ÇANKAYA UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
ELECTRONIC AND COMMUNICATION ENGINEERING

MASTER THESIS

RECURSIVE TWO-STAGE EVOLUTIONARY PROGRAMMING BASED ON SIMILARITY MEASURES

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FEBRUARY 2013

Title of the Thesis : **Recursive Two-Stage Evolutionary Programming Based On Similarity Measures**

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ABSTRACT

RECURSIVE TWO-STAGE EVOLUTIONARY PROGRAMMING BASED ON SIMILARITY MEASURES

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February 2013, 104 Pages

This thesis is devoted to deeper research about the characteristics of the Metaheuristic search algorithm "Recursive Two-Stage Evolutionary Programming" (RTEP). This algorithm is a powerful Metaheuristic where only mutation operation is used in a specific style in order to produce better candidate solutions for the dealt optimization problem. The algorithm has many different parameters and procedures that can be adapted in order to obtain better solutions for the optimization problems. Especially, the distance measure between the chromosomes, how the selection operation will be carried out and the style of the mutation operation are important subjects of this search algorithm. In this thesis, the contribution of parameter and procedure changes for these subjects in the efficiency of the algorithm is investigated.

Key words: Metaheuristics, Evolutionary Algorithms, Evolutionary Programming, Genetic Algorithms, Mutation.

ÖZ

BENZERLİK ÖLÇÜMLEMELERİNE DAYALI YİNELEMELİ İKİ-AŞAMALI EVRİMSEL PROGLAMLAMA

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Tez Yöneticisi: Yrd. Doç. Dr. Ulaş BELDEK

Şubat 2013, 104 Sayfa

Bu tez Yinelemeli İki-Aşamalı Evrimsel Programlama (YİEP) isimli meta-sezgisel araştırma algoritmasının daha detaylı araştırılmasına adanmıştır. Bu algoritma ele alınan optimizasyon problemi için daha iyi aday çözümler üretmek adına sadece mutasyon operasyonunun özel bir biçimde kullanıldığı güçlü bir algoritmadır. Algoritma optimizasyon problemleri için daha iyi sonuçların elde edilmesine olanak veren değiştirilebilen parametrelere ve prosedürlere sahiptir. Özellikle kromozomlar arasındaki mesafenin ölçüm yöntemi, seçim operasyonunun nasıl gerçekleştirileceği ve mutasyon operasyonunun sitili bu araştırma algoritmasının önemli konularıdır. Bu tezde, parametre ve prosedürlerin bu konularla ilgili olarak değiştirilmesinin algoritmanın verimliliğine katkısı araştırılmıştır.

Anahtar kelimeler: Meta-Sezgisel Algoritmalar, Evrimsel Algoritmalar, Evrimsel Programlama, Genetik Algoritmalar, Mutasyon.

ACKNOWLEDGMENTS

First of all, I am grateful to Allah for granting me patience and health to complete my thesis work.

I would like to express my sincere thanks to my advisor Assist. Prof. Dr. Ulaş Beldek for his patience, motivation, effort, and exalted knowledge. His supports and advices motivate me to complete this work.

Also I would like to special thanks to my parent for supporting me whole my education life.

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ACRONYM LIST

Acronym	*Definition*
RTEP	Recursive Two-Stage Evolutionary Programming
RTEPv1	Recursive Two-Stage Evolutionary Programming Version 1
RTEPv2	Recursive Two-Stage Evolutionary Programming Version 2
RTEPv3	Recursive Two-Stage Evolutionary Programming Version 3
RTEPv4	Recursive Two-Stage Evolutionary Programming Version 4
YİEP	Yinelemeli İki-Aşamalı Evrimsel Programlama
EP	Evolutionary Programming
SA	Simulated Annealing
ACO	Ant Colony Optimization
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
MBO	Migrating Birds Optimization
ABC	Artificial Bee Colony Algorithm
TS	Tabu Search

INTRODUCTION

Metaheuristics [1,2,3] are the common name given for the search algorithms that try to solve an optimization problem by not using the knowledge on the strict mathematical characteristics of the problem but by producing candidate solutions iteratively through some procedures that quantize the quality of the candidate solutions. These algorithms are one of the best options to use to solve optimization problems especially when the dimension of the problem search space is vey big or the problem itself contains many local minimums. Metaheuristics can be applied to a variety of optimization problems, as they do not depend on strict mathematical characteristics of the problem at hand. Hence, Metaheuristics are especially effective for problems, that have many local optimums or the directional derivative information cannot be retrieved partially or totally in some sub-portions of the problem search space. That is why; they are usually used on global optimization problems.

Most of the time, the Metaheuristics are population-based algorithms [4-5]. They generally start with a number of feasible candidate solutions of the optimization problem. Later these candidate solutions are combined with or perturbed by the use of some special operators depending on some probabilistic and statistical information gained from the candidate solutions and better solutions emerge. These special operators are chosen such that they generally exhibit two different behaviors with the use of the statistics gained from the candidate solutions. One of the behaviors is known as exploration [6], which is indeed a more wide-ranging investigation of the whole search space in order to find areas in the search space that have potential to include local minimums. The second behavior is known as exploitation [6], which is the deeper search of some critical portion of the search space in order to determine the local minimum(s) precisely. Every Metaheuristic is a reasonable and suitable combination of these two behaviors. Hence these algorithms' parameters and procedures should be determined wisely and precisely for the optimization problem at hand. These parameters in reality adjust the order, activity and strength of

exploration and exploitation in the heuristic search algorithm with respect to each other. Each optimization problem requires the application of these behaviors in different rates. If the search space has a very granular structure or if the dimension of the search space is larger, the exploration behavior is more important in order to localize the local minimums. Inversely, if the search space contains a few local minimums or a single local minimum, the heuristic search should concentrate on precisely determining these points by an extra exploitation power. Indeed all the algorithms have some drawbacks and advantages and due to No Free Lunch theorem [7] and none of the Metaheuristics could be defined as the best one. Hence a deeper and careful search should be done in order to show the advantages [8] and disadvantages [9] of any Metaheuristic.

Each Metaheuristic computes the exploration and exploitation behaviors in a statistical manner with some randomness. How the statistics will be used or how the candidate solutions or portions of the candidate solutions will be selected to take part in the operations of Metaheuristics is another important aspect of these algorithms in order to adjust the exploration and exploitation power.

There are some mathematical test functions [10] in order to compare the power of different Metaheuristics in terms of convergence and computation power. These test functions give us the opportunity of identifying the characteristics of the Metaheuristics practically.

There are many well-known Metaheuristics. Some of these algorithms are; Simulated Annealing (SA) [11-12], Evolutionary Programming (EP) [6,13], Ant Colony Optimization (ACO) [14,15,16,17,18], Particle Swarm Optimization (PSO) [19,20,21,22], Genetic Algorithms (GA) [23,24], Migrating Birds Optimization (MBO) [25], Artificial Bee Colony Algorithm (ABC) [26], Tabu Search (TS) [27]. As can be understood from the names of these algorithms, most of the Metaheuristics mainly imitate some natural or artificial happenings or characteristics of animal populations. These attempts are reasonable as nature is the most effective optimization facility.

GA is the most popular Evolutionary Algorithm in the literature. GAs are search methods based on principles of natural selection and genetics. In 1950’s and 1960’s

several computer scientists independently studied evolutionary systems with the idea that evolution could be used as an optimization tool for engineering problems. So the Evolutionary Computing idea was introduced.

Given a specific optimization problem, the GA starts with a set of candidate solutions (population) to that problem where each candidate solutions is encoded in terms of strings of variables known as chromosome. A subjective criterion reflecting the success of each candidate in the optimization problem allows each candidate to be quantitatively measured. This measure is denoted as the fitness. According to fitness measure the population of chromosomes undergoes an alteration process through generations by the help of some genetic operators like crossover and mutation and next populations are created. The alteration process is generally done in a probabilistic fashion depending on some comparison and post-processing on the fitness of the chromosomes. The comparison and post-processing can be handled in many different ways due to the selection of the methods to be followed in the GA search. If the genetic operators, the alteration process and the parameters of the algorithm are selected wisely, this Metaheuristic in most of the cases puts forward near optimal solutions.

John Koza [28] has used a similar method like GA to improve programs to perform certain tasks in 1992. He called his method Genetic Programming (GP). The main difference between GP and GA is the structure of candidate solutions for the considered optimization problem. For GP tree-like structure are employed in order to implement procedural optimization task whereas GA is usually applied for optimizing the variables of considered optimization problems.

Memetic algorithms [29, 30, 31] can be described as an application of a local search method (sometimes by use of a suitable gradient descent algorithm and sometimes by use of some other Metaheuristics) together with an Evolutionary algorithm. Memetic algorithms are good examples of hybrid algorithms that use the characteristics of more than two search methods. Local search method in the Memetic algorithm is generally employed in order to increase the exploitation power whereas the Evolutionary algorithm is used in order to contribute to the exploration power. There are also other types of hybridization of algorithms [32, 33] in order to increase the exploration and exploitation capacity of the search methods.

In the Evolutionary Algorithms one of the most important operators is mutation. Mutation is employed in order to modify the candidate solutions. For instance in EP mutation is the only source for modification of chromosomes whereas in GA some different operators like crossover are also employed. Hence for EP, how mutation is performed is very critical. Hence various mutation strategies are applied in literature to increase the efficiency of this operator [34, 35, 36].

Recurring Two-Stage Evolutionary Programming (RTEP) [6] is a new type of EP. Since it is new a deeper investigation of this algorithm is necessary in order to identify its characteristics. How the parameters and procedures should be adjusted in order to make it more appropriate for different types of optimization problems is the main contribution of this thesis work. In RTEP, the main idea is to progress the exploration and exploitation stages of EP in a sequential manner with special type of Gaussian mutation and a selection strategy depending on genotype of the chromosomes (the genetic similarity of chromosomes in terms of **Euclidian** distance). What we propose in this thesis is changing the selection strategy such that it allows the use of both genotype and phenotype (the similarity of chromosomes in terms of success in fulfilling the cost function) of the chromosomes, and besides modifying the genotype by using a different metric (**Absolute** distance) to determine the similarity between the chromosomes. Similarly phenotype similarity measure is also adapted in two different ways (by the use of fitness and cost values) to compare the effect of these two measures. Effects of changing the number of mutation points for the efficiency of the algorithm are also test in this thesis.

The remainder of the thesis is organized as follows: in the first chapter RTEP is explained and the parameter and procedure changes planned for RTEP are done and different versions of RTEP are implemented. In the second chapter, the results obtained for versions of RTEP are for different parameter sets are given. In the conclusions part final remarks and future study areas about RTEP are given.

CHAPTER I

1. THE VERSIONS OF RECURSIVE TWO-STAGE EVOLUTIONARY PROGRAMMING

1.1. THE ALGORITHM

The original RTEP [6] algorithm consist of the following steps:

Step 1. Create an initial population with μ chromosomes. Express each chromosome in that population as x_i, $i=1,2,\ldots,\mu$. Let each chromosome be defined as a vector with n real valued components (genes): In this case chromosome will define as $x_i = \{x_i(1), x_i(2),\ldots,x_i(n)\}$ (n)} where $x_i(1)$, $x_i(2),\ldots$, $x_i(n)$ components will form the genes of the chromosome.

Step 2. Determine parameters *K1* and *K2*, which are the successive repetition of the number of generations for exploration and exploitation processes before passing from one process to another (before recurring)

Step 3. Specify the fitness (cost) value of each chromosome according to an objective function that defines the optimization problem. If the best fitness (cost) value exceeds an acceptable threshold value finish the algorithm; else continue.

Step 4. Apply the parts described between Step 5 and Step 8 for *K1* generations. (These parts indicate the performed exploration process for a single generation)

Step 5. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space and for each chromosome x_i select the *M* farthest chromosomes to x_i. These *M* chromosomes are referred as the 'Strangers' of

x_i. Choose one of the Strangers of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 6. For each chromosome in the population: run the mutation operation and create μ new offspring chromosome by mutation. Mutation operation for a single parent chromosome can be described as follows: Each chromosome has n genes. Determine a random value of k where $1 \leq k \leq n$. k is the number of genes, which will be mutated. Randomly choose k genes out of n genes on the chromosome. Indicate the chosen genes as r_t. Hence r_t, $t=1,2,\ldots,k$ are the genes to be mutated. In this case the new offspring chromosome is shown by x'_i and $x'_i = \{x'_i(1), x'_i(2), \ldots, x'_i(n)\}$. Accordingly, the mutated genes of the offspring chromosome will be,

$$t = 1:k, \quad x'_i(r_t) = x_i(r_t) + \sigma_i(r_t) \times N_t(0,1), \qquad (1)$$

In the expression given in (1), $x'_i(r_t)$ is the values of gene r_t of offspring chromosomes x'_i, $x_i(r_t)$ is the values of gene r_t of parent chromosomes x_i, Nt(0,1) is the random number with 0 average and 1 standard deviation according to normal (Gaussian) distribution re-evaluated for every t value and $\sigma_i(r_t)$ is the standard deviation value for mutating the gene r_t of the parent chromosome x_i. In the original RTEP $\sigma_i(r_t)$ is defined as **Euclidian** distance of x_i and y_i along gene r_t. As $\sigma_i(r_t)$ is defined along a single gene, the **Euclidian** distance also turns out to be equal to the **Absolute** distance. This situation can be shown as,

$$\sigma_i(r_t) = \sqrt{(x_i(r_t) - y_i(r_t))^2} = \left| x_i(r_t) - y_i(r_t) \right|, \qquad (2)$$

Step 7. Calculate fitness value of each offspring chromosomes x'_i, $i=1,2,\ldots,\mu$. For every parent chromosome x_i and its corresponding offspring chromosome x'_i: If the fitness value of parent chromosome is greater than the fitness value of offspring chromosomes than pass parent chromosome to the next generation otherwise, pass offspring chromosome to the next generation.

Step 8. If the fitness of the best chromosome of the generation is higher than a sufficient threshold value or if the maximum number of generations is reached then terminate the algorithm, otherwise continue the algorithm.

Step 9. Apply the parts described between Step 10 and Step 13 for *K2* generations. (These parts indicate the performed exploitation process for a single generation)

Step 10. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space and for each chromosome x_i select the M nearest chromosomes to x_i. These M chromosomes are referred as the 'Neighbors' of x_i. Choose one of the Neighbors of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 11. For each chromosome in the population: create μ new offspring chromosomes using (1) as described in **Step 6**. In **Step 10** y_i is selected from the closest chromosome to x_i. Therefore, $\sigma_i(r_t)$ is the **Euclidian** distance between x_i and y_i along the gene r_t. As $\sigma_i(r_t)$ is defined along a single gene, the **Euclidian** distance also turns out to be equal to the **Absolute** distance as stated in (2) before in **Step 6**.

Step 12. Calculate fitness value of each offspring chromosomes x'_i, $i=1,2,\ldots,\mu$. For every parent chromosome x_i and its corresponding offspring chromosome x'_i: If the fitness value of parent chromosome is greater than or equal to the fitness value of offspring chromosomes than pass parent chromosome to the next generation otherwise, pass offspring chromosome to the next generation.

Step 13. If the fitness of the best chromosome of the generation is higher than a sufficient threshold value or if the maximum number of generations is reached then terminate the algorithm, otherwise return back to the **Step 4** and then begin carrying out next exploration and exploit processes.

As can be understood from the algorithm, RTEP has three critical components (exploration process, exploitation process and the implementation of these processes in a repetitive order).

When we examined RTEP, the most critical steps of the algorithm are determination of set of strangers and neighbors mentioned in **Step 5** and **Step 10** respectively. Strangers and Neighbors of any chromosome are determined based on the genotype of the chromosomes. Simply, the **Euclidian** distance measure in n-dimensional search space is used for finding the Strangers and Neighbors. However, different distance measures can be used to determine them. In this thesis, the effect of defining the distance measure according to the **Absolute** distance is tested. These results are compared with the results obtained due to Euclidian distance. Moreover, we also investigated the consequence of determining the Strangers and Neighbors due to a mixture of genotype (similarity between chromosomes) and phenotype (similarity of the fitness or cost values of the chromosomes) measures. That means some of the Strangers and Neighbors can be selected due to genotype and some of the chromosomes can be selected due to phenotype and at the end a random selection can be implemented to choose one of them for mutation operation.

Another important component of the RTEP algorithm is the mutation style. In **Step 6** and **Step 11** where the mutation operation is performed, the mutation is a multi-point mutation operation. Generally multi-point mutation operation destroys Metaheuristics as they might increase the randomness in the algorithms. In our primitive simulations, it is observed that if the number of mutation points is decreased, most of the time the algorithm is more successful. Hence we also decided to change the mutation style explained in **Step 6** and **Step 11**.

Due to these changes we have created some versions of the algorithm. Now we will compare RTEPs versions.

1.2. The First Version

In RTEP version 1 (RTEPv1) the changes in the algorithm are as follows:

Step 5. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space due to genotype. Find the distance of each

chromosome with each other based on their **fitness** values due to phenotype. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are farthest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are farthest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Strangers' of x_i. Choose one of the Strangers of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 6. For each chromosome in the population: run the mutation operation and create μ new offspring chromosome by mutation. Mutation operation for a single parent chromosome can be described as follows: Each chromosome has n genes. Randomly choose *1* gene out of *n* genes on the chromosome. Indicate the chosen gene as r_1. Hence r_1 is the only gene to be mutated **(one point mutation)**. In this case the new offspring chromosome is shown by x'_i and $x'_i = \{x'_i(1), x'_i(2), \ldots, x'_i(n)\}$. Accordingly, the mutated gene of the offspring chromosome will be,

$$x'_i(r_1) = x_i(r_1) + \sigma_i(r_1) \times N_1(0,1), \qquad (3)$$

In the expression given in (3), $x'_i(r_1)$ is the values of gene r_1 of offspring chromosomes x'_i, $x_i(r_1)$ is the values of gene r_1 of parent chromosomes x_i, $N_1(0,1)$ is the random number with 0 average and 1 standard deviation according to normal (Gaussian) distribution and $\sigma_i(r_1)$ is the standard deviation value for mutating the gene r_1 of the parent chromosome x_i. In the original RTEP $\sigma_i(r_1)$ is defined as **Euclidian** distance of x_i and y_i along gene r_1. As $\sigma_i(r_1)$ is defined along a single gene, the **Euclidian** distance also turns out to be equal to the **Absolute** distance. This situation can be shown as,

$$\sigma_i(r_1) = \sqrt{(x_i(r_1) - y_i(r_1))^2} = \left| x_i(r_1) - y_i(r_1) \right|, \qquad (4)$$

Step 10. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space due to genotype. Find the distance of each chromosome with each other based on their **fitness** values due to phenotype. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are closest chromosomes to x_i based of **genotype** and

select $M\times(1\text{-}gr)$ chromosomes, which are closest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Neighbors' of x_i. Choose one of the Neighbors of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 11. For each chromosome in the population: create μ new offspring chromosomes using (3) as described in **Step 6** (using one point mutation). In **Step 10** y_i is selected from the closest chromosome to x_i. Therefore, $\sigma_i(r_1)$ is the **Euclidian** distance between x_i and y_i along the gene r_1. As $\sigma_i(r_1)$ is defined along a single gene, the **Euclidian** distance also turns out to be equal to the **Absolute** distance as stated in (4) before in **Step 6**.

For comparison reasons, how the fitness or the cost value of a chromosome x_i is defined is also important. In order to define the cost and fitness we have done the following:

Let $f_k(x)$ be the objective function to be optimized. Determine the cost value of x_i for $f_k(x)$ as,

$$Cost(x_i) = \left| f_k(x_i) - f_{k,min} \right| \qquad (5)$$

where $Cost(x_i)$ is the **cost** of chromosome x_i for $f_k(x)$, $f_k(x_i)$ is the objective function value for chromosome x_i and $f_{k,min}$ is the global minimum value of $f_k(x)$. Thus the $Cost(x_i)$ is always positive. Similarly **fitness** of a chromosome x_i can be computed using,

$$Fitness(x_i) = \frac{1}{Cost(x_i)} \qquad (6)$$

and the fitness of each chromosome is also positive.

1.3. The Second Version

The basic motivation to implement RTEP version 2 (RTEPv2) comes from an important detail, which remarkable to us at **Step 6** and **Step 11** of original RTEP explained in Section 1.1. For the mutation operation performed in **Step 6** and **Step**

11; $\sigma_i(r_t)$ value in (1) is the **Euclidian** distance of x_i and y_i along the gene r_t. As the parameters are defined along the gene r_t naturally **Euclidian** distance turn into **Absolute** distance as in (2). For this reason, to determine the Strangers and Neighbors, it planned to use the **Absolute** distance at **Step 5** and **Step 10** in this section. Accordingly, in RTEPv2 the changes in the algorithm are as follows

Step 5. Find the distance of each chromosome with each other based on **Absolute** distance in n-dimensional search space due to **genotype**. Find the distance of each chromosome with each other based on their **fitness** values due to **phenotype**. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are farthest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are farthest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Strangers' of x_i. Choose one of the Strangers of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 6. (Same as **Step 6**. In Section 1.2)

Step 10. Find the distance of each chromosome with each other based on **Absolute** distance in n-dimensional search space due to genotype. Find the distance of each chromosome with each other based on their **fitness** values due to phenotype. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are closest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are closest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Neighbors' of x_i. Choose one of the Neighbors of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 11. (Same as **Step 11**. in Section 1.2)

The cost and fitness values of each chromosome are calculated similarly in Section 1.2.

