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Solving fuzzy shortest path problem by genetic algorithm

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Abstract: Shortest Path Problem (SPP) is known as one of well-studied[2] fields in the area Operations[3] Research and Mathematical Optimization. It has been applied[4] for[5] many engineering and management designs. The objective is usually to determine path[6](s) in the network with minimum total cost or traveling time. In the past, the cost value for each arc was usually assigned or estimated as a deteministic[7] value. For some specific real world[8] applications, however, it is often difficult to determine the cost value properly[9]. One way of handling such uncertainty in decision making is by introducing fuzzy[10] approach. With this situation, it will become difficult to solve the problem optimally. This paper presents the investigations on the application of Genetic[11] Algorithm (GA) to a new SPP model in which the cost values are represented[12] as Triangular Fuzzy Number (TFN). We adopts[13] the concept of ranking fuzzy numbers to determine how good the solutions. Here, by giving his/her degree value, the decision maker[14] can determine the range of objective value. This[15] would be very valuable for decision[16] support system in the real world[17] applications.[18]Simulation[19] experiments were carried out by modifying several test problems with 10-25 nodes. It is noted[20] that the proposed approach is capable[21,22] attaining a good[23] solution with different degree[24] of optimism for the tested problems.

Keywords: Shortest Path Problem, Network Design Problem, Genetic Algorithm, Ranking Fuzzy Number, Decision Support System

1. Introduction

In business management, many important[25] problems are expressed[26] as network design problems. Among all classes of problems in network optimization, Shortest Path Problem (SPP) has been one of the most extensively disscused[27] in computer science literature. It is commonly encountered in wide[28] array of practical applications including[29] transportation planning, communication, and production applications, salesperson routing and[30] often imbedded within other types of network optimization problems [1], [2].

Given a weighed[31] network graph, the SPP is to obtain the minimum total weight path(s) between nodes in the network. In the real world applications, the weight value represents the average delivery time of the commodities, reliability of transportation, and accessibility to the users, product deterioration, and so on[32]. Thus, finding a good[33] solution of SPP would be very important[34] and could save millions of transportation and/or[35] industrial cost, yet computationally difficult[36] task. There have been several methods for solving traditional SPP including[37] Dijkstra[38] method [3]. However, due to the intrinsic difficulty, many authors introduced search methods based upon heuristics to give solutions within reasonable computational time [4], [5].

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Traditionally, SPP was investigated in the area of Operations Research and Artificial Intelligence that is modelled by certain/deterministic cost values. However, for many real world applications, the deterministic model can be far from sufficient. For instance, in a transportation network, the path that has the least travel time, during the rush hours would have traffic jams that may lead to a drastic increase in travel time. One way of handling such uncertainty in decision making is by introducing fuzzy programming approach [6].

Artificial Intelligence (AI) has been discussed in many recent research fields. It has been successfully used to solve many difficult-real-world optimization problems. Among them, Genetic algorithm (GA) has been known as one of effective and popular methods. Since introduced by Holland [7], it has been implemented to give optimal or near optimal solution for many NP-hard optimization problems with less computational cost [8]. There are several advantages of using GA as follows: It deals with coding instead of decision variables. It requires no domain knowledge - only the payoff or objectives. In addition, traditional methods use deterministic transition rules to guide the search, such as hill-climbing,[57] and neighbourhood[58] search. Another difference between traditional methods and genetic algorithms is:[59] the latter[60] searches from a set of points, while the former from a single point. This[61] makes GA more robust than traditional methods regarding their potential as optimization techniques [9]. In our previous works, we also have successfully implemented GA to solve various combinatorial optimization problems and found that GA can give very good[62] solutions to the problems within reasonable computational time [10], [11], [12], [13].

In this paper, we develop new[63] model of SPP called fuzzy[64] Shortest Path Problem (f-SPP). Here, the cost values of the f-SPP are represented[65] by using Triangular Fuzzy numbers (TFN). Our major[66] efforts in this work include the adaption of the the rangking[67,68] method for handing the fuzziness. We adopt the concept of the ranking Fuzzy[69] numbers with integral value for the evaluation and selection. In this technique, the decision maker[70] can determine his decision by giving flexible value for the degree of optimism [14].

