} + \ldots + (x_n - x_{in}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_n}\right]$$

$$\hat{T}_{\tilde{\imath}}(x) \cong T_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_j}$$

$$\hat{I}_{\tilde{\imath}}(x) \cong I_{\tilde{\imath}}(x_i^*)$$

$$+\left[(x_1 - x_{i1}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_1} + (x_2 - x_{i2}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_2} + \ldots + (x_n - x_{in}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_n}\right]$$

$$\hat{I}_{\tilde{\imath}}(x) \cong I_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_j}$$

$$\hat{F}_{\tilde{\imath}}(x) \cong F_{\tilde{\imath}}(x_i^*)$$

$$+\left[(x_1 - x_{i1}^*)\frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_1} + (x_2 - x_{i2}^*)\frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_2} + \ldots + (x_n - x_{in}^*)\frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_n}\right]$$

$$\hat{F}_{\tilde{\imath}}(x) \cong F_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_j}$$

Step 3. Find satisfactory $x^* = (x_1{}^*, x_2{}^*, \ldots, x_n{}^*)$ by solving the reduced problem to a single objective for truth-membership function, indeterminacy membership function and falsity membership function respectively.

$$p(x) = \sum_{i=1}^{k} T_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_j},$$

$q(x) = \sum_{i=1}^{k} I_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_j}$ and

$$r(x) = \sum_{i=1}^{k} F_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_j}.$$

Then NFMOQPP is converted into a new mathematical model and is given below:

Maximize or Minimize $\sum_{i=1}^{k} T_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial T_{\tilde{\imath}}(x_i^*)}{\partial x_j}$

Maximize or Minimize $\sum_{i=1}^{k} I_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n}(x_j - x_{ij}^*)\frac{\partial I_{\tilde{\imath}}(x_i^*)}{\partial x_j}$

Maximize or Minimize $\sum_{i=1}^{k} F_{\tilde{\imath}}(x_i^*) + \sum_{j=1}^{n} (x_j - x_{ij}^*) \frac{\partial F_{\tilde{\imath}}(x_i^*)}{\partial x_j}$

4. Fuzzy Linear Complementarity Problem (FLCP)

The following fuzzy linear complementarity problem can be obtained by replacing crisp parameters with single valued triangular Neutrosophic numbers.

$$\widetilde{W} - \widetilde{M}\widetilde{Z} = \tilde{q} \tag{4.1}$$

$$\widetilde{W}_j \geq 0,\ Z_j \geq 0,\ j = 1, 2, 3, \ldots, n \tag{4.2}$$

$$\widetilde{W}_j \widetilde{Z}_j = 0,\ j = 1, 2, 3, \ldots, n \tag{4.3}$$

The pair $(\widetilde{W}_j, \widetilde{Z}_j)$ is said to be a pair of fuzzy linear complementary variables.

Definition 4.1. A solution (w, z) to the above system (4.1)-(4.3) is called a Neutrosophic complementary feasible solution, if (w, z) is a Neutrosophic basic feasible solution to (4.1) and (4.2) with one of the pair (w_j, z_j) basic for each $j = 1, 2, 3, \ldots, n$.

4.2 Algorithm for Neutrosophic fuzzy Linear Complementarity Problem

Consider the Neutrosophic linear complementarity problem (q, M), where the Neutrosophic fuzzy matrix M_j is a positive semi definite matrix of order n. The original table for this version of the algorithm is:

w	z	z_0	
i	-M	-d	q

This method deals only with Neutrosophic complementary basic vectors, beginning with $w = (w_1, w_2, \ldots, w_n)$ as the initial Neutrosophic complementary basic vector. All the Neutrosophic complementary basic vectors obtained in the method, except the terminal one, will be infeasible.

When a Neutrosophic complementary feasible basic vector is obtained, the method terminates.