1.4. The Third Version

In the third version of RTEP (RTEPv3), this time the effect performing the selection operation not due to fitness but due to cost values is investigated. The reason to use cost values instead of fitness values comes from the rationale that the closest and farthest chromosomes to any chromosome due to fitness and cost might be different from each other. Hence the different chromosomes can be selected for mutation depending on how we determined phenotype measure. For RTEPv3, the changes in the algorithm compared to RTEPv1 (given in section 1.2) are as follows:

Step 5. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space due to **genotype**. Find the distance of each chromosome with each other based on their **cost** values due to **phenotype**. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are farthest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are farthest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Strangers' of x_i. Choose one of the Strangers of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 6. (Same as **Step 6**. In Section 1.2)

Step 10. Find the distance of each chromosome with each other based on **Euclidian** distance in n-dimensional search space due to genotype. Find the distance of each chromosome with each other based on their **cost** values due to **phenotype**. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are closest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are closest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Neighbors' of x_i. Choose one of the Neighbors of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 11. (Same as **Step 11**. in Section 1.2)

1.5. The Fourth Version

Similarly as in Section 2.4, in the fourth version of RTEP (RTEPv4), the effect performing the selection operation due phenotype based on the **cost** values of chromosomes is investigated. However this time we used **Absolute** distance between the chromosomes to account for genotype measure. Hence the differences between RTEPv4 and RTEPv1 are as follows:

Step 5. Find the distance of each chromosome with each other based on **Absolute** distance in n-dimensional search space due to **genotype**. Find the distance of each chromosome with each other based on their **cost** values due to **phenotype**. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are farthest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are farthest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Strangers' of x_i. Choose one of the Strangers of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 6. (Same as **Step 6**. In Section 1.2)

Step 10. Find the distance of each chromosome with each other based on **Absolute** distance in n-dimensional search space due to **genotype**. Find the distance of each chromosome with each other based on their **cost** values due to **phenotype**. Define the parameter genotype ratio *gr* where $0 \leq gr \leq 1$. For each chromosome x_i, select $M\times$gr chromosomes, which are closest chromosomes to x_i based of **genotype** and select $M\times(1\text{-}gr)$ chromosomes, which are closest chromosomes to x_i based of **phenotype**. These chromosomes are referred as the 'Neighbors' of x_i. Choose one of the Neighbors of x_i at random to be subjected to mutation with x_i, and name it as $y_i = \{y_i(1), y_i(2), \ldots, y_i(n)\}$.

Step 11. (Same as **Step 11**. in Section 1.2)

CHAPTER II

SIMULATIONS

For simulations different test functions are used. The details of these test functions *(f1(x),…, f23(x))* can be found in [6, 10]. Among these functions the first 7 functions are uni-modal functions. They all have a single local minimum which are also their global minimum points. Besides the dimensions of these functions are comparably high. The functions between 8-13 are multi-modal functions with a lot of local minimums. Besides the dimensions of these functions are also comparably high. The functions between 14-23 are functions with a few local minimums besides all these functions are functions with low dimensions.

In the simulations the following parameters are taken:

$K_1 = 1$ (consecutive number of the exploration process)
$K_2 = 1$ (consecutive number of the exploitation process)
$M = 10$ (number of neighbor and stranger chromosome when applying mutation)
$n = D$ (total number of variables (dimension) of the optimization problem (test function) or the total number of genes on chromosome)
$\mu=50$ (Population size is 50 chromosomes)
Number of function (chromosome) evaluations: 150000 for $(f_1(x),\ldots, f_{13}(x))$ (corresponds to a total of 3000 generations) and 10000 for $(f_{14}(x),\ldots, f_{23}(x))$ (corresponds to a total of 200 generations).
For each version of RTEP (RTEPv1, RTEPv2, RTEPv3, RTEPv4), 11 different *gr* (genotype ratio) values are taken.
gr =0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.

Accordingly, each version of RTEP are evaluated and run independently and all results are taken based on the average of 50 independent runs for each parameter set.

4 different criteria are determined at the end of each simulation to compare the simulation results. These criteria are the best cost value obtained at the last generation in the runs (Criterion1), the best average cost of last generation in the runs (Criterion2), the average of the best cost values obtained at the last generation (the average is calculated for 50 independent runs) (Criterion3), the average of the average costs of last generation in the runs (the average is calculated for 50 independent runs) (Criterion4).

The results are tabulated in Tables 1-23. The test functions are shown in Table 24 and the dimensions, the minimum values and the associated search spaces of the test functions are shown in Table 25. Tables 26-29 show the parameters of some of the test functions. In Tables 1-23, the results written in bold are the best results obtained for each criterion.

Table 1a: The result obtained for function f1 when RTEPv1 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{4.8703\times10^{-21}}$	2.8213×10^{-16}	9.8329×10^{-20}	7.3096×10^{-13}
gr=0.1	5.9091×10^{-21}	8.5942×10^{-17}	1.1069×10^{-19}	5.2534×10^{-13}
gr=0.2	7.0912×10^{-21}	5.9679×10^{-17}	1.0794×10^{-19}	$\mathbf{2.4109\times10^{-13}}$
gr=0.3	1.5483×10^{-20}	7.9152×10^{-17}	$\mathbf{9.3052\times10^{-20}}$	5.2791×10^{-13}
gr=0.4	1.0880×10^{-20}	1.2887×10^{-16}	9.7156×10^{-20}	4.2585×10^{-12}
gr=0.5	2.1183×10^{-20}	1.5575×10^{-16}	1.1913×10^{-19}	2.0805×10^{-13}
gr=0.6	1.6008×10^{-20}	6.9580×10^{-17}	1.1797×10^{-19}	5.1192×10^{-7}
gr=0.7	1.2995×10^{-20}	$\mathbf{5.6283\times10^{-17}}$	1.2818×10^{-19}	7.0009×10^{-12}
gr=0.8	4.4269×10^{-20}	1.7914×10^{-16}	1.1660×10^{-19}	4.2351×10^{-13}
gr=0.9	1.9532×10^{-20}	3.3915×10^{-16}	1.3741×10^{-19}	1.0130×10^{-11}
gr=1	2.8214×10^{-20}	2.3495×10^{-16}	2.1409×10^{-19}	4.3150×10^{-13}

Table 1b: The result obtained for function f1 when RTEPv2 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.0178×10^{-20}	9.7595×10^{-17}	1.0003×10^{-19}	$\mathbf{1.1130\times10^{-13}}$
gr=0.1	6.5655×10^{-21}	9.8482×10^{-17}	1.0291×10^{-19}	1.6055×10^{-12}
gr=0.2	1.7061×10^{-20}	1.1843×10^{-16}	1.0737×10^{-19}	9.8298×10^{-12}
gr=0.3	1.9976×10^{-20}	1.7676×10^{-16}	1.2728×10^{-19}	6.8608×10^{-13}
gr=0.4	1.1807×10^{-20}	9.8536×10^{-17}	1.1372×10^{-19}	3.0288×10^{-12}
gr=0.5	1.0302×10^{-20}	8.6801×10^{-17}	1.0002×10^{-19}	4.1005×10^{-13}
gr=0.6	5.8913×10^{-21}	2.6622×10^{-16}	1.1449×10^{-19}	8.8436×10^{-13}
gr=0.7	6.1583×10^{-21}	7.1697×10^{-17}	$\mathbf{8.8127\times10^{-20}}$	1.4267×10^{-13}
gr=0.8	1.1573×10^{-20}	6.2326×10^{-17}	1.2229×10^{-19}	3.4978×10^{-13}
gr=0.9	2.4073×10^{-20}	$\mathbf{2.1840\times10^{-17}}$	1.2117×10^{-19}	3.5112×10^{-13}
gr=1	$\mathbf{5.2364\times10^{-21}}$	7.6643×10^{-17}	1.5783×10^{-19}	4.6644×10^{-12}

Table 1c: The result obtained for function f1 when RTEPv3 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	4.6545×10^{-20}	$\mathbf{1.2499\times10^{-16}}$	3.1699×10^{-19}	$\mathbf{3.7091\times10^{-13}}$
gr=0.1	3.1299×10^{-20}	2.2856×10^{-16}	4.0775×10^{-19}	3.3064×10^{-11}
gr=0.2	$\mathbf{1.9801\times10^{-20}}$	3.0021×10^{-16}	3.2362×10^{-19}	8.3310×10^{-13}
gr=0.3	1.6178×10^{-20}	7.3490×10^{-16}	3.2697×10^{-19}	1.5784×10^{-12}
gr=0.4	4.4272×10^{-20}	7.1126×10^{-16}	3.5303×10^{-19}	3.6832×10^{-8}
gr=0.5	4.6656×10^{-20}	2.1198×10^{-16}	3.9612×10^{-19}	3.8305×10^{-13}
gr=0.6	1.9869×10^{-20}	3.0216×10^{-16}	3.1903×10^{-19}	4.7018×10^{-12}
gr=0.7	6.2275×10^{-20}	2.8008×10^{-16}	3.0490×10^{-19}	1.5464×10^{-12}
gr=0.8	3.1804×10^{-20}	6.9483×10^{-16}	2.3585×10^{-19}	5.8588×10^{-13}
gr=0.9	2.1554×10^{-20}	2.2026×10^{-16}	$\mathbf{2.1123\times10^{-19}}$	4.9719×10^{-8}
gr=1	2.9034×10^{-20}	1.4289×10^{-16}	2.2644×10^{-19}	1.7702×10^{-11}

Table 1d: The result obtained for function f1 when RTEPv4 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.5662×10^{-20}	2.3788×10^{-16}	3.1025×10^{-19}	1.0910×10^{-12}
gr=0.1	2.5397×10^{-20}	1.4078×10^{-16}	3.5206×10^{-19}	9.4872×10^{-13}
gr=0.2	2.2732×10^{-20}	3.9078×10^{-16}	3.1434×10^{-19}	$\mathbf{1.9676\times10^{-13}}$
gr=0.3	$\mathbf{3.3910\times10^{-21}}$	3.3780×10^{-16}	3.6674×10^{-19}	1.3381×10^{-13}
gr=0.4	1.8074×10^{-20}	3.0716×10^{-16}	3.5743×10^{-19}	1.8844×10^{-12}
gr=0.5	1.1968×10^{-20}	5.9480×10^{-16}	2.5235×10^{-19}	1.8776×10^{-12}
gr=0.6	3.8473×10^{-20}	7.8518×10^{-16}	2.8332×10^{-19}	1.1669×10^{-12}
gr=0.7	1.9039×10^{-20}	2.9107×10^{-16}	2.5154×10^{-19}	2.8268×10^{-12}
gr=0.8	3.1688×10^{-20}	$\mathbf{1.8076\times10^{-17}}$	2.3670×10^{-19}	3.5072×10^{-12}
gr=0.9	6.7827×10^{-21}	2.2479×10^{-16}	$\mathbf{2.0733\times10^{-19}}$	4.9482×10^{-13}
gr=1	2.3967×10^{-20}	9.0253×10^{-17}	2.1805×10^{-19}	2.0730×10^{-11}

Table 2a: The result obtained for function f2 when RTEPv1 is used

f2	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.6452×10^{-11}	8.9030×10^{-10}	8.4836×10^{-11}	$\mathbf{4.5707\times10^{-9}}$
gr=0.1	4.5235×10^{-11}	9.3809×10^{-10}	$\mathbf{8.2420\times10^{-11}}$	4.6364×10^{-9}
gr=0.2	2.5160×10^{-11}	$\mathbf{6.5158\times10^{-10}}$	8.3841×10^{-11}	6.0774×10^{-9}
gr=0.3	3.5293×10^{-11}	8.3945×10^{-10}	8.8690×10^{-11}	6.5495×10^{-9}
gr=0.4	3.6890×10^{-11}	1.3712×10^{-9}	8.9227×10^{-11}	7.4245×10^{-9}
gr=0.5	4.2756×10^{-11}	6.6637×10^{-10}	9.6148×10^{-11}	7.7723×10^{-9}
gr=0.6	4.1854×10^{-11}	9.8001×10^{-10}	9.3635×10^{-11}	2.5030×10^{-8}
gr=0.7	4.2635×10^{-11}	1.0110×10^{-9}	9.2800×10^{-11}	5.1733×10^{-9}
gr=0.8	$\mathbf{2.3815\times10^{-11}}$	8.0534×10^{-10}	8.5374×10^{-11}	8.4623×10^{-9}
gr=0.9	4.1536×10^{-11}	1.2767×10^{-9}	1.0431×10^{-10}	5.4513×10^{-9}
gr=1	5.2142×10^{-11}	1.2271×10^{-9}	1.0998×10^{-10}	8.4376×10^{-9}

Table 2b: The result obtained for function f2 when RTEPv2 is used

f2	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.6452×10^{-11}	8.9030×10^{-10}	8.4836×10^{-11}	4.5707×10^{-9}
gr=0.1	3.8785×10^{-11}	7.2735×10^{-10}	8.4099×10^{-11}	8.0445×10^{-9}
gr=0.2	$\mathbf{3.1723\times10^{-11}}$	8.3195×10^{-10}	8.2526×10^{-11}	5.8692×10^{-9}
gr=0.3	3.4866×10^{-11}	1.1656×10^{-9}	8.9691×10^{-11}	8.2410×10^{-9}
gr=0.4	3.4390×10^{-11}	6.3833×10^{-10}	8.2153×10^{-11}	9.0333×10^{-9}
gr=0.5	5.0586×10^{-11}	9.4270×10^{-10}	$\mathbf{7.9001\times10^{-11}}$	7.5830×10^{-9}
gr=0.6	4.3034×10^{-11}	$\mathbf{6.2873\times10^{-10}}$	8.8021×10^{-11}	1.7174×10^{-8}
gr=0.7	3.7549×10^{-11}	8.6280×10^{-10}	9.5002×10^{-11}	6.8584×10^{-8}
gr=0.8	4.0393×10^{-11}	9.3801×10^{-10}	8.8234×10^{-11}	4.8999×10^{-9}
gr=0.9	3.6100×10^{-11}	9.1892×10^{-10}	9.2780×10^{-11}	1.0545×10^{-8}
gr=1	3.6454×10^{-11}	9.2013×10^{-10}	1.0417×10^{-10}	$\mathbf{3.7971\times10^{-9}}$

Table 2c: The result obtained for function f2 when RTEPv3 is used

f2	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	4.9441×10^{-11}	1.2564×10^{-9}	$\mathbf{1.3272\times10^{-11}}$	$\mathbf{5.3310\times10^{-9}}$
gr=0.1	6.5267×10^{-11}	1.2858×10^{-9}	1.5580×10^{-10}	9.9163×10^{-9}
gr=0.2	6.6597×10^{-11}	1.4143×10^{-9}	1.5548×10^{-10}	5.9129×10^{-9}
gr=0.3	5.9735×10^{-11}	1.7161×10^{-9}	1.2991×10^{-10}	9.8358×10^{-9}
gr=0.4	3.8753×10^{-11}	1.7004×10^{-9}	1.2786×10^{-10}	2.1570×10^{-8}
gr=0.5	5.7231×10^{-11}	1.4735×10^{-9}	1.3762×10^{-10}	1.7869×10^{-8}
gr=0.6	4.5770×10^{-11}	1.5334×10^{-9}	1.4135×10^{-10}	7.3993×10^{-9}
gr=0.7	3.9183×10^{-11}	$\mathbf{1.4543\times10^{-10}}$	1.6343×10^{-8}	1.4173×10^{-8}
gr=0.8	$\mathbf{2.3815\times10^{-11}}$	8.0534×10^{-10}	8.5374×10^{-11}	8.4623×10^{-9}
gr=0.9	5.3251×10^{-11}	1.5767×10^{-9}	1.1356×10^{-10}	7.4891×10^{-9}
gr=1	4.9078×10^{-11}	8.2908×10^{-10}	9.9882×10^{-11}	8.6645×10^{-9}

Table 2d: The result obtained for function f2 when RTEPv4 is used

f2	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.3540×10^{-11}	1.0136×10^{-9}	1.3268×10^{-10}	3.4714×10^{-8}
gr=0.1	5.8354×10^{-11}	1.1116×10^{-9}	1.4231×10^{-10}	1.2645×10^{-8}
gr=0.2	5.8431×10^{-11}	1.6443×10^{-9}	1.3462×10^{-10}	1.8150×10^{-8}
gr=0.3	4.7831×10^{-11}	1.3764×10^{-9}	1.3104×10^{-10}	1.8502×10^{-8}
gr=0.4	6.0740×10^{-11}	1.2726×10^{-9}	1.4126×10^{-10}	9.6812×10^{-9}
gr=0.5	5.8419×10^{-11}	1.3264×10^{-9}	1.2776×10^{-10}	9.9513×10^{-9}
gr=0.6	4.1879×10^{-11}	1.3395×10^{-9}	1.2897×10^{-10}	5.4040×10^{-8}
gr=0.7	4.3651×10^{-11}	$\mathbf{6.1003\times10^{-10}}$	1.2285×10^{-10}	$\mathbf{6.5107\times10^{-9}}$
gr=0.8	5.2081×10^{-11}	9.3985×10^{-10}	1.2867×10^{-10}	1.8458×10^{-8}
gr=0.9	5.4469×10^{-11}	1.0758×10^{-9}	1.1947×10^{-10}	1.5754×10^{-8}
gr=1	$\mathbf{3.1290\times10^{-11}}$	9.6598×10^{-10}	$\mathbf{1.0930\times10^{-10}}$	4.5654×10^{-8}

Table 3a: The result obtained for function f3 when RTEPv1 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.4193×10^{3}	2.5990×10^{4}	1.1489×10^{4}	2.9716×10^{4}
gr=0.1	8.6573×10^{3}	2.5287×10^{4}	1.1798×10^{4}	$\mathbf{2.8399\times10^{4}}$
gr=0.2	6.6118×10^{3}	2.4568×10^{4}	1.1943×10^{4}	2.8949×10^{4}
gr=0.3	5.1863×10^{3}	2.4569×10^{4}	1.1477×10^{4}	2.8838×10^{4}
gr=0.4	8.0729×10^{3}	2.4110×10^{4}	1.2428×10^{4}	2.9002×10^{4}
gr=0.5	8.4532×10^{3}	2.5048×10^{4}	1.2099×10^{4}	2.9013×10^{4}
gr=0.6	6.5747×10^{3}	2.5639×10^{4}	1.1812×10^{4}	2.9300×10^{4}
gr=0.7	7.8864×10^{3}	2.3382×10^{4}	1.1776×10^{4}	2.8795×10^{4}
gr=0.8	7.9768×10^{3}	2.4080×10^{4}	1.1705×10^{4}	2.8473×10^{4}
gr=0.9	$\mathbf{4.6716\times10^{3}}$	2.5092×10^{4}	$\mathbf{1.1410\times10^{4}}$	2.8888×10^{4}
gr=1	8.3860×10^{3}	$\mathbf{2.3737\times10^{4}}$	1.1703×10^{4}	2.9030×10^{4}

Table 3b: The result obtained for function f3 when RTEPv2 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.7059×10^{3}	2.5538×10^{4}	1.1796×10^{4}	2.9032×10^{4}
gr=0.1	6.3634×10^{3}	2.5748×10^{4}	1.1358×10^{4}	2.9464×10^{4}
gr=0.2	7.0499×10^{3}	2.3474×10^{4}	1.1439×10^{4}	$\mathbf{2.8339\times10^{4}}$
gr=0.3	7.9084×10^{3}	2.4687×10^{4}	1.1781×10^{4}	2.9094×10^{4}
gr=0.4	7.2682×10^{3}	2.4025×10^{4}	1.1626×10^{4}	2.8502×10^{4}
gr=0.5	7.7362×10^{3}	2.4670×10^{4}	1.1876×10^{4}	2.8860×10^{4}
gr=0.6	6.6819×10^{3}	2.4653×10^{4}	1.1528×10^{4}	2.8885×10^{4}
gr=0.7	7.9971×10^{3}	2.3866×10^{4}	1.1379×10^{4}	2.8472×10^{4}
gr=0.8	$\mathbf{4.8512\times10^{3}}$	2.5493×10^{4}	$\mathbf{1.1275\times10^{4}}$	2.8626×10^{4}
gr=0.9	7.5570×10^{3}	$\mathbf{2.3250\times10^{4}}$	1.1521×10^{4}	2.8699×10^{4}
gr=1	7.5595×10^{3}	2.4302×10^{4}	1.1805×10^{4}	2.8399×10^{4}

Table 3c: The result obtained for function f3 when RTEPv3 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	6.7450×10^{3}	2.3990×10^{4}	1.1868×10^{4}	2.9706×10^{4}
gr=0.1	7.1982×10^{3}	2.4985×10^{4}	1.1864×10^{4}	2.8816×10^{4}
gr=0.2	5.2593×10^{3}	2.3654×10^{4}	1.1869×10^{4}	2.9024×10^{4}
gr=0.3	5.8794×10^{3}	2.5698×10^{4}	1.1658×10^{4}	2.8888×10^{4}
gr=0.4	7.5471×10^{3}	2.5471×10^{4}	1.2471×10^{4}	2.9122×10^{4}
gr=0.5	6.4032×10^{3}	2.5681×10^{4}	1.2103×10^{4}	2.9693×10^{4}
gr=0.6	5.7650×10^{3}	2.5321×10^{4}	1.1598×10^{4}	2.9410×10^{4}
gr=0.7	7.2541×10^{3}	$\mathbf{2.3874\times10^{4}}$	1.1547×10^{4}	2.8965×10^{4}
gr=0.8	7.6587×10^{3}	2.4021×10^{4}	$\mathbf{1.1510\times10^{4}}$	$\mathbf{2.8163\times10^{4}}$
gr=0.9	4.6978×10^{3}	2.5658×10^{4}	1.1843×10^{4}	2.8778×10^{4}
gr=1	$\mathbf{4.2568\times10^{3}}$	2.3874×10^{4}	1.1903×10^{4}	2.9980×10^{4}