248 The remainder of this paper is organized[71] as follows: The description of the mathematical formulation of the f-SPP is given[72] in Section 2.[73] Section 3 describes a brief discussion design of algorithm.[74] It includes ranking Fuzzy[75] numbers, representation of chromosome, genetic operations and[76] selection method. Section 4 presents the numerical experiments and results obtained by the proposed method.[77] Finally, some concluding remarks are given[78] in Section 5.

249 2. Mathematical Model

In this section, we shall present a comprehensive mathematical model of the problem. Suppose that we are given[79] a graph G in which thr[80] lenght[81] of each arc has associated with a TFN. In some applications, that TFN may actually[82]
250 represent traveling time or some other values. For any two vertices, s and t in G, it is possible that there exist several paths from s to t. The problem involves finding path[83](s) from s to t that has the shortest traveling time.

The model of[84] f-SPP can mathematically be stated[85] as follows:

min

m

n

ååcij xij

....

~

i=1 j=1

n

n

s.t.

åxij

– åxki

j=1

k =1

ì 1

(i =1) ....

ï

= í 0 (i = 2, 3,···, n – 1) ....

ï

(i = n) ....

î– 1

....

(1)

(2)

(3)

(4)

2

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ì 1,

if link[86] (i , j)[87] is included[88] in the path

xij

= í

î 0,

otherwise

In the above model, directed graph G=(V, A) where V is a set of nodes, A is a set of links.

~

is a TFN

c ij[89]

representing[90] fuzzy cost associated with each arc(i, j). Source node and destination node are node 1[91] and node n respectively[92]. The length of a path is defined[93] as the sum of the lengths of all individual arcs comprising the path.[94]

3. Design of the Proposed Algorithm

3.1. Ranking Fuzzy Number (TFN)

When considering an optimization problem that its coefficients are represented with TFNs, the objective values of the problem will also be TFNs. In a fuzzy environment, an effective, efficient, and accurate ranking method becomes a very important[96] decision making procedure. Many authors have investigated various ranking methods for fuzzy numbers [15]. The ranking fuzzy[97] number with integral[98] value technique was proposed by Liou & Wang [14]. The basic concept of this technique is to rank the TFN based on its total integral value that represents a "mean value".[99] The left and right integral values are used to reflect the pessimistic and optimistic viewpoint of decision maker[100] respectively[101]. The total integral value is then computed based on this degree of optimism and each objective function values. A parameter α is given to adjust the degree of optimism.

Definition 1 [14]

~

Let A be a TFN with its membership function μ ~ as[102] shown in Figure 1. A TFN is denoted by a triplet[103]

A

(a1 , a2 , a3) where[104] a1 ,[105] a 2 ,[106] a 3 are real numbers. i.e.[107] a minimum value, a modal value and a maximum

~

value.[108] The membership function of a TFN A ,[109] μ ~ is defined as:

A

~

A

□

0

(x – a1)

(a2 – a1)

(x) = í

(a3 – x)

(a3 – a2)

ïî0ï

□

, x < a1

, a1

 x a2

, a2

 x a3

....

(5)

, x > a3

Figure 1. The membership function of TFN

3

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From the definition of the above membership function, we can see that the left membership function

μ ~ (x) L is continuous and strictly increasing. Its inverse function g ~ (x) L would exist and continuous[111]

A

A

on interval [0, 1]. So we[112] can compute its[113] [114] integral value

on that interval. Similarly for the right

membership function μ ~ (x) R

. We can compute both left and right integral values as follows:

A

~ L

1

A

L

1

(6)

I [115] (A)

=

ò0

(x)

=

(a 1

+ a 2)

....

g ~

dy [116]

2

.

~ R

1

A

R

1

(7)

I [117] (A)

=

ò0

(x)

=

(a

2 + a 3)

....

g ~

dy[118]

2

~

is

Thus, the total integral value for triangular fuzzy number A

~

~

R

(1

~ L

I [119] Tα (A) = α I (A)

+

− α)I (A) ....

=

1

[α a 3 + a 2

+ (1 − α) a1] ....

(8)

2

The following definition is used[120] in relation to[121] the ranking of the TFN:

Definition 2: Suppose that

~

~

~

is a set of convex fuzzy numbers and that ranking fuzzy

S =

{A1

...