If $\widetilde{q} \geq 0,$ then we have the solution satisfying (4.1)-(4.3), by letting $w = q$ and $z = 0.$

If $\widetilde{q} < 0,$ we will consider the following system

$$w - MZ - ez_0 = q \tag{4.4}$$

$$w_j \geq 0, z_j \geq 0, j = 1, 2, 3, \ldots, n \tag{4.5}$$

$$w_j z_j = 0, j = 1, 2, 3, \ldots, n \tag{4.6}$$

Where Z_0 is an artificial Neutrosophic fuzzy variable and $\widetilde{e}$ is an n-vector with all components equal to any constant. Letting $z_0 =$ maximum $\{q_i / 1 \leq i \leq n\}, z = 0$ and $W = q + ez_0.$ We obtain a starting solution to the system (4.4)-(4.6). Through a sequence of pivots, we attempt to drive the Neutrosophic fuzzy artificial variable z_0 to level zero, thus obtaining a solution to the Neutrosophic linear complementarity problem (NLCP).

Step 1. Introduce the Neutrosophic artificial variable z_0 and consider the system (4.4)-(4.6).

(i) If $q \geq 0$ stop; then $(w, z) = (q, 0)$ is a Neutrosophic complementary basic feasible solution.

(ii) If $q < 0$ display the system (4.4), (4.5) as given in the simplex method.

Let $-qs =$ maximum$\{-q_i / 1 \leq i \leq n\},$ and update the table by pivoting at row s and the z_0 column. Thus the Neutrosophic basic variables z_0 and w_s for $j = 1, 2, 3, \ldots, n$ and $j \neq s$ are positive. Let $y_s = z_0$ and go to step: 2.

Step 2. Let d_s be the updated column in the current table under the variable y_s.

If $d_s \leq 0,$ go to step 5, otherwise determine the index r by the following minimum ratio test, $\frac{\overline{q}}{d_{rs}} = \min\left\{\frac{\overline{q}_i}{d_{is}}, d_{is} > 0\right\}$, where $\overline{q}$ is the updated right-hand side column denoting the values of the Neutrosophic basic variables. If the Neutrosophic basic variable at row r is z_0, go to step 4, otherwise, go to step 3.

Step 3. The Neutrosophic basic variable at row r is either w_l or z_l for some $l \neq s$. The variable y_s enters the basis and the table is updated by pivoting at row r and y_s the column. If w_l leaves the basis, then let $y_s = z_l$; and if z leaves the basis, then let $y_s = w_l$; Return to step 2.

Step 4. Here y_s enters the basis, and z_0 leaves the basis. Pivot at the y_s column and the z_0 row, producing a Neutrosophic complementary basic feasible solution. Stop.

Step 5. Stop with ray termination. A ray $R = \{(w, z, z_0) + \lambda d / \lambda \geq 0\}$ is found such that every point in R satisfying (4), (5) and (6), where (w, z, z_0) is the almost Neutrosophic complementary basic feasible solution, and d is an extreme direction of the set defined by (4.4) and (4.5) having a $\tilde{I}$ in the row corresponding to $y_s, -d_s$ in the rows of the current basic variables and zeros everywhere else.

5. Numerical Example

Consider the following Neutrosophic fuzzy multi objective quadratic programming problem

$$\text{Minimize } z_1(x) = -4x_1 + x_1^2 - 2x_1x_2 + 2x_2^2$$

$$\text{Minimize } z_2(x) = -3x_1 + x_1^2 - 2x_1x_2 + 3x_2^2 \tag{5.1}$$

Subject to constraint $3x_1 - x_2 \leq -5$, $4x_1 - 5x_2 \leq 10$ and $x_1, x_2 \geq 0$.

A truth-membership function, indeterminacy membership function and falsity membership function were considered to be neutrosophic triangular. When they depend on three scalar parameters (a_1, b_1, c_1). If z_1 depends on neutrosophic fuzzy aspiration levels (-113, -6.5, 100) when z_2 depends on neutrosophic fuzzy aspiration levels (-113, -6.5, 100). The truth-membership function, indeterminacy membership function and falsity membership function of the goals are obtained as follows:

$$T_1(x) = \begin{cases} 0, & \text{if } z_1(x) \ge c_1 \\ \dfrac{c_1 - z_1(x)}{c_1 - b_1}, & \text{if } b_1 \le z_1(x) \le c_1 \\ \dfrac{z_1(x) - a_1}{b_1 - a_1}, & \text{if } a_1 \le z_1(x) \le b_1 \\ 0, & \text{if } z_1(x) \le a_1 \end{cases}$$

$$\text{i.e. } T_1(x) = \begin{cases} 0, & \text{if } z_1(x) \ge 100 \\ \dfrac{100 - (-4x_1 + x_1^2 - 2x_1x_2 + 2x_2^2)}{100 - (-6.5)}, & \text{if } b_1 \le z_1(x) \le 100 \\ \dfrac{(-4x_1 + x_1^2 - 2x_1x_2 + 2x_2^2) - (-113)}{-6.5 - (-113)}, & \text{if } a_1 \le z_1(x) \le -6.5 \\ 0, & \text{if } z_1(x) \le -113 \end{cases}$$

Similarly,

$$T_2(x) = \begin{cases} 0, & \text{if } z_1(x) \ge 250 \\ \dfrac{250 - (-3x_1 + x_1^2 - 2x_1x_2 + 3x_2^2)}{250 - 5}, & \text{if } 5 \le z_1(x) \le 250 \\ \dfrac{(-3x_1 + x_1^2 - 2x_1x_2 + 3x_2^2) - (-240)}{5 - (-240)}, & \text{if } -240 \le z_1(x) \le 5 \\ 0, & \text{if } z_1(x) \le -240 \end{cases}$$

If $T_1(x) = \max(\min(\dfrac{100 - (-4x_1 + x_1^2 - 2x_1x_2 + 2x_2^2)}{100 - (-6.5)},$

$\dfrac{(-4x_1 + x_1^2 - 2x_1x_2 + 2x_2^2) - (-113)}{-6.5 - (-113)}), 0)$ and

$T_2(x) = \max(\min(\dfrac{250 - (-3x_1 + x_1^2 - 2x_1x_2 + 3x_2^2)}{250 - 5},$

$\dfrac{(-3x_1 + x_1^2 - 2x_1x_2 + 3x_2^2) - (-240)}{5 - (-240)}), 0)$

If the problem is solved for each membership function, one by one, then $T_1(2.46, 1.08)$ and $T_2(0.89, 0.22)$. The truth membership function, indeterminacy membership function and falsity membership function are transformed by using first order Taylor polynomial series

$$\widehat{T}_1(x) \cong T_1(2.46, 1.08) + \left[(x_1 - 2.46) \frac{\partial T_1(2.46, 1.08)}{\partial x_1} + (x_2 - 1.08) \frac{\partial T_2(2.46, 1.08)}{\partial x_2} \right]$$

$$\widehat{T}_{\tilde{1}}(x) = 0.012 x_1 - 0.006 x_2 + 0.974 \tag{5.2}$$

$$\widehat{T}_2(x) \cong T_2(0.89,\ 0.22) + \left[(x_1 - 0.89) \frac{\partial T_1(0.89,\ 0.22)}{\partial x_1} + (x_2 - 0.22) \frac{\partial T_2(0.89,\ 0.22)}{\partial x_2} \right]$$

$$\widehat{T}_{\tilde{2}}(x) = 0.003 x_1 - 0.013 x_2 + 0.974. \tag{5.3}$$

Then the objective of the NFMOQPP is obtained by adding (5.2) and (5.3) that is

$$p(x) = \widehat{T}_{\tilde{1}}(x) + \widehat{T}_{\tilde{2}}(x) = 0.015 x_1 - 0.019 x_2 + 1.948$$

Subject to constraint $3x_1 - x_2 \le -5,\ 4x_1 - 5x_2 \le 10$ and $x_1,\ x_2 \ge 0$

$$M = \begin{bmatrix} 3 & -1 \\ 4 & -5 \end{bmatrix},\ q = \begin{bmatrix} -5 \\ 10 \end{bmatrix}$$

A Linear complementary problem is solved by the proposed algorithm and the results are tabulated in Table 5.1.