Table 3d: The result obtained for function f3 when RTEPv4 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.2895×10^{3}	2.6030×10^{4}	1.1975×10^{4}	2.9158×10^{4}
gr=0.1	6.3874×10^{3}	2.5785×10^{4}	1.1784×10^{4}	2.9964×10^{4}
gr=0.2	7.0356×10^{3}	$\mathbf{2.2614\times10^{4}}$	1.1659×10^{4}	2.8039×10^{4}
gr=0.3	7.9130×10^{3}	2.4237×10^{4}	1.1963×10^{4}	2.9774×10^{4}
gr=0.4	7.2263×10^{3}	2.4035×10^{4}	1.1730×10^{4}	2.8302×10^{4}
gr=0.5	7.4785×10^{3}	2.4760×10^{4}	1.1546×10^{4}	$\mathbf{2.8027\times10^{4}}$
gr=0.6	6.6745×10^{3}	2.4650×10^{4}	1.1569×10^{4}	2.8225×10^{4}
gr=0.7	7.0244×10^{3}	2.3874×10^{4}	1.1373×10^{4}	2.8362×10^{4}
gr=0.8	$\mathbf{4.8749\times10^{3}}$	2.5369×10^{4}	$\mathbf{1.1203\times10^{4}}$	2.8876×10^{4}
gr=0.9	7.5874×10^{3}	2.3123×10^{4}	1.1555×10^{4}	2.8769×10^{4}
gr=1	7.5659×10^{3}	2.4742×10^{4}	1.1869×10^{4}	2.8350×10^{4}

Table 4a: The result obtained for function f4 when RTEPv1 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.6635	18.3675	**12.5331**	**20.7273**
gr=0.1	9.5068	18.3552	13.2806	21.1319
gr=0.2	8.7556	19.1225	12.8190	21.3831
gr=0.3	8.1985	**18.3228**	13.1411	21.6815
gr=0.4	8.0402	19.0034	13.3808	22.0153
gr=0.5	10.0096	20.0743	13.4233	22.2123
gr=0.6	6.4891	20.9216	13.2699	22.9367
gr=0.7	8.0555	21.0023	13.4874	23.2677
gr=0.8	7.9376	20.4767	13.7986	23.8470
gr=0.9	**5.9505**	22.3923	13.6555	24.3709
gr=1	10.3646	22.7075	14.1216	25.5681

Table 4b: The result obtained for function f4 when RTEPv2 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.5550	17.9440	**12.7953**	**20.7293**
gr=0.1	8.9649	18.3822	13.1372	21.0840
gr=0.2	8.8104	**17.8908**	12.8232	21.2435
gr=0.3	8.7560	19.1593	13.5423	21.9528
gr=0.4	9.7531	18.6607	13.7100	22.1106
gr=0.5	**8.5535**	19.2123	13.3918	22.4029
gr=0.6	7.6167	20.0668	13.5584	22.6230
gr=0.7	8.6012	21.1652	13.7465	23.2342
gr=0.8	9.6230	21.7183	13.7542	23.6240
gr=0.9	7.9866	22.5205	13.7964	24.3950
gr=1	8.7858	21.9801	14.2512	25.3364

Table 4c: The result obtained for function f4 when RTEPv3 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.3350	**17.1799**	**12.2018**	**20.0641**
gr=0.1	9.3113	18.2843	12.8756	20.6618
gr=0.2	9.3821	18.1678	12.3916	20.8616
gr=0.3	8.5109	18.0520	12.4465	20.6243
gr=0.4	8.9461	18.2683	13.0518	20.9834
gr=0.5	7.6403	19.3817	12.6263	21.1202
gr=0.6	8.2545	18.5677	12.6891	21.3162
gr=0.7	9.8188	19.0817	12.9547	21.4100
gr=0.8	**7.1590**	19.9381	12.7657	21.7426
gr=0.9	8.8018	19.3629	12.6094	21.9215
gr=1	8.7575	19.7772	12.7859	22.3889

Table 4d: The result obtained for function f4 when RTEPv4 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.7574	17.9493	12.4094	**20.4462**
gr=0.1	8.1957	18.0075	**12.2509**	20.5394
gr=0.2	8.7433	17.9785	12.4613	20.5399
gr=0.3	9.2234	**17.9288**	12.4028	20.9142
gr=0.4	8.1850	18.6406	12.6089	20.9488
gr=0.5	8.9983	19.0192	12.6993	21.1846
gr=0.6	8.4564	19.0355	12.5297	21.1714
gr=0.7	**8.0762**	19.7745	12.5024	21.7373
gr=0.8	9.4956	17.9057	12.7867	21.6976
gr=0.9	8.9276	19.5983	12.8675	22.0174
gr=1	9.8398	20.3305	13.4841	22.7264

Table 5a: The result obtained for function f5 when RTEPv1 is used

f5	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.1843	153.0680	1.4327	**1.5063×10^{3}**
gr=0.1	0.2122	214.8060	1.0465	1.8884×10^{3}
gr=0.2	0.0581	**132.9814**	1.0369	1.8208×10^{3}
gr=0.3	**0.0598**	271.3024	0.9948	1.5819×10^{3}
gr=0.4	0.0634	270.4581	0.7663	1.8080×10^{3}
gr=0.5	0.0795	350.6152	0.7949	1.9935×10^{3}
gr=0.6	0.1002	329.2396	0.9463	1.7032×10^{3}
gr=0.7	0.0763	201.4361	0.9724	1.9189×10^{3}
gr=0.8	0.0859	362.9856	**0.6950**	1.6637×10^{3}
gr=0.9	0.0942	301.5972	1.0137	2.0431×10^{3}
gr=1	0.1143	77.9025	0.9742	1.8357×10^{3}

Table 5b: The result obtained for function f5 when RTEPv2 is used

f5	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.1374	513.4455	0.9962	**1.6102×10^{3}**
gr=0.1	0.1918	**101.5044**	0.8987	2.0300×10^{3}
gr=0.2	0.1643	179.2036	**0.8321**	1.7754×10^{3}
gr=0.3	0.1383	249.9489	0.8967	1.8122×10^{3}
gr=0.4	0.2023	493.3376	0.8778	1.7932×10^{3}
gr=0.5	**0.0314**	357.1059	1.0758	1.9567×10^{3}
gr=0.6	0.1659	310.9758	0.9467	1.8049×10^{3}
gr=0.7	0.0825	207.3746	0.7845	1.6893×10^{3}
gr=0.8	0.1386	207.3759	1.1299	1.9338×10^{3}
gr=0.9	0.2375	264.1854	0.9387	1.8034×10^{3}
gr=1	0.1048	289.5313	0.8867	1.7673×10^{3}

Table 5c: The result obtained for function f5 when RTEPv3 is used

f5	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.1588	185.1453	1.1266	1.6656×10^{3}
gr=0.1	0.1644	320.2531	0.9558	2.0048×10^{3}
gr=0.2	**0.0250**	**105.5081**	1.0733	1.7675×10^{3}
gr=0.3	0.0564	127.3548	0.9698	1.5546×10^{3}
gr=0.4	0.0897	190.4968	0.7663	1.8502×10^{3}
gr=0.5	0.0265	262.6743	0.7547	2.1366×10^{3}
gr=0.6	0.1221	156.2169	0.9596	1.7415×10^{3}
gr=0.7	0.0458	195.4907	0.9698	1.9368×10^{3}
gr=0.8	0.1230	212.9999	**0.6234**	2.1874×10^{3}
gr=0.9	0.0896	245.5555	0.7203	2.0564×10^{3}
gr=1	0.1088	129.9015	0.9470	$\mathbf{1.4202\times10^{3}}$

Table 5d: The result obtained for function f5 when RTEPv4 is used

f5	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.1552	515.4486	1.1926	1.8450×10^{3}
gr=0.1	0.1547	267.5541	0.8985	2.0312×10^{3}
gr=0.2	0.1225	252.2479	0.8456	1.7874×10^{3}
gr=0.3	0.1478	**189.9745**	0.8985	2.0562×10^{3}
gr=0.4	0.2036	399.3210	0.8769	1.7947×10^{3}
gr=0.5	0.0749	256.1369	1.0747	1.9565×10^{3}
gr=0.6	0.1548	425.9872	1.0359	2.0059×10^{3}
gr=0.7	**0.0548**	221.3578	**0.7974**	$\mathbf{1.6589\times10^{3}}$
gr=0.8	0.1478	225.3698	1.1288	1.9335×10^{3}
gr=0.9	0.0575	265.8613	1.0286	2.0208×10^{3}
gr=1	0.1794	220.3383	1.1507	1.6935×10^{3}

Table 6a: The result obtained for function f6 when RTEPv1 is used

f6	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	**7.4200**	**0**	65.6692
gr=0.1	**0**	10.1000	**0**	65.8388
gr=0.2	**0**	13.8400	**0**	69.4912
gr=0.3	**0**	8.4200	**0**	72.1800
gr=0.4	**0**	13.8000	**0**	76.5612
gr=0.5	**0**	8.8000	**0**	59.3268
gr=0.6	**0**	13.3200	**0**	**54.3264**
gr=0.7	**0**	10.9800	**0**	61.9984
gr=0.8	**0**	13.7600	**0**	70.9276
gr=0.9	**0**	10.8200	**0**	71.1476
gr=1	**0**	10.9600	**0**	75.6276

Table 6b: The result obtained for function f6 when RTEPv2 is used

f6	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	14.4600	**0**	59.7488
gr=0.1	**0**	16.8000	**0**	66.8868
gr=0.2	**0**	11.5600	**0**	66.3892
gr=0.3	**0**	18.8200	**0**	68.8020
gr=0.4	**0**	12.7000	**0**	57.9156
gr=0.5	**0**	**11.0400**	**0**	63.6128
gr=0.6	**0**	13.7200	**0**	71.4440
gr=0.7	**0**	12.5800	**0**	**52.4708**
gr=0.8	**0**	16.6600	**0**	67.7120
gr=0.9	**0**	11.6200	**0**	62.3020
gr=1	**0**	12.7200	**0**	60.6276

Table 6c: The result obtained for function f6 when RTEPv3 is used

f6	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	11.6200	**0**	58.0584
gr=0.1	**0**	13.7600	**0**	**57.0712**
gr=0.2	**0**	14.2800	**0**	62.0756
gr=0.3	**0**	**11.5600**	**0**	61.7908
gr=0.4	**0**	15.8566	**0**	65.5748
gr=0.5	**0**	12.8256	**0**	69.3156
gr=0.6	**0**	14.3478	**0**	58.3366
gr=0.7	**0**	12.9444	**0**	64.9988
gr=0.8	**0**	12.7547	**0**	73.9254
gr=0.9	**0**	11.6200	**0**	71.4496
gr=1	**0**	12.8600	**0**	71.3552

Table 6d: The result obtained for function f6 when RTEPv4 is used

f6	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	**9.1000**	**0**	61.3484
gr=0.1	**0**	11.2600	**0**	61.7220
gr=0.2	**0**	13.6533	**0**	62.6598
gr=0.3	**0**	16.8340	**0**	65.8547
gr=0.4	**0**	15.6894	**0**	59.9658
gr=0.5	**0**	13.0474	**0**	60.4789
gr=0.6	**0**	17.7354	**0**	74.5563
gr=0.7	**0**	12.5894	**0**	**56.4974**
gr=0.8	**0**	11.6540	**0**	62.8146
gr=0.9	**0**	9.2400	**0**	72.1568
gr=1	**0**	17.1400	**0**	56.7952

Table 7a: The result obtained for function f7 when RTEPv1 is used

f7	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0289	0.1489	0.0701	0.1861
gr=0.1	0.0306	**0.1407**	0.0703	0.1861
gr=0.2	0.0371	0.1594	0.0730	0.1915
gr=0.3	**0.0271**	0.1513	0.0702	0.1840
gr=0.4	0.0383	0.1482	**0.0676**	0.1873
gr=0.5	0.0410	0.1515	0.0737	0.1894
gr=0.6	0.0449	0.1426	0.0723	**0.1853**
gr=0.7	0.0371	0.1600	0.1600	0.1879
gr=0.8	0.0438	0.1566	0.0709	0.1888
gr=0.9	0.0443	0.1457	0.0737	0.1904
gr=1	0.0339	0.1620	0.0695	0.1893

Table 7b: The result obtained for function f7 when RTEPv2 is used

f7	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0357	0.1476	**0.0696**	0.1829
gr=0.1	0.0368	0.1446	0.0703	0.1837
gr=0.2	0.0466	0.1567	0.0701	0.1883
gr=0.3	**0.0342**	0.1524	0.0732	0.1873
gr=0.4	0.0472	0.1542	0.0758	0.1866
gr=0.5	0.0395	**0.1412**	0.0700	**0.1802**
gr=0.6	0.0446	0.1548	0.0732	0.1882
gr=0.7	0.0414	0.1542	0.0700	0.1849
gr=0.8	0.0375	0.1622	0.0739	0.1879
gr=0.9	0.0435	0.1554	0.0784	0.1914
gr=1	0.0349	0.1586	0.0734	0.1863

Table 7c: The result obtained for function f7 when RTEPv3 is used

f7	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0385	0.1490	0.0712	0.1843
gr=0.1	0.0358	0.1571	0.0747	0.1888
gr=0.2	0.0658	0.1535	0.0733	0.1947
gr=0.3	**0.0279**	0.1569	0.0720	0.1896
gr=0.4	0.0478	0.1434	**0.0667**	**0.1833**
gr=0.5	0.0698	0.1554	0.0772	0.1865
gr=0.6	0.0354	0.1479	0.0765	0.1835
gr=0.7	0.0355	0.1960	0.1789	0.1874
gr=0.8	0.0745	0.1347	0.0711	0.1862
gr=0.9	0.0425	**0.1214**	0.0777	0.1940
gr=1	0.0477	0.1457	0.0770	0.1890

Table 7d: The result obtained for function f7 when RTEPv4 is used

f7	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0324	0.1478	0.0721	0.1861
gr=0.1	0.0398	0.1487	**0.0706**	0.1854
gr=0.2	0.0455	0.1562	0.0776	0.1825
gr=0.3	0.0256	0.1541	0.0726	0.1837
gr=0.4	0.0457	0.1532	0.0785	0.1896
gr=0.5	0.0953	**0.1421**	0.0709	**0.1822**
gr=0.6	0.0644	0.1586	0.0774	0.1854
gr=0.7	**0.0144**	0.1534	0.0763	0.1869
gr=0.8	0.0537	0.1698	0.0798	0.1874
gr=0.9	0.0534	0.1455	0.0742	0.1963
gr=1	0.0372	0.1555	0.0763	0.1882

Table 8a: The result obtained for function f8 when RTEPv1 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**1.4376×10^{-10}**	1.6196	0.0248	**2.0574**
gr=0.1	4.1439×10^{-10}	1.6154	0.0115	2.1867
gr=0.2	1.5706×10^{-9}	**1.4135**	0.0014	2.1201
gr=0.3	1.3730×10^{-9}	1.6714	0.0031	2.1593
gr=0.4	2.2487×10^{-10}	1.5904	0.0022	2.1747
gr=0.5	1.4396×10^{-9}	1.7157	**4.0240×10^{-4}**	2.2622
gr=0.6	4.8948×10^{-10}	1.6768	0.0019	2.1983
gr=0.7	2.0702×10^{-10}	1.8310	0.0062	2.2296
gr=0.8	1.1961×10^{-9}	1.7420	0.0237	2.2053
gr=0.9	3.0639×10^{-10}	1.6323	0.0605	2.2559
gr=1	4.9300×10^{-10}	2.0071	0.0017	2.2888

Table 8b: The result obtained for function f8 when RTEPv2 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.1936×10^{-10}	1.7214	2.6863×10^{-5}	2.0657
gr=0.1	7.3499×10^{-11}	1.5870	**6.3825×10^{-6}**	2.1779
gr=0.2	6.3164×10^{-10}	**1.5044**	0.0035	**2.0957**
gr=0.3	6.9093×10^{-10}	1.6583	0.0013	2.1167
gr=0.4	4.2900×10^{-10}	1.5649	0.0052	2.1001
gr=0.5	**1.4381×10^{-11}**	1.6905	0.0058	2.1787
gr=0.6	3.7272×10^{-10}	1.6957	0.0212	2.1893
gr=0.7	4.1155×10^{-10}	1.7159	0.0012	2.1775
gr=0.8	1.8559×10^{-10}	1.5651	0.0045	2.1973
gr=0.9	6.0140×10^{-11}	1.7264	0.0054	2.2395
gr=1	1.5363×10^{-11}	1.7215	0.0037	2.2198

Table 8c: The result obtained for function f8 when RTEPv3 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.0929×10^{-10}	1.7025	**2.1565×10^{-4}**	2.1482
gr=0.1	4.5162×10^{-10}	**1.5825**	0.0029	2.2255
gr=0.2	1.8007×10^{-9}	1.8139	0.0011	2.2366
gr=0.3	2.3547×10^{-9}	1.6352	0.0022	**2.1383**
gr=0.4	3.2698×10^{-10}	1.5917	0.0045	2.1967
gr=0.5	2.4586×10^{-9}	1.7598	0.0135	2.2672
gr=0.6	**1.8878×10^{-10}**	1.6872	0.0030	2.1963
gr=0.7	2.0762×10^{-10}	1.8960	0.0031	2.2346
gr=0.8	3.1871×10^{-9}	1.7875	0.0247	2.2043
gr=0.9	2.0599×10^{-10}	1.6550	0.0105	2.2669
gr=1	9.9476×10^{-10}	1.7304	0.0166	2.2874

Table 8d: The result obtained for function f8 when RTEPv4 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.3478×10^{-9}	1.5749	0.0044	2.1392
gr=0.1	2.1231×10^{-10}	1.6933	**2.3702×10^{-4}**	2.2002
gr=0.2	5.3154×10^{-10}	**1.5066**	0.0069	**2.0947**
gr=0.3	4.9083×10^{-10}	1.6565	0.0031	2.1150
gr=0.4	5.2870×10^{-10}	1.5786	0.0056	2.1002
gr=0.5	**1.4241×10^{-11}**	1.6365	0.0074	2.1793
gr=0.6	2.7962×10^{-10}	1.6745	0.0236	2.1856
gr=0.7	3.2233×10^{-10}	1.7269	0.0017	2.1730
gr=0.8	1.8741×10^{-10}	1.5158	0.0099	2.1985
gr=0.9	4.0256×10^{-11}	1.7356	0.0066	2.2895
gr=1	5.1568×10^{-10}	1.8514	8.8976×10^{-4}	2.3030

Table 9a: The result obtained for function f9 when RTEPv1 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	6.1391×10^{-12}	**0.9574**	$\mathbf{8.2115\times10^{-8}}$	1.4523
gr=0.1	$\mathbf{5.6843\times10^{-13}}$	1.0440	2.3016×10^{-6}	**1.4427**
gr=0.2	1.0232×10^{-12}	1.0902	9.5404×10^{-7}	1.4583
gr=0.3	4.6043×10^{-12}	1.0926	3.9044×10^{-6}	1.4951
gr=0.4	2.5011×10^{-12}	1.2591	2.3561×10^{-5}	1.5829
gr=0.5	3.0809×10^{-11}	1.1515	3.1982×10^{-7}	1.5076
gr=0.6	4.5475×10^{-12}	1.3027	2.7878×10^{-5}	1.5903
gr=0.7	1.1369×10^{-12}	1.1012	7.5982×10^{-7}	1.5555
gr=0.8	6.8212×10^{-13}	0.9919	3.2657×10^{-7}	1.5436
gr=0.9	5.9117×10^{-12}	1.2106	1.5282×10^{-7}	1.5585
gr=1	2.7853×10^{-12}	1.1805	2.6526×10^{-7}	1.5667

Table 9b: The result obtained for function f9 when RTEPv2 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{6.8212\times10^{-13}}$	1.0440	2.3418×10^{-7}	**1.4212**
gr=0.1	2.7285×10^{-12}	1.1483	7.1416×10^{-6}	1.4785
gr=0.2	3.3538×10^{-12}	1.1588	1.2713×10^{-7}	1.5038
gr=0.3	1.0232×10^{-12}	**0.8678**	1.8178×10^{-6}	1.5004
gr=0.4	1.9327×10^{-12}	1.0840	$\mathbf{5.9675\times10^{-8}}$	1.4747
gr=0.5	5.0591×10^{-12}	1.0394	2.3748×10^{-6}	1.5082
gr=0.6	1.8190×10^{-12}	0.9157	2.4746×10^{-5}	1.5443
gr=0.7	1.1653×10^{-11}	1.0163	1.7086×10^{-5}	1.5519
gr=0.8	1.7053×10^{-12}	1.1335	4.7985×10^{-6}	1.5258
gr=0.9	6.6734×10^{-11}	0.9882	6.5101×10^{-6}	1.5420
gr=1	8.5834×10^{-12}	1.0359	4.3057×10^{-4}	1.5709

Table 9c: The result obtained for function f9 when RTEPv3 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.3874×10^{-12}	1.0943	**2.0915×10^{-8}**	1.5046
gr=0.1	5.7412×10^{-12}	1.1451	1.2208×10^{-6}	1.5267
gr=0.2	6.3096×10^{-12}	1.2410	1.7170×10^{-6}	1.5403
gr=0.3	5.6078×10^{-12}	1.0587	2.8695×10^{-6}	1.4875
gr=0.4	7.5077×10^{-12}	1.2697	1.4789×10^{-5}	1.5745
gr=0.5	2.0079×10^{-11}	1.1456	2.2564×10^{-7}	1.5365
gr=0.6	5.7695×10^{-12}	1.3368	3.7656×10^{-5}	1.5478
gr=0.7	4.6987×10^{-12}	1.1897	4.5745×10^{-7}	**1.4444**
gr=0.8	**2.8582×10^{-13}**	**0.9564**	2.2655×10^{-7}	1.6354
gr=0.9	4.6223×10^{-12}	1.2789	1.5472×10^{-7}	1.5855
gr=1	7.3896×10^{-13}	1.1919	1.3112×10^{-5}	1.5660

Table 9d: The result obtained for function f9 when RTEPv4 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.0718×10^{-12}	1.0793	**3.3180×10^{-8}**	**1.4641**
gr=0.1	6.8212×10^{-12}	1.2466	1.0983×10^{-6}	1.5867
gr=0.2	2.3478×10^{-12}	1.4447	1.2693×10^{-7}	1.5069
gr=0.3	**1.0563×10^{-12}**	1.3478	1.9878×10^{-6}	1.5023
gr=0.4	9.9657×10^{-11}	1.0126	9.6535×10^{-8}	1.4747
gr=0.5	2.0658×10^{-12}	**0.8498**	2.3668×10^{-6}	1.5258
gr=0.6	1.8450×10^{-12}	1.3547	2.4446×10^{-5}	1.5478
gr=0.7	1.2568×10^{-11}	1.0246	1.7123×10^{-5}	1.5519
gr=0.8	1.3507×10^{-12}	0.9558	2.7985×10^{-6}	1.5598
gr=0.9	9.5478×10^{-11}	0.9225	9.5658×10^{-6}	1.5417
gr=1	1.5916×10^{-12}	1.1675	2.1503×10^{-4}	1.6148

Table 10a: The result obtained for function f10 when RTEPv1 is used

f10	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.5513×10^{-10}	$\mathbf{3.3999\times10^{-8}}$	2.5471×10^{-9}	5.1448×10^{-7}
gr=0.1	$\mathbf{4.3607\times10^{-10}}$	4.6854×10^{-8}	$\mathbf{2.2896\times10^{-9}}$	$\mathbf{4.3417\times10^{-7}}$
gr=0.2	6.4325×10^{-10}	5.5208×10^{-8}	2.6001×10^{-9}	5.5440×10^{-7}
gr=0.3	9.9720×10^{-10}	6.1391×10^{-8}	2.5439×10^{-9}	7.7991×10^{-7}
gr=0.4	1.4093×10^{-9}	5.8969×10^{-8}	3.3692×10^{-9}	6.6006×10^{-7}
gr=0.5	1.1858×10^{-9}	6.8220×10^{-8}	3.1193×10^{-9}	8.0797×10^{-7}
gr=0.6	7.9708×10^{-10}	6.9219×10^{-8}	3.1753×10^{-9}	6.7871×10^{-7}
gr=0.7	1.1816×10^{-9}	8.1724×10^{-8}	2.9966×10^{-9}	5.1807×10^{-7}
gr=0.8	8.6927×10^{-10}	5.5278×10^{-8}	3.4565×10^{-9}	1.2958×10^{-6}
gr=0.9	1.1163×10^{-9}	6.4126×10^{-8}	3.5871×10^{-9}	2.3304×10^{-6}
gr=1	1.2084×10^{-9}	6.0449×10^{-8}	3.4773×10^{-9}	5.7988×10^{-7}

Table 10b: The result obtained for function f10 when RTEPv2 is used

f10	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	6.4716×10^{-10}	$\mathbf{2.8291\times10^{-8}}$	$\mathbf{2.1746\times10^{-9}}$	$\mathbf{5.1528\times10^{-7}}$
gr=0.1	$\mathbf{5.3174\times10^{-10}}$	4.9637×10^{-8}	2.5631×10^{-9}	1.3685×10^{-6}
gr=0.2	9.4042×10^{-10}	7.2866×10^{-8}	2.7412×10^{-9}	6.0993×10^{-7}
gr=0.3	7.1507×10^{-10}	5.6254×10^{-8}	2.5858×10^{-9}	8.8124×10^{-7}
gr=0.4	9.6002×10^{-10}	6.6570×10^{-8}	2.9838×10^{-9}	1.7763×10^{-6}
gr=0.5	9.3546×10^{-10}	8.2384×10^{-8}	3.0400×10^{-9}	1.5485×10^{-6}
gr=0.6	1.0984×10^{-9}	5.1281×10^{-8}	2.9882×10^{-9}	8.3677×10^{-7}
gr=0.7	1.3390×10^{-9}	4.2543×10^{-8}	3.3389×10^{-9}	2.4687×10^{-6}
gr=0.8	1.2736×10^{-9}	7.5206×10^{-8}	3.2284×10^{-9}	2.4888×10^{-6}
gr=0.9	1.1358×10^{-9}	4.1154×10^{-8}	3.2961×10^{-9}	1.6619×10^{-6}
gr=1	1.2534×10^{-9}	6.5442×10^{-8}	3.6469×10^{-9}	6.6104×10^{-7}

Table 10c: The result obtained for function f10 when RTEPv3 is used

f10	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.4070×10^{-9}	7.0482×10^{-8}	3.8466×10^{-9}	9.7136×10^{-7}
gr=0.1	1.0495×10^{-9}	$\mathbf{5.3328\times10^{-8}}$	4.5612×10^{-9}	7.7163×10^{-7}
gr=0.2	3.4587×10^{-10}	6.5698×10^{-8}	3.6224×10^{-9}	6.5960×10^{-7}
gr=0.3	$\mathbf{1.9698\times10^{-10}}$	7.1391×10^{-8}	3.5424×10^{-9}	8.0771×10^{-7}
gr=0.4	2.4123×10^{-9}	6.8630×10^{-8}	4.3683×10^{-9}	2.6566×10^{-7}
gr=0.5	1.1858×10^{-9}	5.8147×10^{-8}	4.1297×10^{-9}	2.0327×10^{-7}
gr=0.6	5.9547×10^{-10}	6.9745×10^{-8}	$\mathbf{3.1453\times10^{-9}}$	8.7368×10^{-7}
gr=0.7	2.1478×10^{-9}	7.1897×10^{-8}	3.8855×10^{-9}	$\mathbf{1.1871\times10^{-7}}$
gr=0.8	6.6786×10^{-10}	6.5564×10^{-8}	3.4687×10^{-9}	5.2546×10^{-6}
gr=0.9	4.1258×10^{-9}	6.4322×10^{-8}	4.1785×10^{-9}	3.3254×10^{-6}
gr=1	8.0125×10^{-10}	8.1443×10^{-8}	3.9807×10^{-9}	1.5294×10^{-6}

Table 10d: The result obtained for function f10 when RTEPv4 is used

f10	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.6403×10^{-9}	9.5246×10^{-8}	4.1310×10^{-9}	5.9424×10^{-7}
gr=0.1	1.4976×10^{-9}	4.9537×10^{-8}	3.9450×10^{-9}	8.4732×10^{-7}
gr=0.2	9.4745×10^{-10}	5.2866×10^{-8}	3.7489×10^{-9}	4.0996×10^{-7}
gr=0.3	1.1457×10^{-9}	7.6474×10^{-8}	4.5787×10^{-9}	7.8123×10^{-7}
gr=0.4	9.6332×10^{-10}	5.6698×10^{-8}	3.9999×10^{-9}	2.7789×10^{-6}
gr=0.5	$\mathbf{9.3366\times10^{-10}}$	6.2256×10^{-8}	$\mathbf{3.0500\times10^{-9}}$	3.5658×10^{-6}
gr=0.6	1.0784×10^{-9}	7.1347×10^{-8}	3.8962×10^{-9}	$\mathbf{1.3589\times10^{-7}}$
gr=0.7	9.3485×10^{-10}	5.2658×10^{-8}	4.3279×10^{-9}	5.4568×10^{-6}
gr=0.8	1.2774×10^{-9}	8.5689×10^{-8}	4.2364×10^{-9}	1.4778×10^{-6}
gr=0.9	1.1247×10^{-9}	$\mathbf{4.1478\times10^{-8}}$	3.2991×10^{-9}	6.4479×10^{-6}
gr=1	1.1879×10^{-9}	6.4694×10^{-8}	3.6230×10^{-9}	1.2561×10^{-6}

Table 11a: The result obtained for function f11 when RTEPv1 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	0.0544	1.9977×10^{-11}	0.0680
gr=0.1	**0**	0.0528	$\mathbf{1.5839\times10^{-12}}$	0.0694
gr=0.2	**0**	0.0568	8.3793×10^{-11}	0.0684
gr=0.3	**0**	0.0558	3.2870×10^{-6}	0.0691
gr=0.4	**0**	0.0573	9.5863×10^{-6}	0.0716
gr=0.5	**0**	0.0518	7.9891×10^{-10}	0.0702
gr=0.6	**0**	0.0577	7.7765×10^{-8}	0.0722
gr=0.7	**0**	0.0527	7.5837×10^{-10}	0.0710
gr=0.8	**0**	0.0534	1.3641×10^{-8}	**0.0673**
gr=0.9	**0**	0.0522	1.2782×10^{-10}	0.0698
gr=1	**0**	**0.0502**	4.5833×10^{-12}	0.0688

Table 11b: The result obtained for function f11 when RTEPv2 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	0.0544	3.4185×10^{-11}	0.0676
gr=0.1	**0**	0.0517	$\mathbf{1.6057\times10^{-12}}$	0.0705
gr=0.2	**0**	0.0580	2.2491×10^{-4}	0.0713
gr=0.3	**0**	0.0552	1.9154×10^{-11}	0.0690
gr=0.4	**0**	**0.0504**	3.8153×10^{-9}	0.0702
gr=0.5	**0**	0.0519	3.7515×10^{-11}	0.0702
gr=0.6	**0**	0.0507	4.1389×10^{-9}	**0.0692**
gr=0.7	**0**	0.0567	4.3925×10^{-10}	0.0722
gr=0.8	**0**	0.0516	1.7614×10^{-11}	0.0698
gr=0.9	**0**	0.0497	7.3653×10^{-8}	0.0701
gr=1	**0**	0.0545	1.4978×10^{-8}	0.0701

Table 11c: The result obtained for function f11 when RTEPv3 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	0.0543	1.0047×10^{-11}	0.0671
gr=0.1	**0**	0.0569	$\mathbf{1.5739\times10^{-12}}$	0.0669
gr=0.2	**0**	0.0578	9.3633×10^{-11}	0.0678
gr=0.3	**0**	0.0578	2.2680×10^{-6}	0.0695
gr=0.4	**0**	0.0573	8.5173×10^{-6}	0.0789
gr=0.5	**0**	0.0556	8.9256×10^{-10}	0.0736
gr=0.6	**0**	0.0587	7.7874×10^{-8}	0.0777
gr=0.7	**0**	**0.0531**	8.5568×10^{-10}	0.0714
gr=0.8	**0**	0.0587	2.3987×10^{-8}	**0.0637**
gr=0.9	**0**	0.0599	2.2892×10^{-10}	0.0656
gr=1	**0**	0.0537	7.7883×10^{-11}	0.0712

Table 11d: The result obtained for function f11 when RTEPv4 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	0.0500	1.2350×10^{-8}	0.0708
gr=0.1	**0**	**0.0452**	1.3613×10^{-9}	0.0700
gr=0.2	**0**	0.0510	5.3447×10^{-11}	0.0682
gr=0.3	**0**	0.0548	7.0983×10^{-10}	0.0690
gr=0.4	**0**	0.0555	6.8189×10^{-9}	0.0756
gr=0.5	**0**	0.0557	3.7523×10^{-11}	0.0756
gr=0.6	**0**	0.0527	7.1399×10^{-9}	0.0629
gr=0.7	**0**	0.0596	1.3565×10^{-10}	0.0721
gr=0.8	**0**	0.0537	$\mathbf{2.7655\times10^{-11}}$	**0.0601**
gr=0.9	**0**	0.0472	3.3678×10^{-8}	0.0725
gr=1	**0**	0.0548	8.1065×10^{-11}	0.0698

Table 12a: The result obtained for function f12 when RTEPv1 is used

f12	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**2.6924×10^{-22}**	**1.0916×10^{-17}**	**4.7084×10^{-21}**	**8.7876×10^{-4}**
gr=0.1	7.0996×10^{-22}	4.0926×10^{-17}	5.2266×10^{-21}	0.0011
gr=0.2	9.9999×10^{-22}	2.4909×10^{-16}	1.2346×10^{-20}	0.0012
gr=0.3	4.4269×10^{-22}	1.2961×10^{-17}	8.8954×10^{-21}	9.1433×10^{-4}
gr=0.4	6.2940×10^{-22}	4.0083×10^{-17}	1.2801×10^{-20}	0.0012
gr=0.5	1.3815×10^{-21}	6.2248×10^{-17}	1.6174×10^{-20}	0.0013
gr=0.6	7.6571×10^{-22}	6.4507×10^{-17}	2.6187×10^{-20}	0.0016
gr=0.7	9.4194×10^{-22}	1.5330×10^{-17}	2.4436×10^{-20}	0.0015
gr=0.8	1.6568×10^{-21}	1.9447×10^{-17}	2.9231×10^{-20}	0.0012
gr=0.9	9.4629×10^{-22}	2.0765×10^{-16}	1.3356×10^{-19}	0.0013
gr=1	1.8901×10^{-21}	6.1515×10^{-16}	1.3597×10^{-19}	9.1768×10^{-4}

Table 12b: The result obtained for function f12 when RTEPv2 is used

f12	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	4.4930×10^{-22}	1.0123×10^{-16}	**4.0900×10^{-21}**	**9.0408×10^{-4}**
gr=0.1	**2.3956×10^{-22}**	**6.9128×10^{-18}**	9.8213×10^{-21}	0.0015
gr=0.2	6.5804×10^{-22}	1.2327×10^{-15}	8.2757×10^{-21}	0.0015
gr=0.3	2.9361×10^{-22}	1.1792×10^{-17}	1.1408×10^{-20}	0.0015
gr=0.4	1.2017×10^{-21}	9.9787×10^{-17}	1.3175×10^{-20}	0.0016
gr=0.5	7.6287×10^{-22}	1.5453×10^{-15}	1.6252×10^{-20}	0.0015
gr=0.6	5.7116×10^{-22}	1.9228×10^{-17}	1.9291×10^{-20}	0.0012
gr=0.7	1.4172×10^{-21}	1.0124×10^{-17}	2.5935×10^{-20}	0.0014
gr=0.8	6.1957×10^{-22}	9.2634×10^{-18}	1.9293×10^{-20}	0.0011
gr=0.9	2.5857×10^{-22}	1.2916×10^{-16}	4.0222×10^{-20}	0.0010
gr=1	4.3461×10^{-22}	2.7337×10^{-18}	2.8715×10^{-19}	0.0013

Table 12c: The result obtained for function f12 when RTEPv3 is used

f12	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.5561×10^{-21}	$\mathbf{7.3794\times10^{-19}}$	7.3794×10^{-19}	0.0011
gr=0.1	2.3305×10^{-21}	3.4908×10^{-15}	3.1551×10^{-19}	0.0016
gr=0.2	3.2824×10^{-21}	3.7315×10^{-17}	4.3643×10^{-19}	9.9023×10^{-4}
gr=0.3	7.3668×10^{-21}	1.9195×10^{-16}	5.5651×10^{-19}	0.0019
gr=0.4	2.5478×10^{-22}	5.0983×10^{-17}	$\mathbf{1.2365\times10^{-20}}$	0.0017
gr=0.5	4.5625×10^{-21}	6.3348×10^{-17}	1.6534×10^{-20}	0.0016
gr=0.6	3.9871×10^{-22}	3.9907×10^{-17}	1.2577×10^{-20}	0.0013
gr=0.7	5.6894×10^{-22}	2.5220×10^{-17}	2.2266×10^{-20}	0.0015
gr=0.8	2.2588×10^{-21}	1.9557×10^{-17}	1.9111×10^{-20}	0.0010
gr=0.9	$\mathbf{2.4987\times10^{-22}}$	2.0365×10^{-16}	1.3653×10^{-19}	0.0019
gr=1	1.9167×10^{-21}	2.1960×10^{-17}	1.2109×10^{-19}	$\mathbf{9.5060\times10^{-4}}$

Table 12d: The result obtained for function f12 when RTEPv4 is used

f12	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.1796×10^{-21}	3.0426×10^{-15}	7.4355×10^{-19}	**0.0012**
gr=0.1	4.9491×10^{-21}	3.2928×10^{-17}	1.0991×10^{-18}	0.0013
gr=0.2	3.4854×10^{-22}	3.2258×10^{-15}	$\mathbf{9.3557\times10^{-21}}$	0.0021
gr=0.3	$\mathbf{1.8861\times10^{-22}}$	3.1392×10^{-17}	1.4118×10^{-20}	0.0019
gr=0.4	2.1023×10^{-21}	2.2637×10^{-17}	1.4533×10^{-20}	0.0013
gr=0.5	5.5845×10^{-22}	1.6445×10^{-15}	2.5636×10^{-20}	0.0089
gr=0.6	4.8226×10^{-22}	1.8228×10^{-17}	1.1571×10^{-20}	0.0061
gr=0.7	2.2189×10^{-21}	2.1123×10^{-17}	3.3963×10^{-20}	0.0041
gr=0.8	2.2965×10^{-22}	$\mathbf{3.0987\times10^{-18}}$	3.0124×10^{-20}	0.0033
gr=0.9	3.9637×10^{-22}	2.6026×10^{-16}	2.0895×10^{-20}	0.0058
gr=1	1.4507×10^{-21}	1.1915×10^{-17}	1.1938×10^{-19}	0.0032

Table 13a: The result obtained for function f13 when RTEPv1 is used

f13	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.8818×10^{-16}	0.0016	6.1193×10^{-12}	0.0105
gr=0.1	8.8818×10^{-16}	0.0018	4.4246×10^{-12}	0.0143
gr=0.2	4.4409×10^{-16}	0.0018	4.2351×10^{-12}	0.0079
gr=0.3	1.6653×10^{-15}	0.0026	6.7411×10^{-12}	0.0091
gr=0.4	2.2204×10^{-16}	0.0014	8.5485×10^{-12}	0.0095
gr=0.5	4.8572×10^{-17}	0.0017	4.5576×10^{-12}	**0.0075**
gr=0.6	5.9952×10^{-15}	0.0013	6.0220×10^{-12}	0.0093
gr=0.7	**0**	0.0022	4.1913×10^{-12}	0.0108
gr=0.8	8.8818×10^{-16}	0.0013	4.4332×10^{-12}	0.0091
gr=0.9	9.9920×10^{-16}	0.0014	**3.7151×10^{-12}**	0.0092
gr=1	6.6613×10^{-16}	**7.8615×10^{-4}**	5.2157×10^{-12}	0.0098

Table 13b: The result obtained for function f13 when RTEPv2 is used

f13	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.8866×10^{-15}	0.0012	5.1235×10^{-12}	**0.0076**
gr=0.1	4.4409×10^{-16}	0.0015	8.8664×10^{-12}	0.0105
gr=0.2	3.3307×10^{-16}	3.0833×10^{-4}	5.4685×10^{-12}	0.0092
gr=0.3	2.7756×10^{-15}	6.2612×10^{-4}	**4.3812×10^{-12}**	0.0085
gr=0.4	**0**	5.2522×10^{-4}	4.7344×10^{-12}	0.0091
gr=0.5	4.2188×10^{-15}	**0.0013×10^{-4}**	6.9065×10^{-12}	0.0080
gr=0.6	**0**	0.0013	7.2650×10^{-12}	0.0083
gr=0.7	1.5543×10^{-15}	0.0026	7.7045×10^{-12}	0.0090
gr=0.8	**0**	0.0026	2.0997×10^{-11}	0.0086
gr=0.9	8.8818×10^{-16}	0.0017	6.0315×10^{-12}	0.0095
gr=1	**0**	6.3734×10^{-4}	8.2017×10^{-12}	0.0102