Table 5.1.

	w_1	w_2	w_3	w_4	z_0	q
w_1	1	0	-3	1	-1	-5
w_2	0	1	-4	5	-1	10
z_0	-1	0	3	-1	1	5
w_2	-1	1	-1	4	0	15
w_3	-1/3	0	1	-1/3	1/3	5/3
w_2	-4/3	1	0	11/3	1/3	50/3
w_3	-15/33	1/11	1	0	12/33	105/33

w_4	-4/11	3/11	0	1	1/11	50/11

Hence the solution of this linear complementary problem (q, M) is $w_3 = \frac{105}{33} = 3.18$, $w_4 = \frac{50}{11} = 4.55$; $z_1(x) = 9.8594$ and $z_2(x) = 91.6179$.

The obtained solution is $x_1 = 3.18$, $x_2 = 4.55$, $P(x) = 1.90925$.

Proceeding in this way, the solution for indeterminacy membership and Falsity membership are as follows:

The Indeterminacy-membership functions are transformed by using first-order Taylor poly nomialseries

$$\widehat{I}_1(x) \cong I_1(2.46, 1.08) + \left[(x_1 - 2.46)\frac{\partial I_1(2.46, 1.08)}{\partial x_1} + (x_2 - 1.08)\frac{\partial I_2(2.46, 1.08)}{\partial x_2}\right]$$

$$\widehat{I}_{\tilde{1}}(x) = 0.009x_1 - 0.008x_2 + 0.976 \tag{5.4}$$

$$\widehat{I}_2(x) \cong I_2(0.89, 0.22) + \left[(x_1 - 0.89)\frac{\partial I_1(0.89, 0.22)}{\partial x_1} + (x_2 - 0.22)\frac{\partial I_2(0.89, 0.22)}{\partial x_2}\right]$$

$$\widehat{I}_{\tilde{2}}(x) = 0.006x_1 - 0.011x_2 + 0.974. \tag{5.5}$$

Then the objective of the NFMOQPP is obtained by adding (5.4) and (5.5) that is

$$q(x) = \widehat{I}_{\tilde{1}}(x) + \widehat{I}_{\tilde{2}}(x) = 0.015x_1 - 0.019x_2 + 1.940$$

The obtained solution is $x_1 = 3.18$, $x_2 = 4.55$, $q(x) = 1.90125$.

The Falsity-membership functions are transformed by using first-order Taylor poly nomialseries

$$\widehat{F}_1(x) \cong F_1(2.46, 1.08) + \left[(x_1 - 2.46)\frac{\partial F_1(2.46, 1.08)}{\partial x_1} + (x_2 - 1.08)\frac{\partial F_2(2.46, 1.08)}{\partial x_2}\right]$$

$$\widehat{F}_{\tilde{1}}(x) = 0.012x_1 - 0.006x_2 + 0.977 \tag{5.6}$$

$$\widehat{F}_2(x) \cong F_2(0.89, 0.22) + \left[(x_1 - 0.89)\frac{\partial F_1(0.89, 0.22)}{\partial x_1} + (x_2 - 0.22)\frac{\partial F_2(0.89, 0.22)}{\partial x_2}\right]$$

$$\widehat{F}_{\tilde{2}}(x) = 0.003x_1 - 0.013x_2 + 1. \tag{5.7}$$

Then the objective of the NFMOQPP is obtained by adding (5.6) and (5.7) that is

$$q(x) = \widehat{I}_{\tilde{1}}(x) + \widehat{I}_{\tilde{2}}(x) = 0.015x_1 - 0.019x_2 + 1.977$$

The obtained solution is $x_1 = 3.18$, $x_2 = 4.55$, $r(x) = 1.93825$.

6. Conclusion

In this paper based on Taylor series is proposed to solve multi-objective fuzzy quadratic programming problems to truth membership, Indeterminacy membership and Falsity membership associated with each objective of multi-objective quadratic programming problem are transformed to a single objective linear complementarity problem by using a Taylor series. Here, the MOFQPP is reduced to an equivalent MOLCP by using first order Taylor polynomial series. The obtained MOLPP is solved assuming that the weights of the objectives are equal.

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