Table 13c: The result obtained for function f13 when RTEPv3 is used

f13	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	4.0246×10^{-16}	0.0011	1.6060×10^{-12}	0.0091
gr=0.1	2.5535×10^{-15}	$\mathbf{4.5058\times10^{-4}}$	1.0582×10^{-11}	**0.0090**
gr=0.2	**0**	6.1243×10^{-4}	6.9367×10^{-12}	0.0106
gr=0.3	4.6583×10^{-16}	0.0023	6.0961×10^{-12}	0.0560
gr=0.4	1.2894×10^{-15}	0.0056	6.3562×10^{-12}	0.0366
gr=0.5	3.8622×10^{-16}	0.0028	2.4896×10^{-12}	0.0258
gr=0.6	5.9883×10^{-15}	0.0027	1.6336×10^{-12}	0.0487
gr=0.7	**0**	0.0050	2.2786×10^{-12}	0.0192
gr=0.8	6.8975×10^{-15}	0.0024	$\mathbf{1.4520\times10^{-12}}$	0.0332
gr=0.9	7.9880×10^{-15}	0.0083	6.8861×10^{-12}	0.0488
gr=1	1.1102×10^{-15}	0.0014	2.7798×10^{-12}	0.0100

Table 13d: The result obtained for function f13 when RTEPv4 is used

f13	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.5511×10^{-16}	0.0018	8.3176×10^{-12}	0.0085
gr=0.1	2.2204×10^{-16}	**0.0012**	7.8342×10^{-12}	0.0072
gr=0.2	4.5521×10^{-16}	0.0016	5.9375×10^{-12}	**0.0053**
gr=0.3	3.2349×10^{-15}	0.0019	3.5821×10^{-12}	0.0079
gr=0.4	**0**	0.0015	6.5921×10^{-12}	0.0085
gr=0.5	3.3445×10^{-15}	0.0013	7.8679×10^{-12}	0.0082
gr=0.6	**0**	0.0016	8.0471×10^{-12}	0.0089
gr=0.7	2.7781×10^{-15}	0.0022	$\mathbf{2.6826\times10^{-12}}$	0.0095
gr=0.8	**0**	0.0023	4.6792×10^{-12}	0.0083
gr=0.9	**0**	0.0025	5.5072×10^{-12}	0.0098
gr=1	**0**	0.0021	3.7412×10^{-12}	0.0090

Table 14a: The result obtained for function f14 when RTEPv1 is used

f14	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.8378×10^{-6}**	0.4591	**3.8378×10^{-6}**	1.5833
gr=0.1	**3.8378×10^{-6}**	0.4963	**3.8378×10^{-6}**	1.8943
gr=0.2	**3.8378×10^{-6}**	0.5390	**3.8378×10^{-6}**	1.6843
gr=0.3	**3.8378×10^{-6}**	0.6842	**3.8378×10^{-6}**	1.4532
gr=0.4	**3.8378×10^{-6}**	0.6564	**3.8378×10^{-6}**	1.9563
gr=0.5	**3.8378×10^{-6}**	0.4533	**3.8378×10^{-6}**	1.3455
gr=0.6	**3.8378×10^{-6}**	0.5190	**3.8378×10^{-6}**	1.4356
gr=0.7	**3.8378×10^{-6}**	**0.4327**	**3.8378×10^{-6}**	1.2483
gr=0.8	**3.8378×10^{-6}**	0.4612	**3.8378×10^{-6}**	1.3619
gr=0.9	**3.8378×10^{-6}**	0.4376	**3.8378×10^{-6}**	1.4611
gr=1	**3.8378×10^{-6}**	0.6900	**3.8378×10^{-6}**	**1.2457**

Table 14b: The result obtained for function f14 when RTEPv2 is used

f14	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.8378×10^{-6}**	0.6573	**3.8378×10^{-6}**	1.3503
gr=0.1	**3.8378×10^{-6}**	0.4196	**3.8378×10^{-6}**	1.5680
gr=0.2	**3.8378×10^{-6}**	0.4365	**3.8378×10^{-6}**	1.8945
gr=0.3	**3.8378×10^{-6}**	0.5170	**3.8378×10^{-6}**	1.8473
gr=0.4	**3.8378×10^{-6}**	0.8366	**3.8378×10^{-6}**	1.9674
gr=0.5	**3.8378×10^{-6}**	0.5928	**3.8378×10^{-6}**	1.4063
gr=0.6	**3.8378×10^{-6}**	0.9661	**3.8378×10^{-6}**	1.4735
gr=0.7	**3.8378×10^{-6}**	0.6737	**3.8378×10^{-6}**	1.5834
gr=0.8	**3.8378×10^{-6}**	0.6847	**3.8378×10^{-6}**	1.9562
gr=0.9	**3.8378×10^{-6}**	**0.3723**	**3.8378×10^{-6}**	1.7540
gr=1	**3.8378×10^{-6}**	0.5834	**3.8378×10^{-6}**	**1.0474**

Table 14c: The result obtained for function f14 when RTEPv3 is used

f14	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.8378×10^{-6}**	0.5856	**3.8378×10^{-6}**	1.3258
gr=0.1	**3.8378×10^{-6}**	0.6984	**3.8378×10^{-6}**	1.3947
gr=0.2	**3.8378×10^{-6}**	0.6931	**3.8378×10^{-6}**	1.6726
gr=0.3	**3.8378×10^{-6}**	0.5349	**3.8378×10^{-6}**	1.6983
gr=0.4	**3.8378×10^{-6}**	0.4690	**3.8378×10^{-6}**	1.5845
gr=0.5	**3.8378×10^{-6}**	0.6733	**3.8378×10^{-6}**	1.5931
gr=0.6	**3.8378×10^{-6}**	0.5865	**3.8378×10^{-6}**	1.5483
gr=0.7	**3.8378×10^{-6}**	0.5168	**3.8378×10^{-6}**	1.2984
gr=0.8	**3.8378×10^{-6}**	0.5172	**3.8378×10^{-6}**	1.4918
gr=0.9	**3.8378×10^{-6}**	0.5397	**3.8378×10^{-6}**	1.3970
gr=1	**3.8378×10^{-6}**	**0.2585**	**3.8378×10^{-6}**	**1.2887**

Table 14d: The result obtained for function f14 when RTEPv4 is used

f14	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.8378×10^{-6}**	0.4353	**3.8378×10^{-6}**	**1.4234**
gr=0.1	**3.8378×10^{-6}**	0.5575	**3.8378×10^{-6}**	1.5823
gr=0.2	**3.8378×10^{-6}**	0.4456	**3.8378×10^{-6}**	1.7472
gr=0.3	**3.8378×10^{-6}**	0.6433	**3.8378×10^{-6}**	1.5801
gr=0.4	**3.8378×10^{-6}**	0.5184	**3.8378×10^{-6}**	1.4430
gr=0.5	**3.8378×10^{-6}**	0.5254	**3.8378×10^{-6}**	1.5892
gr=0.6	**3.8378×10^{-6}**	0.4517	**3.8378×10^{-6}**	1.7843
gr=0.7	**3.8378×10^{-6}**	0.7361	**3.8378×10^{-6}**	1.4552
gr=0.8	**3.8378×10^{-6}**	0.5814	**3.8378×10^{-6}**	1.5620
gr=0.9	**3.8378×10^{-6}**	**0.3432**	**3.8378×10^{-6}**	1.5842
gr=1	**3.8378×10^{-6}**	0.5421	**3.8378×10^{-6}**	1.6493

Table 15a: The result obtained for function f15 when RTEPv1 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.3197×10^{-8}	$\mathbf{1.2847\times10^{-5}}$	3.6366×10^{-7}	2.8919×10^{-5}
gr=0.1	7.0170×10^{-9}	1.6370×10^{-5}	2.5562×10^{-7}	2.7163×10^{-5}
gr=0.2	$\mathbf{1.6164\times10^{-9}}$	1.4480×10^{-5}	3.6981×10^{-7}	2.7882×10^{-5}
gr=0.3	5.5154×10^{-9}	1.6978×10^{-5}	2.6978×10^{-7}	2.8445×10^{-5}
gr=0.4	3.4832×10^{-9}	1.8731×10^{-5}	2.4841×10^{-7}	2.8346×10^{-5}
gr=0.5	6.5921×10^{-8}	1.3484×10^{-5}	3.3545×10^{-7}	2.7353×10^{-5}
gr=0.6	5.5921×10^{-9}	1.4428×10^{-5}	$\mathbf{2.0283\times10^{-7}}$	2.7584×10^{-5}
gr=0.7	1.3548×10^{-8}	2.0285×10^{-5}	3.6627×10^{-7}	2.8536×10^{-5}
gr=0.8	4.1045×10^{-9}	1.5822×10^{-5}	2.9457×10^{-7}	$\mathbf{2.6092\times10^{-5}}$
gr=0.9	4.0352×10^{-9}	1.8586×10^{-5}	3.6948×10^{-7}	2.6927×10^{-5}
gr=1	9.5422×10^{-9}	1.7552×10^{-5}	2.5942×10^{-7}	2.7221×10^{-5}

Table 15b: The result obtained for function f15 when RTEPv2 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.4786×10^{-8}	1.7848×10^{-5}	3.7193×10^{-7}	2.9635×10^{-5}
gr=0.1	1.6614×10^{-8}	1.6422×10^{-5}	5.0795×10^{-7}	2.8350×10^{-5}
gr=0.2	$\mathbf{7.8826\times10^{-10}}$	1.9591×10^{-5}	3.4679×10^{-7}	2.7653×10^{-5}
gr=0.3	8.5187×10^{-9}	1.5592×10^{-5}	$\mathbf{2.7249\times10^{-7}}$	2.8238×10^{-5}
gr=0.4	1.0274×10^{-9}	1.5579×10^{-5}	3.3835×10^{-7}	2.9053×10^{-5}
gr=0.5	2.7474×10^{-9}	1.4449×10^{-5}	3.5608×10^{-7}	$\mathbf{2.7200\times10^{-5}}$
gr=0.6	1.0845×10^{-9}	1.5771×10^{-5}	2.9722×10^{-7}	2.8209×10^{-5}
gr=0.7	2.0167×10^{-9}	$\mathbf{1.4339\times10^{-5}}$	3.2093×10^{-7}	2.7313×10^{-5}
gr=0.8	5.0195×10^{-9}	1.7178×10^{-5}	3.3810×10^{-7}	2.7480×10^{-5}
gr=0.9	2.2211×10^{-9}	1.8470×10^{-5}	3.0019×10^{-7}	2.7839×10^{-5}
gr=1	4.6695×10^{-9}	1.5485×10^{-5}	3.7954×10^{-7}	2.8708×10^{-5}

Table 15c: The result obtained for function f15 when RTEPv3 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.0322×10^{-8}	1.7488×10^{-5}	3.6959×10^{-7}	3.3478×10^{-5}
gr=0.1	4.9281×10^{-11}	1.7011×10^{-5}	3.6915×10^{-7}	3.0123×10^{-5}
gr=0.2	8.8315×10^{-9}	1.6453×10^{-5}	3.4584×10^{-7}	2.8786×10^{-5}
gr=0.3	**8.8315×10^{-11}**	**1.4558×10^{-5}**	**2.6759×10^{-7}**	2.9581×10^{-5}
gr=0.4	2.7726×10^{-10}	1.9464×10^{-5}	5.0680×10^{-7}	3.0087×10^{-5}
gr=0.5	8.2840×10^{-10}	1.7433×10^{-5}	4.2043×10^{-7}	2.9985×10^{-5}
gr=0.6	6.2432×10^{-9}	1.6250×10^{-5}	3.8599×10^{-7}	2.9470×10^{-5}
gr=0.7	1.7128×10^{-9}	1.5595×10^{-5}	3.5353×10^{-7}	3.0629×10^{-5}
gr=0.8	3.9821×10^{-10}	1.8196×10^{-5}	3.4869×10^{-7}	2.8747×10^{-5}
gr=0.9	3.2510×10^{-9}	1.6057×10^{-5}	4.0462×10^{-7}	2.8817×10^{-5}
gr=1	7.8181×10^{-10}	1.7555×10^{-5}	3.0703×10^{-7}	**2.7777×10^{-5}**

Table 15d: The result obtained for function f15 when RTEPv4 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.5328×10^{-9}	1.8019×10^{-5}	4.0498×10^{-7}	3.1348×10^{-5}
gr=0.1	2.5422×10^{-9}	2.0018×10^{-5}	4.3380×10^{-7}	2.8824×10^{-5}
gr=0.2	1.9890×10^{-10}	1.4761×10^{-5}	3.4100×10^{-7}	2.8546×10^{-5}
gr=0.3	**1.6329×10^{-10}**	1.8989×10^{-5}	4.5325×10^{-7}	3.0060×10^{-5}
gr=0.4	9.4595×10^{-9}	1.8537×10^{-5}	3.1824×10^{-7}	2.8376×10^{-5}
gr=0.5	3.0356×10^{-9}	1.7108×10^{-5}	3.5102×10^{-7}	2.7437×10^{-5}
gr=0.6	3.8088×10^{-9}	1.4968×10^{-5}	**2.3250×10^{-7}**	2.7458×10^{-5}
gr=0.7	8.6373×10^{-9}	1.5214×10^{-5}	4.0395×10^{-7}	2.8546×10^{-5}
gr=0.8	9.0019×10^{-10}	**1.4721×10^{-5}**	3.6993×10^{-7}	2.7818×10^{-5}
gr=0.9	4.1938×10^{-9}	1.7079×10^{-5}	4.0760×10^{-7}	**2.7258×10^{-5}**
gr=1	6.6816×10^{-10}	1.7746×10^{-5}	2.7226×10^{-7}	2.7564×10^{-5}

Table 16a: The result obtained for function f16 when RTEPv1 is used

f16	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.6510×10^{-8}**	4.7473×10^{-8}	**4.6510×10^{-8}**	3.7004×10^{-7}
gr=0.1	**4.6510×10^{-8}**	4.7338×10^{-8}	**4.6510×10^{-8}**	6.2320×10^{-7}
gr=0.2	**4.6510×10^{-8}**	4.7424×10^{-8}	**4.6510×10^{-8}**	8.4520×10^{-7}
gr=0.3	**4.6510×10^{-8}**	4.8837×10^{-8}	**4.6510×10^{-8}**	5.4438×10^{-7}
gr=0.4	**4.6510×10^{-8}**	4.7945×10^{-8}	**4.6510×10^{-8}**	3.5059×10^{-7}
gr=0.5	**4.6510×10^{-8}**	4.7198×10^{-8}	**4.6510×10^{-8}**	3.4645×10^{-7}
gr=0.6	**4.6510×10^{-8}**	4.7306×10^{-8}	**4.6510×10^{-8}**	6.2185×10^{-7}
gr=0.7	**4.6510×10^{-8}**	**4.6634×10^{-8}**	**4.6510×10^{-8}**	1.6634×10^{-7}
gr=0.8	**4.6510×10^{-8}**	4.6664×10^{-8}	**4.6510×10^{-8}**	9.2463×10^{-8}
gr=0.9	**4.6510×10^{-8}**	4.6641×10^{-8}	**4.6510×10^{-8}**	**6.4264×10^{-8}**
gr=1	**4.6510×10^{-8}**	4.6532×10^{-8}	**4.6510×10^{-8}**	1.0818×10^{-7}

Table 16b: The result obtained for function f16 when RTEPv2 is used

f16	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.6510×10^{-8}**	4.7588×10^{-8}	**4.6510×10^{-8}**	1.5039×10^{-7}
gr=0.1	**4.6510×10^{-8}**	4.7360×10^{-8}	**4.6510×10^{-8}**	1.7767×10^{-7}
gr=0.2	**4.6510×10^{-8}**	4.7295×10^{-8}	**4.6510×10^{-8}**	3.8731×10^{-7}
gr=0.3	**4.6510×10^{-8}**	4.7308×10^{-8}	**4.6510×10^{-8}**	4.7717×10^{-7}
gr=0.4	**4.6510×10^{-8}**	4.6983×10^{-8}	**4.6510×10^{-8}**	5.3231×10^{-7}
gr=0.5	**4.6510×10^{-8}**	4.6752×10^{-8}	**4.6510×10^{-8}**	3.7278×10^{-7}
gr=0.6	**4.6510×10^{-8}**	4.6956×10^{-8}	**4.6510×10^{-8}**	2.0227×10^{-7}
gr=0.7	**4.6510×10^{-8}**	4.6888×10^{-8}	**4.6510×10^{-8}**	1.7326×10^{-7}
gr=0.8	**4.6510×10^{-8}**	4.6737×10^{-8}	**4.6510×10^{-8}**	**9.7892×10^{-8}**
gr=0.9	**4.6510×10^{-8}**	4.6631×10^{-8}	**4.6510×10^{-8}**	1.0304×10^{-7}
gr=1	**4.6510×10^{-8}**	**4.6572×10^{-8}**	**4.6510×10^{-8}**	7.3003×10^{-7}

Table 16c: The result obtained for function f16 when RTEPv3 is used

f16	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.6510×10^{-8}**	5.5136×10^{-8}	**4.6511×10^{-8}**	2.4132×10^{-6}
gr=0.1	**4.6510×10^{-8}**	6.8688×10^{-8}	**4.6512×10^{-8}**	3.5025×10^{-6}
gr=0.2	**4.6510×10^{-8}**	5.8927×10^{-8}	**4.6511×10^{-8}**	1.0927×10^{-6}
gr=0.3	**4.6510×10^{-8}**	5.1691×10^{-8}	**4.6510×10^{-8}**	5.0837×10^{-6}
gr=0.4	**4.6510×10^{-8}**	5.6858×10^{-8}	**4.6510×10^{-8}**	3.4731×10^{-6}
gr=0.5	**4.6510×10^{-8}**	4.9221×10^{-8}	**4.6510×10^{-8}**	1.0697×10^{-6}
gr=0.6	**4.6510×10^{-8}**	4.9528×10^{-8}	**4.6510×10^{-8}**	2.3006×10^{-6}
gr=0.7	**4.6510×10^{-8}**	4.6868×10^{-8}	**4.6510×10^{-8}**	**8.9399×10^{-8}**
gr=0.8	**4.6510×10^{-8}**	4.6937×10^{-8}	**4.6510×10^{-8}**	4.3915×10^{-7}
gr=0.9	**4.6510×10^{-8}**	4.6629×10^{-8}	**4.6510×10^{-8}**	1.5377×10^{-7}
gr=1	**4.6510×10^{-8}**	**4.6616×10^{-8}**	**4.6510×10^{-8}**	1.7299×10^{-7}

Table 16d: The result obtained for function f16 when RTEPv4 is used

f16	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.6510×10^{-8}**	5.2404×10^{-8}	**4.6511×10^{-8}**	3.9159×10^{-7}
gr=0.1	**4.6510×10^{-8}**	6.9929×10^{-8}	**4.6512×10^{-8}**	7.2548×10^{-7}
gr=0.2	**4.6510×10^{-8}**	6.7549×10^{-8}	**4.6512×10^{-8}**	1.1777×10^{-7}
gr=0.3	**4.6510×10^{-8}**	5.4602×10^{-8}	**4.6512×10^{-8}**	1.0827×10^{-7}
gr=0.4	**4.6510×10^{-8}**	6.8003×10^{-8}	**4.6511×10^{-8}**	9.0131×10^{-8}
gr=0.5	**4.6510×10^{-8}**	4.8606×10^{-8}	**4.6510×10^{-8}**	4.4036×10^{-7}
gr=0.6	**4.6510×10^{-8}**	4.9924×10^{-8}	**4.6512×10^{-8}**	2.3828×10^{-7}
gr=0.7	**4.6510×10^{-8}**	4.7431×10^{-8}	**4.6510×10^{-8}**	4.2918×10^{-7}
gr=0.8	**4.6510×10^{-8}**	4.7215×10^{-8}	**4.6511×10^{-8}**	1.3338×10^{-7}
gr=0.9	**4.6510×10^{-8}**	4.6816×10^{-8}	**4.6512×10^{-8}**	2.1165×10^{-7}
gr=1	**4.6510×10^{-8}**	**4.6604×10^{-8}**	**4.6510×10^{-8}**	**7.0506×10^{-8}**

Table 17a: The result obtained for function f17 when RTEPv1 is used

f17	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.4251×10^{-11}	0.0079	2.2436×10^{-8}	0.0860
gr=0.1	6.5789×10^{-11}	0.0049	1.9810×10^{-8}	0.0811
gr=0.2	1.7527×10^{-11}	0.0059	1.5941×10^{-8}	0.0867
gr=0.3	**1.2264×10^{-11}**	0.0054	1.1089×10^{-8}	0.0577
gr=0.4	2.5340×10^{-11}	0.0038	1.2297×10^{-8}	0.0486
gr=0.5	7.3754×10^{-11}	0.0016	9.8497×10^{-9}	**0.0328**
gr=0.6	3.6671×10^{-11}	0.0022	1.1202×10^{-8}	0.0344
gr=0.7	1.4939×10^{-11}	0.0012	1.3407×10^{-8}	0.0525
gr=0.8	1.9906×10^{-11}	0.0013	1.9071×10^{-8}	0.0512
gr=0.9	6.5857×10^{-11}	0.0015	**9.7653×10^{-9}**	0.0449
gr=1	2.8962×10^{-11}	**8.9834×10^{-4}**	1.3213×10^{-8}	0.0414

Table 17b: The result obtained for function f17 when RTEPv2 is used

f17	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.4365×10^{-11}	0.0044	3.8781×10^{-8}	0.0791
gr=0.1	**9.8587×10^{-12}**	0.0073	1.3526×10^{-8}	0.0807
gr=0.2	3.9961×10^{-11}	0.0077	1.3022×10^{-8}	0.0605
gr=0.3	3.0013×10^{-11}	0.0058	2.2905×10^{-8}	0.0657
gr=0.4	2.8347×10^{-11}	0.0041	9.7202×10^{-9}	0.0508
gr=0.5	7.9233×10^{-11}	0.0046	**6.5452×10^{-9}**	0.0752
gr=0.6	1.2339×10^{-10}	0.0050	8.3092×10^{-9}	0.0739
gr=0.7	2.5681×10^{-10}	0.0018	1.3751×10^{-8}	0.0524
gr=0.8	1.0506×10^{-11}	0.0031	1.0692×10^{-8}	**0.0480**
gr=0.9	6.4176×10^{-11}	**0.0014**	1.5685×10^{-8}	0.0546
gr=1	4.0514×10^{-11}	0.0026	1.7740×10^{-8}	0.0512

Table 17c: The result obtained for function f17 when RTEPv3 is used

f17	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.7383×10^{-10}	0.0070	6.7696×10^{-10}	0.0808
gr=0.1	$\mathbf{1.0131\times10^{-10}}$	0.0090	$\mathbf{4.0920\times10^{-10}}$	0.0700
gr=0.2	5.5161×10^{-10}	0.0024	2.1816×10^{-7}	0.0669
gr=0.3	9.1861×10^{-9}	0.0027	7.7082×10^{-8}	0.0439
gr=0.4	1.4299×10^{-9}	0.0015	8.6216×10^{-8}	0.0416
gr=0.5	2.2117×10^{-10}	0.0016	5.5295×10^{-8}	0.0314
gr=0.6	3.5328×10^{-10}	8.8304e	4.7101×10^{-8}	0.0602
gr=0.7	2.1783×10^{-10}	0.0016	3.9213×10^{-8}	0.0320
gr=0.8	1.7075×10^{-10}	$\mathbf{7.4750\times10^{-4}}$	2.3081×10^{-8}	**0.0237**
gr=0.9	6.4783×10^{-10}	0.0019	2.2639×10^{-8}	0.0448
gr=1	2.7532×10^{-10}	0.0015	1.4692×10^{-8}	0.0389

Table 17d: The result obtained for function f17 when RTEPv4 is used

f17	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	4.5717×10^{-9}	0.0089	4.9362×10^{-7}	0.0879
gr=0.1	4.2598×10^{-9}	0.0048	1.5904×10^{-7}	0.0641
gr=0.2	3.0517×10^{-9}	0.0033	1.2932×10^{-7}	0.0886
gr=0.3	2.0333×10^{-9}	0.0047	1.0353×10^{-7}	0.0602
gr=0.4	1.2713×10^{-9}	0.0015	7.3435×10^{-8}	0.0423
gr=0.5	1.5417×10^{-10}	0.0032	6.2721×10^{-8}	0.0384
gr=0.6	7.6833×10^{-10}	0.0015	3.3341×10^{-8}	0.0538
gr=0.7	8.8500×10^{-10}	0.0019	2.4293×10^{-8}	0.0690
gr=0.8	$\mathbf{2.0877\times10^{-11}}$	$\mathbf{9.7683\times10^{-4}}$	2.3470×10^{-8}	0.0550
gr=0.9	3.1409×10^{-10}	0.0016	$\mathbf{1.8627\times10^{-8}}$	0.0663
gr=1	5.4515×10^{-11}	0.0020	2.1470×10^{-8}	**0.0363**

Table 18a: The result obtained for function f18 when RTEPv1 is used

f18	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	9.4591×10^{-14}	43.2984	9.0980×10^{-8}	187.3885
gr=0.1	3.4639×10^{-14}	36.2231	3.0305×10^{-5}	192.6867
gr=0.2	6.3061×10^{-14}	44.1187	2.6820×10^{-6}	175.8959
gr=0.3	2.2204×10^{-15}	44.3163	9.0983×10^{-8}	188.5211
gr=0.4	5.3291×10^{-15}	36.3073	3.4358×10^{-7}	176.3587
gr=0.5	**4.4409×10^{-16}**	42.6759	2.6928×10^{-6}	**161.6562**
gr=0.6	8.4377×10^{-15}	42.1605	**1.9298×10^{-9}**	196.8332
gr=0.7	1.2434×10^{-14}	44.0898	7.3406×10^{-7}	186.3301
gr=0.8	7.8781×10^{-13}	**34.9199**	9.8176×10^{-8}	179.5936
gr=0.9	2.2959×10^{-12}	45.5196	1.2491×10^{-5}	172.3502
gr=1	2.5877×10^{-12}	40.5714	3.7097×10^{-6}	196.4728

Table 18b: The result obtained for function f18 when RTEPv2 is used

f18	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.8192×10^{-14}	59.6136	1.2676×10^{-6}	199.1052
gr=0.1	2.1760×10^{-14}	35.1965	2.7244×10^{-7}	190.3814
gr=0.2	1.5099×10^{-15}	38.8309	7.0434×10^{-9}	191.9595
gr=0.3	**0**	48.7110	2.0045×10^{-7}	179.7888
gr=0.4	1.7764×10^{-15}	**29.0240**	3.6993×10^{-5}	193.5929
gr=0.5	4.4409×10^{-16}	49.3127	**6.4667×10^{-10}**	199.1196
gr=0.6	7.5495×10^{-15}	40.0964	8.2513×10^{-7}	177.0600
gr=0.7	8.8818×10^{-16}	47.2951	3.0050×10^{-8}	175.8443
gr=0.8	4.8850×10^{-15}	49.6254	8.1790×10^{-7}	182.7833
gr=0.9	1.3620×10^{-12}	45.0522	7.1103×10^{-7}	215.7388
gr=1	2.2689×10^{-12}	43.8850	5.7905×10^{-6}	**163.9159**

Table 18c: The result obtained for function f18 when RTEPv3 is used

f18	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.8412×10^{-11}	43.8768	2.1741×10^{-6}	197.9437
gr=0.1	3.9968×10^{-12}	46.6734	2.4755×10^{-5}	206.8356
gr=0.2	2.2036×10^{-12}	46.9041	**5.4757×10^{-7}**	179.7838
gr=0.3	6.6525×10^{-13}	38.4702	1.5650×10^{-5}	190.2812
gr=0.4	3.6380×10^{-12}	46.6297	5.6481×10^{-5}	220.7573
gr=0.5	8.7841×10^{-13}	68.5914	1.6501×10^{-5}	208.8426
gr=0.6	2.6823×10^{-13}	39.0459	3.4168×10^{-6}	235.1231
gr=0.7	**1.2967×10^{-13}**	**38.8877**	1.0766×10^{-5}	174.1313
gr=0.8	3.5363×10^{-13}	50.8254	4.9862×10^{-5}	191.7671
gr=0.9	3.7095×10^{-12}	45.3627	2.1816×10^{-5}	**159.2808**
gr=1	5.9757×10^{-12}	40.6905	9.2204×10^{-6}	173.0347

Table 18d: The result obtained for function f18 when RTEPv4 is used

f18	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.8959×10^{-12}	**34.6022**	1.2818×10^{-5}	208.7502
gr=0.1	1.6938×10^{-11}	41.3399	3.3523×10^{-6}	190.9927
gr=0.2	4.3978×10^{-12}	49.1759	6.4980×10^{-6}	213.4630
gr=0.3	**7.9492×10^{-14}**	45.8263	**3.1573×10^{-7}**	202.0409
gr=0.4	9.0372×10^{-14}	43.3068	1.1526×10^{-6}	233.8893
gr=0.5	6.5814×10^{-12}	40.2953	7.8196×10^{-7}	186.8627
gr=0.6	2.9856×10^{-13}	52.4058	1.2216×10^{-6}	194.9392
gr=0.7	8.5616×10^{-14}	53.9056	1.7985×10^{-6}	189.7842
gr=0.8	1.1263×10^{-11}	43.5807	9.0638×10^{-7}	191.5539
gr=0.9	1.4576×10^{-11}	46.1728	4.7493×10^{-6}	186.6593
gr=1	37.1067×10^{-12}	37.1067	8.2851×10^{-5}	**155.7485**

Table 19a: The result obtained for function f19 when RTEPv1 is used

f19	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.7581×10^{-8}	0.3523	1.0788×10^{-6}	**0.6818**
gr=0.1	3.3039×10^{-9}	0.3257	7.3941×10^{-7}	0.7191
gr=0.2	2.1215×10^{-9}	0.2796	6.8273×10^{-7}	0.7257
gr=0.3	4.8510×10^{-9}	0.4292	5.3569×10^{-7}	0.7524
gr=0.4	9.2083×10^{-9}	0.3829	8.2492×10^{-7}	0.7238
gr=0.5	**3.1037×10^{-10}**	0.2795	**4.4850×10^{-7}**	0.7147
gr=0.6	4.9087×10^{-9}	0.3940	7.0190×10^{-7}	0.7810
gr=0.7	2.2899×10^{-10}	0.3984	9.3282×10^{-7}	0.7589
gr=0.8	1.1991×10^{-8}	0.2487	9.5387×10^{-7}	0.7455
gr=0.9	1.7702×10^{-8}	0.4622	1.1334×10^{-6}	0.7908
gr=1	1.8337×10^{-8}	**0.2277**	1.1991×10^{-6}	0.7418

Table 19b: The result obtained for function f19 when RTEPv2 is used

f19	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.8305×10^{-9}	**0.1236**	**4.0375×10^{-7}**	0.7119
gr=0.1	3.2857×10^{-9}	0.3059	7.5948×10^{-7}	**0.6666**
gr=0.2	6.6709×10^{-9}	0.3829	5.0530×10^{-7}	0.7016
gr=0.3	1.8003×10^{-9}	0.4247	5.6342×10^{-7}	0.7232
gr=0.4	3.3969×10^{-9}	0.2949	7.3328×10^{-7}	0.6837
gr=0.5	2.1429×10^{-9}	0.4247	5.1984×10^{-7}	0.7363
gr=0.6	1.1709×10^{-9}	0.3213	6.7251×10^{-7}	0.7222
gr=0.7	**1.0503×10^{-9}**	0.3367	1.1219×10^{-6}	0.6995
gr=0.8	1.3237×10^{-9}	0.3983	7.9870×10^{-7}	0.7903
gr=0.9	2.0050×10^{-9}	0.3566	1.0992×10^{-6}	0.8131
gr=1	5.3375×10^{-8}	0.3830	1.4042×10^{-6}	0.7977

Table 19c: The result obtained for function f_{19} when RTEPv3 is used

f19	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**8.6762×10^{-9}**	0.2842	3.5776×10^{-6}	**0.7000**
gr=0.1	1.5845×10^{-8}	0.4601	1.9873×10^{-6}	0.7135
gr=0.2	1.9034×10^{-8}	0.4893	1.6755×10^{-6}	0.7675
gr=0.3	1.4683×10^{-8}	0.4564	1.6765×10^{-6}	0.7354
gr=0.4	1.6493×10^{-8}	0.3345	1.8756×10^{-6}	0.7843
gr=0.5	1.2495×10^{-8}	0.4345	1.9573×10^{-6}	0.7854
gr=0.6	9.4642×10^{-9}	0.3732	1.6842×10^{-6}	0.7742
gr=0.7	9.6492×10^{-9}	0.3444	1.6832×10^{-6}	0.7843
gr=0.8	9.0373×10^{-9}	**0.2753**	1.7832×10^{-6}	0.7874
gr=0.9	9.7302×10^{-9}	0.4622	1.9726×10^{-6}	0.7967
gr=1	9.7434×10^{-9}	0.4336	**1.5507×10^{-6}**	0.7935

Table 19d: The result obtained for function f19 when RTEPv4 is used

f19	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.8487×10^{-9}	0.3216	1.9545×10^{-6}	0.6905
gr=0.1	1.9493×10^{-9}	0.2563	1.8484×10^{-6}	0.6848
gr=0.2	1.8582×10^{-9}	0.2505	1.5924×10^{-6}	0.7564
gr=0.3	1.9593×10^{-9}	0.2220	1.5932×10^{-6}	0.7456
gr=0.4	1.2522×10^{-8}	0.2067	1.9742×10^{-6}	**0.6234**
gr=0.5	1.6923×10^{-9}	0.2643	**1.2939×10^{-6}**	0.7267
gr=0.6	**1.4969×10^{-9}**	0.2583	1.3945×10^{-6}	0.7155
gr=0.7	1.8693×10^{-9}	0.2936	1.4320×10^{-6}	0.6568
gr=0.8	1.6782×10^{-8}	**0.2014**	1.8754×10^{-6}	0.7710
gr=0.9	1.4533×10^{-9}	0.2461	1.5693×10^{-6}	0.8083
gr=1	1.4379×10^{-8}	0.2269	1.3534×10^{-6}	0.7286

Table 20a: The result obtained for function f20 when RTEPv1 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.0799×10^{-6}	0.0278	7.9543×10^{-6}	0.0499
gr=0.1	5.0294×10^{-6}	0.0236	8.3328	0.0526
gr=0.2	4.9884×10^{-6}	0.0240	8.7904	**0.0492**
gr=0.3	5.1387×10^{-6}	0.0234	8.7435	0.0517
gr=0.4	5.1521×10^{-6}	0.0261	1.1636×10^{-6}	0.0531
gr=0.5	$\mathbf{4.9509\times10^{-6}}$	**0.0209**	$\mathbf{1.1213\times10^{-6}}$	0.0545
gr=0.6	5.1285×10^{-6}	0.0236	1.2607×10^{-6}	**0.0492**
gr=0.7	5.0131×10^{-6}	0.0246	1.6696×10^{-6}	0.0535
gr=0.8	5.5815×10^{-6}	0.0259	2.0169×10^{-6}	0.0539
gr=0.9	5.0084×10^{-6}	0.0285	2.0875×10^{-6}	0.0565
gr=1	7.7489×10^{-6}	0.0271	3.1988×10^{-6}	0.0520

Table 20b: The result obtained for function f20 when RTEPv2 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{5.0314\times10^{-6}}$	0.0283	8.7548×10^{-6}	**0.0478**
gr=0.1	5.0909×10^{-6}	0.0219	9.1241×10^{-6}	0.0554
gr=0.2	5.0978×10^{-6}	0.0225	9.8924×10^{-6}	0.0548
gr=0.3	5.2188×10^{-6}	0.0252	9.0323×10^{-6}	0.0505
gr=0.4	5.1208×10^{-6}	0.0216	9.1606×10^{-6}	0.0509
gr=0.5	5.1116×10^{-6}	0.0269	1.1463×10^{-6}	0.0502
gr=0.6	5.0944×10^{-6}	0.0272	1.0910×10^{-6}	0.0486
gr=0.7	5.3372×10^{-6}	**0.0144**	$\mathbf{1.0447\times10^{-6}}$	0.0523
gr=0.8	5.9445×10^{-6}	0.0308	1.9046×10^{-6}	0.0542
gr=0.9	5.9337×10^{-6}	0.0281	2.8994×10^{-6}	0.0546
gr=1	6.9709×10^{-6}	0.0363	3.5618×10^{-6}	0.0558

Table 20c: The result obtained for function f20 when RTEPv3 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.0947×10^{-6}**	0.0242	**1.6068×10^{-5}**	**0.0498**
gr=0.1	5.6061×10^{-6}	0.0259	1.7891×10^{-5}	0.0499
gr=0.2	5.3171×10^{-6}	0.0271	2.1309×10^{-5}	0.0538
gr=0.3	5.3499×10^{-6}	0.0249	1.6570×10^{-5}	0.0521
gr=0.4	5.9407×10^{-6}	**0.0169**	2.0941×10^{-5}	0.0532
gr=0.5	5.3646×10^{-6}	0.0301	2.3410×10^{-5}	0.0555
gr=0.6	5.8263×10^{-6}	0.0220	2.4631×10^{-5}	0.0535
gr=0.7	5.5211×10^{-6}	0.0315	3.3025×10^{-5}	0.0587
gr=0.8	5.9800×10^{-6}	0.0252	2.9689×10^{-5}	0.0554
gr=0.9	5.7735×10^{-6}	0.0185	2.8716×10^{-5}	0.0564
gr=1	5.7589×10^{-6}	0.0252	3.5845×10^{-5}	0.0592

Table 20d: The result obtained for function f20 when RTEPv4 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	5.3291×10^{-6}	**0.0213**	**1.4919×10^{-5}**	0.0521
gr=0.1	5.3088×10^{-6}	0.0227	1.8833×10^{-5}	**0.0494**
gr=0.2	5.3676×10^{-6}	0.0235	1.9077×10^{-5}	**0.0494**
gr=0.3	**5.2540×10^{-6}**	0.0264	1.9996×10^{-5}	0.0538
gr=0.4	6.6272×10^{-6}	0.0383	2.2147×10^{-5}	0.0562
gr=0.5	5.8621×10^{-6}	0.0287	1.9547×10^{-5}	0.0538
gr=0.6	5.9109×10^{-6}	0.0263	2.7197×10^{-5}	0.0514
gr=0.7	7.0347×10^{-6}	0.0318	2.0484×10^{-5}	0.0553
gr=0.8	6.4820×10^{-6}	0.0350	2.4959×10^{-5}	0.0559
gr=0.9	6.8300×10^{-6}	0.0311	4.0505×10^{-5}	0.0565
gr=1	7.1410×10^{-6}	0.0213	3.2323×10^{-5}	0.0550

Table 21a: The result obtained for function f21 when RTEPv1 is used

f21	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.4299×10^{-7}	3.3625	0.0022	**4.5472**
gr=0.1	6.9695×10^{-7}	3.7367	9.7949×10^{-4}	4.7290
gr=0.2	1.9409×10^{-7}	3.2412	0.0011	4.5600
gr=0.3	5.5498×10^{-7}	3.6430	0.0041	4.5973
gr=0.4	4.6377×10^{-7}	3.1332	0.0014	4.7192
gr=0.5	3.3091×10^{-7}	**3.1119**	3.9063	4.6141
gr=0.6	$\mathbf{1.7219\times10^{-7}}$	3.1163	5.6586×10^{-4}	4.5982
gr=0.7	4.5151×10^{-6}	3.7288	4.8525×10^{-4}	4.5948
gr=0.8	2.1707×10^{-6}	3.5267	$\mathbf{3.9982\times10^{-4}}$	4.6146
gr=0.9	2.2359×10^{-6}	3.1796	6.0899×10^{-4}	4.5886
gr=1	2.0162×10^{-6}	3.2083	7.7097×10^{-4}	4.7051

Table 21b: The result obtained for function f21 when RTEPv2 is used

f21	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.3671×10^{-6}	**2.9363**	0.0010	4.6485
gr=0.1	4.9525×10^{-6}	3.5956	3.4911×10^{-4}	4.5578
gr=0.2	2.4485×10^{-6}	3.4576	4.6010×10^{-4}	4.5375
gr=0.3	2.1084×10^{-6}	3.3534	$\mathbf{3.0069\times10^{-4}}$	4.6335
gr=0.4	1.2151×10^{-6}	3.6664	4.8161×10^{-4}	4.5341
gr=0.5	9.3214×10^{-7}	3.2529	4.8828×10^{-4}	4.6051
gr=0.6	7.0191×10^{-7}	3.6795	4.9430×10^{-4}	4.5641
gr=0.7	8.1944×10^{-7}	3.1366	4.3090×10^{-4}	**4.4572**
gr=0.8	1.7160×10^{-6}	3.4289	4.8961×10^{-4}	4.6608
gr=0.9	1.3366×10^{-6}	3.7464	6.8111×10^{-4}	4.7436
gr=1	$\mathbf{1.1850\times10^{-6}}$	3.5884	0.0011	4.6164

Table 21c: The result obtained for function f21 when RTEPv3 is used

f21	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.4553×10^{-6}	**3.1793**	6.4313×10^{-4}	4.7423
gr=0.1	7.7255×10^{-7}	3.5226	6.6505×10^{-4}	4.6243
gr=0.2	4.7150×10^{-6}	3.4037	0.0010	4.7514
gr=0.3	9.7227×10^{-7}	3.4600	0.0010	4.7013
gr=0.4	**6.5163×10^{-8}**	3.7518	**4.4681×10^{-4}**	4.6788
gr=0.5	2.2953×10^{-6}	3.7761	0.0011	4.7459
gr=0.6	7.2561×10^{-6}	3.7368	4.5159×10^{-4}	**4.4746**
gr=0.7	7.4011×10^{-6}	3.6592	6.0223×10^{-4}	4.5629
gr=0.8	1.1150×10^{-7}	3.5932	7.5539×10^{-4}	4.6314
gr=0.9	2.6880×10^{-6}	3.3533	8.6531×10^{-4}	4.6153
gr=1	2.5540×10^{-7}	3.2555	4.8324×10^{-4}	4.5717

Table 21d: The result obtained for function f21 when RTEPv4 is used

f21	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.4530×10^{-6}	3.6585	0.0019	4.7387
gr=0.1	5.6665×10^{-7}	3.3745	7.7645×10^{-4}	4.7001
gr=0.2	4.9015×10^{-6}	2.9287	**4.1658×10^{-4}**	**4.5235**
gr=0.3	5.3149×10^{-7}	3.6528	5.6071×10^{-4}	4.7056
gr=0.4	**3.4599×10^{-7}**	3.0363	6.7606×10^{-4}	4.6448
gr=0.5	1.5214×10^{-6}	3.1739	6.7608×10^{-4}	4.5389
gr=0.6	5.4688×10^{-7}	**2.6083**	6.2863×10^{-4}	4.6518
gr=0.7	3.6482×10^{-6}	3.2935	5.2782×10^{-4}	4.6486
gr=0.8	1.1890×10^{-6}	3.2206	5.3677×10^{-4}	4.5760
gr=0.9	4.2140×10^{-7}	3.6447	6.3971×10^{-4}	4.6936
gr=1	5.1603×10^{-7}	3.5581	5.6609×10^{-4}	4.5846

Table 22a: The result obtained for function f22 when RTEPv1 is used

f22	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	6.4610×10^{-6}	3.6665	0.0041	4.9540
gr=0.1	9.9301×10^{-6}	3.9863	0.0013	**4.7412**
gr=0.2	1.6769×10^{-6}	3.3294	0.0017	4.8158
gr=0.3	4.6862×10^{-6}	4.0019	0.0015	4.8873
gr=0.4	3.5419×10^{-6}	3.7301	0.0015	4.7663
gr=0.5	**5.6674×10^{-7}**	3.6909	0.0023	4.8441
gr=0.6	1.2663×10^{-5}	3.5344	0.0014	4.8663
gr=0.7	4.5159×10^{-6}	3.4694	0.0014	4.9425
gr=0.8	1.0728×10^{-5}	**2.9821**	**0.0011**	4.9579
gr=0.9	5.0286×10^{-6}	3.9376	0.0015	4.9993
gr=1	5.8080×10^{-6}	3.5536	0.0026	4.9216

Table 22b: The result obtained for function f22 when RTEPv2 is used

f22	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.8384×10^{-5}	4.0043	0.0020	5.0060
gr=0.1	1.1712×10^{-6}	3.9057	0.0012	4.9273
gr=0.2	1.2257×10^{-6}	3.8409	0.0017	5.0007
gr=0.3	**1.0772×10^{-7}**	**3.2533**	**0.0012**	4.8954
gr=0.4	4.9619×10^{-7}	3.7041	7.8281	4.9638
gr=0.5	7.0206×10^{-6}	3.3972	0.0016	4.8447
gr=0.6	6.7951×10^{-6}	3.6280	0.0021	**4.8164**
gr=0.7	1.8866×10^{-5}	3.7628	0.0022	4.9371
gr=0.8	1.5943×10^{-6}	3.7327	0.0027	4.8318
gr=0.9	1.4247×10^{-6}	3.4900	0.0013	4.9119
gr=1	1.0136×10^{-5}	4.0722	0.0034	4.9855

Table 22c: The result obtained for function f22 when RTEPv3 is used

f22	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	8.4947×10^{-6}	4.2322	0.0021	5.0761
gr=0.1	$\mathbf{1.5058\times10^{-7}}$	3.6508	0.0023	4.8872
gr=0.2	3.9073×10^{-6}	3.6760	0.0020	5.0009
gr=0.3	8.2359×10^{-6}	3.8123	0.0017	4.9351
gr=0.4	3.7101×10^{-7}	**3.6475**	0.0036	5.0169
gr=0.5	5.8716×10^{-6}	4.1114	0.0021	4.8950
gr=0.6	2.2479×10^{-5}	3.8934	**0.0016**	5.0315
gr=0.7	3.9664×10^{-6}	3.9992	0.0046	4.9574
gr=0.8	1.6230×10^{-6}	4.0467	0.0014	**4.8161**
gr=0.9	1.3310×10^{-6}	4.0049	0.0017	5.0081
gr=1	7.7046×10^{-6}	4.0210	0.0101	4.9731

Table 22d: The result obtained for function f22 when RTEPv4 is used

f22	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.9059×10^{-5}	3.8509	0.0019	4.9748
gr=0.1	6.7779×10^{-7}	**3.2177**	0.0032	4.9299
gr=0.2	2.0731×10^{-5}	3.8245	0.0019	4.8772
gr=0.3	2.7564×10^{-5}	3.9884	0.0019	4.8564
gr=0.4	$\mathbf{3.3369\times10^{-7}}$	4.0216	0.0037	4.9843
gr=0.5	1.7758×10^{-6}	3.9208	0.0018	4.8508
gr=0.6	5.4022×10^{-6}	4.2007	0.0020	4.9681
gr=0.7	6.0511×10^{-6}	3.7771	0.0035	4.9977
gr=0.8	8.5163×10^{-6}	3.9367	$\mathbf{9.8134\times10^{-4}}$	**4.8083**
gr=0.9	8.7069×10^{-6}	3.9193	0.0013	4.8642
gr=1	2.2441×10^{-5}	4.0027	0.0020	4.9822

Table 23a: The result obtained for function f23 when RTEPv1 is used

f23	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	9.8431×10^{-6}	4.3699	0.0107	5.6130
gr=0.1	1.0857×10^{-6}	4.0594	0.0044	5.5102
gr=0.2	8.7534×10^{-6}	4.4193	0.0018	5.4969
gr=0.3	2.7575×10^{-6}	**3.8688**	0.0022	**5.3751**
gr=0.4	4.7256×10^{-6}	4.4838	0.0040	5.5051
gr=0.5	1.1792×10^{-6}	4.1930	**0.0016**	5.5194
gr=0.6	$\mathbf{1.3580\times10^{-7}}$	4.4738	0.0098	5.5664
gr=0.7	2.8866×10^{-6}	4.2260	0.0050	5.6357
gr=0.8	2.6048×10^{-5}	4.7621	0.0036	5.6079
gr=0.9	1.0541×10^{-5}	4.5718	0.0111	5.5739
gr=1	1.1057×10^{-5}	4.7708	0.0032	5.6350

Table 23b: The result obtained for function f23 when RTEPv2 is used

f23	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.2689×10^{-5}	4.3166	0.0107	5.5832
gr=0.1	1.2676×10^{-5}	**3.7647**	0.0038	**5.4556**
gr=0.2	$\mathbf{2.2844\times10^{-7}}$	4.2255	0.0059	5.5002
gr=0.3	1.6258×10^{-5}	4.3515	0.0041	5.5737
gr=0.4	4.2176×10^{-6}	4.5972	0.0050	5.5552
gr=0.5	1.0221×10^{-5}	4.7375	**0.0034**	5.5086
gr=0.6	1.0744×10^{-5}	4.4086	0.0041	5.5467
gr=0.7	2.0137×10^{-5}	4.6579	0.0044	5.5402
gr=0.8	1.4834×10^{-5}	4.3901	0.0071	5.5621
gr=0.9	2.6505×10^{-5}	4.6678	0.0131	5.5246
gr=1	6.5389×10^{-6}	4.2535	0.0061	5.6172

Table 23c: The result obtained for function f23 when RTEPv3 is used

f23	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.5802×10^{-5}	4.2874	0.0096	5.5901
gr=0.1	3.8634×10^{-5}	4.6489	0.0042	5.4986
gr=0.2	4.5081×10^{-5}	4.5798	0.0030	5.4947
gr=0.3	4.7895×10^{-6}	4.2361	0.0093	5.5741
gr=0.4	6.9807×10^{-6}	4.5356	0.0031	5.5180
gr=0.5	4.0927×10^{-5}	**3.6524**	0.0057	5.5317
gr=0.6	7.1623×10^{-6}	4.5139	0.0025	5.6075
gr=0.7	**1.5324×10^{-6}**	4.1976	**0.0023**	**5.4755**
gr=0.8	8.7658×10^{-6}	4.5063	0.0031	5.5096
gr=0.9	1.7275×10^{-5}	4.6649	0.0100	5.6159
gr=1	1.7840×10^{-5}	4.4089	0.0209	5.7436

Table 23d: The result obtained for function f23 when RTEPv4 is used

f23	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.4731×10^{-6}	4.2612	0.0045	5.5275
gr=0.1	1.3741×10^{-6}	4.4932	0.0193	5.6134
gr=0.2	2.4317×10^{-5}	4.6587	0.0043	**5.3681**
gr=0.3	8.6936×10^{-5}	4.4180	0.0121	5.5451
gr=0.4	1.0759×10^{-5}	4.1684	0.0054	5.5205
gr=0.5	3.5707×10^{-5}	4.1732	0.0104	5.6297
gr=0.6	1.8152×10^{-5}	4.3184	0.0038	5.4508
gr=0.7	**1.4320×10^{-7}**	4.3675	0.0054	5.4411
gr=0.8	1.6944×10^{-5}	**3.8357**	**0.0029**	5.4639
gr=0.9	4.1664×10^{-5}	4.0865	0.0157	5.5806
gr=1	4.1763×10^{-5}	4.4645	0.0099	5.6281

Table 24: Test Functions

Test Functions
$f_1(x) = \sum_{i=1}^{D} (x_i^2)$
$f_2(x) = \sum_{i=1}^{D} \lvert x_i \rvert + \prod_{i=1}^{D} \lvert x_i \rvert$
$f_3(x) = \sum_{i=1}^{D} \left(\sum_{j=1}^{i} x_j \right)^2$
$f_4(x) = max_i \{ \lvert x_i \rvert, 1 \leq i < D \}$
$f_5(x) = \sum_{i=1}^{D-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$
$f_6(x) = \sum_{i=1}^{D} (\lfloor x_i + 0.5 \rfloor)^2$
$f_7(x) = \sum_{i=1}^{D} i x_i^4 + random[0,1)$
$f_8(x) = \sum_{i=1}^{D} [y_i^2 - 10\cos(2\pi y_i) + 10]$ $y_i = x_i \quad \lvert x_i \rvert < \frac{1}{2}$ $y_i = \frac{round\,(2x_i)}{2} \quad \lvert x_i \rvert \geq \frac{1}{2}$
$f_9(x) = \sum_{i=1}^{D} [x_i^2 - 10\cos(2\pi x_i) + 10]$
$f_{10}(x) = -20 \exp\left(-0.2 \sqrt{\frac{1}{D} \sum_{i=1}^{D} x_i^2} \right) - \exp\left(\frac{1}{D} \sum_{i=1}^{D} cos 2\pi x_i \right) + 20 + e$
$f_{11}(x) = \frac{1}{4000} \sum_{i=1}^{D} x_i^2 - \prod_{i=1}^{D} \cos\left(\frac{x_i}{\sqrt{i}} \right) + 1$
$f_{12}(x) = \frac{\pi}{D} \left\{ 10 sin^2(\pi y_i) + \sum_{i=1}^{D-1} (y_i - 1)^2 [1 + 10 sin^2(\pi y_{i+1})] + (y_D - 1)^2 \right\}$ $\sum_{i=1}^{D} u(x_i, 10,100,4), \qquad y_i = 1 + \frac{1}{4}(x_i + 1)$
$f_{13}(x) = \frac{1}{10} \left\{ 10 sin^2(3\pi x_i) + \sum_{i=1}^{D-1} (x_i - 1)^2 [1 + sin^2(3\pi x_{i+1})] + \frac{1}{10} (x_D - 1) [1 + sin^2(2\pi x_D)] \right\} + \sum_{i=1}^{D} u(x_i, 10,100,4)$
$f_{14}(x) = \frac{1}{500} + \sum_{j=1}^{25} \frac{1}{j + \sum_{i=1}^{2} (x_i - a_{ij})^6}$
$f_{15}(x) = \sum_{i=1}^{11} \left[a_i - \frac{x_1(b_i^2 + b_i x_2)}{b_i^2 + b_i x_3 + x_4} \right]$
$f_{16}(x) = 4x_1^2 - 2.1x_1^4 + \frac{1}{3}x_1^6 + x_1 x_2 - 4x_2^2 + 4x_2^4$

$f_{17}(x) = \left(x_2 - \frac{5.1}{4\pi^2}x_1^2 + \frac{5}{\pi}x_1 - 6\right)^2$
$f_{18}(x) = [1 + (x_1 + x_2 + x_3)^2(19 - 14x_1 + 3x_1^2 - 14x_2 + 6x_1x_2 + 3x_2^2)]\ x$ $[30 + (2x_2 - 3x_2)^2(18 - 32x_1 + 12x_1^2 + 48x_2 - 36x_1x_2 + 27x_2^2)]$
$f_{19}(x) = \sum_{i=1}^{4} c_i \exp\left[-\sum_{j=1}^{4} a_{ij}\left(x_j - p_{ij}\right)\right]$
$f_{20}(x) = \sum_{i=1}^{4} c_i \exp\left[-\sum_{j=1}^{6} a_{ij}\left(x_j - p_{ij}\right)\right]$
$f_{21}(x) = -\sum_{i=1}^{5}\left\{\sum_{j=1}^{4}(x_{j-}a_{ij})^2 + C_i\right\}^{-1}$
$f_{22}(x) = -\sum_{i=1}^{7}\left\{\sum_{j=1}^{4}(x_{j-}a_{ij})^2 + C_i\right\}^{-1}$
$f_{23}(x) = -\sum_{i=1}^{10}\left\{\sum_{j=1}^{4}(x_{j-}a_{ij})^2 + C_i\right\}^{-1}$

Table 25: Size, dimension and minimum values of test functions

Functions	Dimension (D)	Size (S)	Minimum value (f_{min})
f1	30	$[-100,100]^D$	0
f2	30	$[-10,10]^D$	0
f3	30	$[-100,100]^D$	0
f4	30	$[-100,100]^D$	0
f5	30	$[-30,30]^D$	0
f6	30	$[-100,100]^D$	0
f7	30	$[-1.28,1.28]^D$	0
f8	30	$[-5.12,5.12]^D$	0
f9	30	$[-5.12,5.12]^D$	0
f10	30	$[-32,32]^D$	0
f11	30	$[-600,600]^D$	0
f12	30	$[-50,50]^D$	0
f13	30	$[-50,50]^D$	0
f14	2	$[-65.5,65.5]^D$	1
f15	4	$[-5.5]^D$	0.0003
f16	2	$[-5,5]^D$	-1.03
f17	2	$[-100,100]^D$	0.398
f18	4	$[5,15]^D$	-10
f19	4	$[0,10]^D$	3.86
f20	6	$[-2,2]^D$	-3.82
f21	4	$[0,1]^D$	-10
f22	4	$[0,10]^D$	-10
f23	4	$[0,10]^D$	-10

Table 26: Kowalik Function f15

i	a_i	b_i^{-1}
1	0.1957	0.25
2	0.1947	0.5
3	0.1735	1
4	0.1600	2
5	0.0844	4
6	0.0627	6
7	0.0456	8
8	0.0342	10
9	0.0323	12
10	0.0235	14
11	0.0246	16

Table 27: Hartman Function f19

i	a_{ij}, j = 1,2,3			c_i	p_{ij},j = 1,2,3		
1	3	10	30	1	0.3689	0.1170	0.2673
2	0.1	10	35	1.2	0.4699	0.4387	0.7470
3	3	10	30	3	0.1091	0.8732	0.5547
4	0.1	10	35	3.2	0.038150	0.5743	0.8828

Table 28: Hartman Function f20

i	a_{ij}, j = 1,…..,6						c_i	p_{ij}, j = 1,…..,6					
1	10	3	17	3.5	1.7	8	1	0.1312	0.1696	0.5569	0.0124	0.8283	0.5886
2	0.05	10	17	0.1	8	14	1.2	0.2329	0.4135	0.8307	0.3736	0.1004	0.9991
3	3	3.5	1.7	10	17	8	3	0.2348	0.1415	0.3522	0.2883	0.3047	0.6650
4	17	8	0.05	10	0.1	14	3.2	0.4047	0.8828	0.8732	0.5743	0.1091	0.0381

Table 29: Shekel Functions f21, f22, f23

i	a_{ij}, j = 1,…..,4				c_i
1	4	4	4	4	0.1
2	1	1	1	1	0.2
3	8	8	8	8	0.2
4	6	6	6	6	0.4
5	3	7	3	7	0.4
6	2	9	2	9	0.6
7	5	5	3	3	0.3
8	8	1	8	1	0.7
9	6	2	6	2	0.5
10	7	3.6	7	3.6	0.5

In order to check the effect of the number of mutation points in the efficiency of the algorithm, parameter *k* (number of mutation points) is also varied for some of the selected test functions. In all the versions of RTEP parameter *k* is taken to be equal to 1 (Check **Step 6** and **Step 10** of the versions of RTEP algorithm). This time, *k* is taken to be equal to 2 and new optimization simulations are done for test functions f1, f3. f4, f8, f9, f11, f15 and f20 with these new settings using each version of RTEP. For the sake of simplicity, the *gr* value is taken as either 1 or 0. Other parameters in

the simulations are taken as in the previous simulations the results are shown in Tables 30-37.

Table 30a: The result obtained for function f1 when RTEPv1 is used

f1	Criterion1	Criteria2	Criteria3	Criteria4
gr=0	$\mathbf{1.3659\times10^{-18}}$	$\mathbf{8.7131\times10^{-18}}$	$\mathbf{4.3034\times10^{-18}}$	$\mathbf{2.4417\times10^{-17}}$
gr=1	6.2451×10^{-18}	4.0168×10^{-17}	1.6708×10^{-17}	1.0685×10^{-16}

Table 30b: The result obtained for function f1 when RTEPv2 is used

f1	Criterion1	Criteria2	Criteria3	Criteria4
gr=0	$\mathbf{1.6675\times10^{-18}}$	$\mathbf{9.1228\times10^{-18}}$	$\mathbf{4.3942\times10^{-18}}$	$\mathbf{2.5935\times10^{-17}}$
gr=1	2.4803×10^{-18}	3.4339×10^{-17}	1.5538×10^{-17}	9.0635×10^{-17}

Table 30c: The result obtained for function f1 when RTEPv3 is used

f1	Criterion1	Criteria2	Criteria3	Criteria4
gr=0	5.8958×10^{-18}	4.6360×10^{-17}	2.1660×10^{-17}	1.3250×10^{-16}
gr=1	$\mathbf{4.6093\times10^{-18}}$	$\mathbf{2.9838\times10^{-17}}$	$\mathbf{1.5476\times10^{-17}}$	$\mathbf{9.6487\times10^{-17}}$

Table 30d: The result obtained for function f1 when RTEPv4 is used

f1	Criterion1	Criteria2	Criteria3	Criteria4
gr=0	7.9775×10^{-18}	4.8548×10^{-17}	2.1941×10^{-17}	1.2217×10^{-16}
gr=1	$\mathbf{6.5555\times10^{-18}}$	$\mathbf{4.3312\times10^{-17}}$	$\mathbf{1.5075\times10^{-17}}$	$\mathbf{9.1737\times10^{-17}}$

Table 31a: The result obtained for function f3 when RTEPv1 is used

f3	Criterion1	Criterion2	Criteria3	Criteria4
gr=0	**4.2009×10^{3}**	**1.8931×10^{3}**	7.9359×10^{3}	**2.2422×10^{4}**
gr=1	4.2475×10^{3}	1.8539×10^{4}	**7.6204×10^{3}**	2.2506×10^{4}

Table 31b: The result obtained for function f3 when RTEPv2 is used

f3	Criterion1	Criterion2	Criteria3	Criteria4
gr=0	**3.5206×10^{3}**	**1.8748×10^{4}**	8.0357×10^{3}	**2.2369×10^{4}**
gr=1	4.5407×10^{4}	1.9545×10^{4}	**7.4137×10^{3}**	2.2454×10^{4}

Table 31c: The result obtained for function f3 when RTEPv3 is used

f3	Criterion1	Criterion2	Criteria3	Criteria4
gr=0	**4.0196×10^{3}**	2.0245×10^{4}	**7.9237×10^{3}**	2.3110×10^{4}
gr=1	5.4031×10^{3}	**1.9218×10^{4}**	8.0432×10^{3}	**2.2352×10^{4}**

Table 31d: The result obtained for function f3 when RTEPv4 is used

f3	Criterion1	Criterion2	Criterion3	Criteria4
gr=0	4.2085×10^{3}	1.9443×10^{4}	8.0065×10^{3}	2.3300×10^{4}
gr=1	**4.0384×10^{3}**	**1.7583×10^{4}**	**7.9540×10^{3}**	**2.2378×10^{4}**

Table 32a: The result obtained for function f4 when RTEPv1 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.5587**	**6.4790**	**5.0038**	**7.8532**
gr=1	4.2137	8.7841	5.9827	10.0139

Table 32b: The result obtained for function f4 when RTEPv2 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**2.9677**	**6.5545**	**4.9984**	**7.8776**
gr=1	4.0485	9.0208	6.1081	10.0660

Table 32c: The result obtained for function f4 when RTEPv3 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.9030	**7.1679**	**5.4260**	**8.5647**
gr=1	**3.3610**	8.9899	6.1961	10.0101

Table 32d: The result obtained for function f4 when RTEPv4 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**3.9790**	**7.1860**	**5.4945**	**8.5044**
gr=1	4.2647	9.0423	5.8087	9.9169

Table 33a: The result obtained for function f8 when RTEPv1 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.4982×10^{-6}**	**1.4537**	**7.0888×10^{-4}**	**2.2472**
gr=1	1.7523×10^{-5}	1.8858	0.0137	2.5388

Table 33b: The result obtained for function f8 when RTEPv2 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.1214×10^{-6}**	**1.4545**	**0.0037**	**2.1322**
gr=1	2.1156×10^{-5}	1.7882	0.0218	2.6039

Table 33c: The result obtained for function f8 when RTEPv3 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**4.8356×10^{-6}**	**1.4664**	0.0336	**2.4014**
gr=1	1.5069×10^{-5}	1.6813	**0.0317**	2.4759

Table 33d: The result obtained for function f8 when RTEPv4 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**8.4240×10^{-6}**	1.4543	**0.0082**	**2.4089**
gr=1	1.2354×10^{-5}	**1.3608**	0.0296	2.6109

Table 34a: The result obtained for function f9 when RTEPv1 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**7.3468×10^{-8}**	**0.3462**	**2.4744×10^{-6}**	**0.9514**
gr=1	9.9599×10^{-7}	0.7775	1.1499×10^{-5}	1.3079

Table 34b: The result obtained for function f9 when RTEPv2 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**1.6471×10^{-7}**	**0.5812**	**3.5160×10^{-6}**	**1.0307**
gr=1	1.3707×10^{-6}	0.9731	9.8845×10^{-6}	1.3290

Table 34c: The result obtained for function f9 when RTEPv3 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.6779×10^{-7}**	**0.8196**	**1.0351×10^{-5}**	**1.2081**
gr=1	1.0857×10^{-6}	0.9796	1.4245×10^{-5}	1.3570

Table 34d: The result obtained for function f9 when RTEPv4 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**6.6108×10^{-7}**	**0.8530**	**1.2730×10^{-5}**	**1.2395**
gr=1	9.1985×10^{-7}	0.9141	1.2789×10^{-5}	1.4035

Table 35a: The result obtained for function f11 when RTEPv1 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	0.0182	**1.4344×10^{-15}**	**0.0247**
gr=1	2.2204×10^{-16}	**0.0155**	3.8480×10^{-15}	0.0252

Table 35b: The result obtained for function f11 when RTEPv2 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0**	**0.0144**	**2.2649×10^{-15}**	0.0249
gr=1	2.2204×10^{-16}	0.0172	5.5422×10^{-15}	**0.0245**

Table 35c: The result obtained for function f11 when RTEPv3 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**1.1102×10^{-16}**	**0.0154**	**3.8725×10^{-15}**	**0.0243**
gr=1	3.3307×10^{-16}	0.0167	4.2344×10^{-15}	**0.0243**

Table 35d: The result obtained for function f11 when RTEPv4 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.3307×10^{-16}	0.0157	6.2172×10^{-15}	0.0247
gr=1	**1.1102×10^{-16}**	**0.0148**	**4.7495×10^{-15}**	**0.0244**

Table 36a: The result obtained for function f15 when RTEPv1 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{3.5023\times10^{-9}}$	4.8302×10^{-5}	1.3208×10^{-6}	8.1774×10^{-5}
gr=1	6.2341×10^{-9}	$\mathbf{4.7986\times10^{-5}}$	$\mathbf{1.2090\times10^{-6}}$	$\mathbf{7.5281\times10^{-5}}$

Table 36b: The result obtained for function f15 when RTEPv2 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{3.4069\times10^{-8}}$	5.0240×10^{-5}	$\mathbf{1.1096\times10^{-6}}$	8.0225×10^{-5}
gr=1	4.6174×10^{-8}	$\mathbf{4.6947\times10^{-5}}$	1.3118×10^{-6}	$\mathbf{7.6727\times10^{-5}}$

Table 36c: The result obtained for function f15 when RTEPv3 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{5.8599\times10^{-9}}$	$\mathbf{4.8110\times10^{-5}}$	$\mathbf{9.9679\times10^{-7}}$	8.6188×10^{-5}
gr=1	1.0280×10^{-8}	5.3647×10^{-5}	1.1485×10^{-6}	$\mathbf{7.9790\times10^{-5}}$

Table 36d: The result obtained for function f15 when RTEPv4 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	9.3122×10^{-9}	5.0944×10^{-5}	1.3693×10^{-6}	8.2918×10^{-5}
gr=1	$\mathbf{1.6960\times10^{-9}}$	$\mathbf{5.0510\times10^{-5}}$	$\mathbf{1.0865\times10^{-6}}$	$\mathbf{7.5794\times10^{-5}}$

Table 37a: The result obtained for function f20 when RTEPv1 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.0353×10^{-6}**	0.0244	**1.0008×10^{-5}**	**0.0427**
gr=1	1.2272×10^{-5}	**0.0212**	3.8739×10^{-5}	0.0469

Table 37b: The result obtained for function f20 when RTEPv2 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.0356×10^{-6}**	**0.0194**	**7.2382×10^{-6}**	**0.0400**
gr=1	6.0209×10^{-6}	0.0227	4.6447×10^{-5}	0.0475

Table 37c: The result obtained for function f20 when RTEPv3 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**6.2885×10^{-6}**	**0.0206**	**4.0975×10^{-5}**	0.0464
gr=1	1.1774×10^{-5}	0.0213	4.7603×10^{-5}	**0.0456**

Table 37d: The result obtained for function f20 when RTEPv4 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.0410×10^{-5}	0.0157	**4.7564×10^{-5}**	0.0465
gr=1	**6.4032×10^{-6}**	**0.0153**	4.8588×10^{-5}	**0.0457**

To further discover the effect of increasing mutation rate this time parameter k is determined as in the original RTEP (check Step 6 and Step 10 of original RTEP algorithm). Test functions f1, f3. f4, f8, f9, f11, f15, f20 with these new settings are optimized by using each version of RTEP. Again for the sake of simplicity, the *gr* value is taken as either 1 or 0. Other parameters in the simulations are taken as in the previous simulations the results are shown in Tables 38-45.

Table 38a: The result obtained for function f1 when RTEPv1 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0.0010**	**0.0020**	**0.0022**	**0.0048**
gr=1	0.0012	0.0033	0.0027	0.0061

Table 38b: The result obtained for function f1 when RTEPv2 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**0.0011**	**0.0027**	**0.0022**	**0.0049**
gr=1	0.0013	0.0039	0.0028	0.0064

Table 38c: The result obtained for function f1 when RTEPv3 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0028	0.0063	0.0056	0.0121
gr=1	**0.0012**	**0.0025**	**0.0025**	**0.0060**

Table 38d: The result obtained for function f1 when RTEPv4 is used

f1	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0019	**0.0034**	0.0055	0.0122
gr=1	**0.0012**	0.0032	**0.0027**	**0.0062**

Table 39a: The result obtained for function f3 when RTEPv1 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.7722×10^4	7.5188×10^4	2.9800×10^4	$\mathbf{8.6581\times10^4}$
gr=1	$\mathbf{1.6265\times10^4}$	$\mathbf{7.1768\times10^4}$	$\mathbf{2.8108\times10^4}$	8.8102×10^4

Table 39b: The result obtained for function f3 when RTEPv2 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{1.8897\times10^4}$	6.8250×10^4	2.8800×10^4	8.7804×10^4
gr=1	1.8955×10^4	$\mathbf{6.6388\times10^4}$	$\mathbf{2.8379\times10^4}$	$\mathbf{8.6201\times10^4}$

Table 39c: The result obtained for function f3 when RTEPv3 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.0501×10^4	7.6043×10^4	3.0268×10^4	9.3131×10^4
gr=1	$\mathbf{1.8995\times10^4}$	$\mathbf{7.3676\times10^4}$	$\mathbf{2.9968\times10^4}$	$\mathbf{8.8320\times10^4}$

Table 39d: The result obtained for function f3 when RTEPv4 is used

f3	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.1529×10^4	7.7266×10^4	3.1481×10^4	9.2068×10^4
gr=1	$\mathbf{1.8119\times10^4}$	$\mathbf{6.8794\times10^4}$	$\mathbf{2.8183\times10^4}$	$\mathbf{8.7703\times10^4}$

Table 40a: The result obtained for function f4 when RTEPv1 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**17.4006**	**29.4554**	**23.7001**	**33.6505**
gr=1	17.4704	32.8603	26.2552	37.8116

Table 40b: The result obtained for function f4 when RTEPv2 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**19.6171**	**29.2436**	**24.1906**	**33.7947**
gr=1	21.1447	33.5505	26.8397	37.4265

Table 40c: The result obtained for function f4 when RTEPv3 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**20.0502**	**29.6552**	**24.9118**	**34.6905**
gr=1	21.4179	32.6787	26.4874	37.8635

Table 40d: The result obtained for function f4 when RTEPv4 is used

f4	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**18.1405**	**29.7402**	**24.0284**	**34.3246**
gr=1	21.3498	32.8802	26.5755	37.6876

Table 41a: The result obtained for function f8 when RTEPv1 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	29.6891	**58.1255**	37.8234	**65.6395**
gr=1	**24.7749**	59.0712	**36.3424**	66.0581

Table 41b: The result obtained for function f8 when RTEPv2 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**27.7847**	**58.5253**	**35.9681**	**64.7090**
gr=1	28.3571	59.1577	37.2024	65.6017

Table 41c: The result obtained for function f8 when RTEPv3 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**25.2869**	61.0568	37.2421	66.7953
gr=1	27.4763	**60.3445**	**37.0868**	**65.7007**

Table 41d: The result obtained for function f8 when RTEPv4 is used

f8	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	29.6634	61.0756	37.9704	65.6696
gr=1	**27.9793**	**58.9344**	**36.2575**	**65.3620**

Table 42a: The result obtained for function f9 when RTEPv1 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**41.3779**	**83.1596**	56.3619	**89.5321**
gr=1	42.4601	84.8329	**56.0584**	90.6616

Table 42b: The result obtained for function f9 when RTEPv2 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	38.5631	**83.2675**	**56.2350**	90.5637
gr=1	**37.9256**	84.6534	57.0330	**90.5463**

Table 42c: The result obtained for function f9 when RTEPv3 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**34.0721**	**85.2851**	**57.2641**	**91.6980**
gr=1	40.1642	86.5268	58.1045	92.0515

Table 42d: The result obtained for function f9 when RTEPv4 is used

f9	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	47.8894	85.7381	57.2342	**90.3695**
gr=1	**43.8615**	**82.3238**	**56.9236**	90.7877

Table 43a: The result obtained for function f11 when RTEPv1 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0132	0.0656	0.0339	0.1134
gr=1	**0.0096**	**0.0631**	**0.0266**	**0.1084**

Table 43b: The result obtained for function f11 when RTEPv2 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0143	0.0778	0.0393	0.1221
gr=1	**0.0103**	**0.0597**	**0.0276**	**0.1023**

Table 43c: The result obtained for function f11 when RTEPv3 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0177	0.0803	0.0536	0.1620
gr=1	**0.0088**	**0.0416**	**0.0296**	**0.1099**

Table 43d: The result obtained for function f11 when RTEPv4 is used

f11	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	0.0248	0.0898	0.0518	0.1545
gr=1	**0.0097**	**0.0517**	**0.0298**	**0.1050**

Table 44a: The result obtained for function f15 when RTEPv1 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	7.0771×10^{-4}	4.3589×10^{-5}	$\mathbf{7.9721\times10^{-7}}$	$\mathbf{6.2993\times10^{-5}}$
gr=1	$\mathbf{8.7290\times10^{-9}}$	$\mathbf{4.0527\times10^{-5}}$	1.0584×10^{-6}	6.7504×10^{-5}

Table 44b: The result obtained for function f15 when RTEPv2 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	2.9094×10^{-8}	3.9189×10^{-5}	$\mathbf{7.5279\times10^{-7}}$	6.3952×10^{-5}
gr=1	$\mathbf{2.3146\times10^{-8}}$	$\mathbf{3.5552\times10^{-5}}$	7.8393×10^{-7}	$\mathbf{5.9652\times10^{-5}}$

Table 44c: The result obtained for function f15 when RTEPv3 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{8.2917\times10^{-11}}$	4.8858×10^{-5}	1.4326×10^{-6}	6.9744×10^{-5}
gr=1	4.6709×10^{-9}	$\mathbf{3.2325\times10^{-5}}$	$\mathbf{8.2534\times10^{-7}}$	$\mathbf{6.3810\times10^{-5}}$

Table 44d: The result obtained for function f15 when RTEPv4 is used

f15	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	$\mathbf{7.8567\times10^{-9}}$	4.0752×10^{-5}	8.5762×10^{-7}	6.8405×10^{-5}
gr=1	3.7331×10^{-8}	$\mathbf{3.5617\times10^{-5}}$	$\mathbf{7.3732\times10^{-7}}$	$\mathbf{6.2816\times10^{-5}}$

Table 45a: The result obtained for function f20 when RTEPv1 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.6599×10^{-6}**	**0.0193**	**5.6555×10^{-5}**	**0.0545**
gr=1	2.6685×10^{-5}	0.0320	1.6526×10^{-4}	0.0559

Table 45b: The result obtained for function f20 when RTEPv2 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	**5.8327×10^{-6}**	**0.0249**	**4.4159×10^{-5}**	0.0523
gr=1	1.2283×10^{-5}	0.0253	1.1355×10^{-4}	**0.0518**

Table 45c: The result obtained for function f20 when RTEPv3 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	1.6916×10^{-5}	0.0341	2.4217×10^{-4}	**0.0560**
gr=1	**1.6579×10^{-5}**	**0.0274**	**1.4759×10^{-4}**	0.0592

Table 45d: The result obtained for function f20 when RTEPv4 is used

f20	Criterion1	Criterion2	Criterion3	Criterion4
gr=0	3.8920×10^{-5}	**0.0242**	3.4342×10^{-4}	**0.0559**
gr=1	**1.8175×10^{-5}**	0.0320	**1.1936×10^{-4}**	0.0575

After all these simulations, it is better to demonstrate which version of RTEP is more successful compared to the other versions. For this reason, Table 46 is constructed. Table 46 shows the best simulation results for each of the test functions in case of one point mutation (All the results of these simulations can be seen in Tables 1-23) when Criterion3 and Criterion4 are considered.

Table 46: The most successful version of RTEP obtained for Criterion3 and Criterion4 for each test function

	Criterion 3		Criterion 4	
f1	RTEPv2	gr=0.7	RTEPv2	gr=0
f2	RTEPv3	gr=0	RTEPv2	gr=1
f3	RTEPv4	gr=0.8	RTEPv4	gr=0.5
f4	RTEPv1	gr=0	RTEPv3	gr=0.4
f5	RTEPv3	gr=0.8	RTEPv3	gr=1
f6	Equal		RTEPv2	gr=0.7
f7	RTEPv3	gr=0.4	RTEPv2	gr=0.5
f8	RTEPv2	gr=0.1	RTEPv1	gr=0
f9	RTEPv3	gr=0	RTEPv1	gr=0
f10	RTEPv2	gr=0	RTEPv3	gr=0.7
f11	RTEPv3	gr=0.1	RTEPv4	gr=0.8
f12	RTEPv2	gr=0	RTEPv1	gr=0
f13	RTEPv3	gr=0.8	RTEPv4	gr=0.2
f14	Equal		RTEPv2	gr=1
f15	RTEPv1	gr=0.6	RTEPv1	gr=0.8
f16	Equal		RTEPv1	gr=0.9
f17	RTEPv3	gr=0.1	RTEPv3	gr=0.8
f18	RTEPv2	gr=0.5	RTEPv4	gr=1
f19	RTEPv2	gr=0	RTEPv4	gr=0.4
f20	RTEPv2	gr=0.7	RTEPv2	gr=0
f21	RTEPv2	gr=0.3	RTEPv2	gr=0.7
f22	RTEPv2	gr=0.2	RTEPv1	gr=0.6
f23	RTEPv4	gr=0.8	RTEPv1	gr=0.1

As we check Table 46, we can observe that RTEPv2 is especially effective for the test function where we have a few local minimums and the dimension of the search space of the test function small (i.e. test functions f14, f15.., f23). Out of these 10 test functions in 5 of them, RTEPv2 outperformed the other versions of RTEP. In two of the test functions each version of RTEP have shown the same performance (All versions were able to find the global minimum values). So absolute distance measure

between the chromosomes seems to play an important role for these test functions (RTEPv2 and RTEPv4 uses absolute distance measure).

For the uni-modal test functions (f1, f2, …, f7) RETPv3 seems a little better than the other algorithms (the most successful algorithm in 3 of the 7 test functions) in terms of Criterion3. However the other versions have also managed to be successful in some test function in this category.

For multi-modal (f8,f9,… f13) test functions it seem RTEPv2 and RTEPv3 are more dominant compared to the other versions.

When we consider Criterion4 without checking the type of the test function (uni-modal, multi-modal, with low dimension and a few local minimum values), we can say that none of the algorithms of RTEP have a perfect dominance for any type of function. However RTEPv1 seems to be more powerful in Criterion4 compared to Criterion3 (RTEPv1 outperformed other versions of RTEP in 7 of the 23 test functions for Criterion4). That means RTEPv1 is a good algorithm for directing the population of candidate solutions to the global minimum altogether (it is successful in decreasing the average cost of the populations) however it is not such good for making a specific candidate solution to directly converge to the global minimum (not so successful to find the global minimum compared to other RTEP functions)

In Table 47, for the selected test functions (f1, f3, f4, f8, f9, f11, f15, f20) the best results obtained using one point mutation, two point mutation and k point mutation (where k is a random number between 1 and *n* and *n* is the number of the variables of the test function) in versions of RTEP.

Table 47: The best results obtained for selected test function using one point two point and k point mutation. The most successful results are printed in dark.

	One point mutation	Two point mutation	K point mutation
f1	$\mathbf{8.8127\times10^{-20}}$	4.3034×10^{-18}	2.2×10^{-2}
f3	1.1203×10^{4}	$\mathbf{7.4137\times10^{3}}$	2.8108×10^{4}
f4	12.2018	**4.9984**	23.7001
f8	$\mathbf{1.4241\times10^{-11}}$	7.0888×10^{-4}	35.9681
f9	$\mathbf{2.8582\times10^{-13}}$	2.4744×10^{-6}	56.0584
f11	1.5739×10^{-12}	$\mathbf{1.4344\times10^{-15}}$	0.0266
f15	$\mathbf{2.0283\times10^{-7}}$	9.9679×10^{-7}	7.3732×10^{-7}
f20	$\mathbf{1.0447\times10^{-6}}$	7.2382×10^{-6}	4.4159×10^{-5}

The worst results are always obtained when *k* is a random number between 1 and n where n is the number of variables of the test function. However although in most of the selected test functions one point mutation has given the best results (5 of the 8 selected test functions), in 3 of the test functions increasing the number of mutation points have proven to be more useful.

Finally we want to compare the best results (the best results for Criterion3) that we have obtained and the best results obtain in original RTEP [6] when K=1 and K2=1 for both RTEP and versions of RTEP. This comparison is given in Table 48. In Table 48 the value written in bold is the winner of the comparison.

Table 48: Comparison of original RTEP with the versions of RTEP

Function	RTEP (versions)	RTEP (original)
f1	**8.8127×10^{-20} (RTEPv2)**	3.1×10^{-18}
f2	**1.3272×10^{-11} (RTEPv3)**	9.8×10^{-8}
f3	7.4127×10^{4} (RTEP with two point mutation)	**7.2×10^{-14}**
f4	4.9984 (RTEP with two point mutation)	**1.1**
f5	**0.6234 (RTEPv3)**	1.5
f6	**0 (all RTEP versions)**	**0**
f7	0.0667 (RTEPv3)	**5.3×10^{-34}**
f8	**6.3825×10^{-6} (RTEPv2)**	2.7×10^{-4}
f9	2.0915×10^{-8} (RTEPv3)	**1×10^{-12}**
f10	**2.1746×10^{-9} (RTEPv2)**	6.1×10^{-9}
f11	1.4344×10^{-15} (RTEP with two point mutation)	**3.4×10^{-17}**
f12	**4.0900×10^{-21} (RTEPv2)**	1.7×10^{-10}
f13	**1.4520×10^{-12} (RTEPv3)**	9.2×10^{-3}
f14	**3.8378×10^{-6} (all RTEP versions)**	0.002
f15	**2.0283×10^{-7} (RTEPv1)**	0.0007
f16*	**4.6511×10^{-8} (all RTEP versions)**	**0**
f17	4.0920×10^{-10} (RTEPv3)	**0**
f18	6.4667×10^{-10} (RTEPv2)	**0**
f19	**4.0375×10^{-7} (RTEPv2)**	0.04
f20	1.0447×10^{-6} (RTEPv2)	**0**
f21	**3.0069×10^{-4} (RTEPv2)**	0.89
f22	**9.8134×10^{-4} (RTEPv4)**	0.42
f23	**0.0016 (RTEPv1)**	0.27

Looking at Table 48, it seems that the version of RTEP have proven to have given comparable results with the original RTEP: in 13 of 24 test functions versions of RTEP has given better results, in 2 test functions there is no dominance of original RTEP and the versions of RTEP and in 8 test functions original RTEP is more successful. For f16 original RTEP seems to be better however when we check Table 16 once again, it is observed that all versions of RTEP have given the same result for Criterion3 meaning they converged to the global minimum. That means the difference observed in Table 48 for f16 is due to the precision of the decimal point of the minimum value of the test function.

CONCLUSIONS

In the simulations, 4 different versions of RTEP are tested for 23 different test functions. All these test functions have different characteristics. Some of them are uni-modal, some of them are multi-model and some of them have just a few local minimum. We observed that although there are some differences in the results depending on 4 different criteria, these differences are not so sharp. It is observed that for different parameter sets (different genotype ratio values), versions of RTEP have demonstrated most of the time very close results.

The effect of one-point, two-point and multiple-point mutation in different test functions are also studied in this thesis. It is observed that the results are in favor of one and two-point mutations in most of the simulations.

In the future, the research about RTEP can be deepened in three directions. The first direction is the effect of the use of one-point and multiple-point mutations in RTEP in the test functions. The second one is the use of different mutation strategies on the success of the algorithm. Finally, the last direction can be selection of different parameter set (Different values for *K1, K2, M,* μ and different number of function evaluations).

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APPENDIX

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