, An }

, A2 ,

~

~

number [122] R is a mapping from S to the real numbers. For any distinct

Ai

, A j ∈ S the ranking has the

following [123] properties.

~

~

~

) <

~

) then

1.

if

R (Ai

R (A j

Ai

< A j

~

) =

~

) then

~

~

2.

if

R (Ai

R (A j

Ai

= A j

~

) >

~

) then

~

~

3.

if

R (Ai

R (A j

Ai

> A j

~

~

Based on the above definition, thus for any fuzzy numbers Ai and

A j[124]

we shall have:

if

α

~

α

~

)

then

~

~

I T[125]

(Ai

) < I T

(A j[126]

Ai

< A j

if

α

~

α

~

) then

~

~

I T[127]

(Ai

) = I T[128]

(A j[129]

Ai

= A j

if

α

~

α

~

) then

~

~

I T[130]

(Ai

) > I T[131]

(A j[132]

Ai

> A j .[133]

3.2. Design of Genetic Algorithm (GA)

Generally, the behaviour[134] of GAs depends on many uncertain factors. One of the important[135] factors is the balance between exploitation and exploration in the search space. The balance is strongly affected by design[136] strategy for GA and GA parameter values. Here, we would like to describe the consideration underlying the design of GA[137] approach including[138] representation method, genetic operators and[139] selection method.

3.2.1. Chromosome Representation and Evaluation

It is well known[140] that the first step in applying GA is to find a representation for a possible solution. An efficient design of the chromosome would lead to a good[14] performance of GA.

For this problem, we adopt permutation-based representation. In this representation, the value of gene[142] represents the priority of the node number for being included in the arc.[143] There are several advantages of using this representation for network problems [9]. Those include, first, any permutation[14]

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146 of the encoding corresponds to a path (legality). Most existing genetic operators can be easily applied 147 to the encoding. Any path has a corresponding encoding (completeness). And, 148 any point in solution space is accessible for genetic search.

The following Figure 2 shows the illustration of priority based representation.

7

2

5

1

4

3

9

8

6

Figure 2. Priority-based chromosome

In order to compute the fitness value, we decode the above chromosome using the decoding procedure as follows:

Procedure: Decoding

Step 1:

number of nodes n,

the alpha value

the set of nodes Si with[149] all nodes adjacent to node i.

the set of the TFN weight values denoted by (a1 ,[150] a2 ,[151] a3)

Step 2

Determine path[152] corresponding to the chromosome as follows:

initial source node i←[153]1, Pk ←φ;

while Si ≠φ do

select l from Si with the highest priority;

if vk[154](l)≠0 then vk[155](l)=0;

Pk ← Pk[156]∪{xil};

157,158
i←l;

else Si ← Si \{l}

end

output the complete path Pk ;

end

Step 3

Compute the fuzzy objective values

Step 4

Determine the integral values of TFNs

3.2.2. Crossover and Mutation

The next step of GA is to select chromosome[159] for replication by using genetic[160] operator,[161] in order to have new[162] chromosome to be evaluated further. Basically,[163] GA use[164] two genetic operators, crossover and mutation.

251 Crossover is known as the most important[165] recombination operator in GA. There have been many variants of crossover operations given in the literature for permutation based[166] representation such as:[167] PMX method (Partially Matched Crossover) [16], PX (Position-based crossover) [17] and WMX (Weight mapping crossover) [18].

In this paper, we adopt PMX crossover operations as follows:

Procedure : [168] PMX

Step 1: Select a section of chromosome randomly

Selected sub string [169]

5

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Parent 1

1

7

2

3

4

6

5

8

Parent 2

4

6

3

5

7

1

8

2

Step 2: Exchanged each sub string [171]

Parent 1

1

7

3

5

7

6

5

8

Parent 2

4

6

2

3

4

1

8

2

Step 3: Determine the mapping of genes in each substring [172]

3

5

7

2

3

4

□

2 3 5

4 7

Step 4: Update chromosome with information [173] given by Step 3

Offspring 1

1

4

3

5

7

6

2

8

Offspring 2

7

6

2

3

4

1

8

5

Mutation [174] is usually done to prevent premature loss of information by exchanging the information within a chromosome. In this paper, we adopt the inversion mutation. It is done by selecting two positions within a chromosome at random and then inverts the sub-string between these two positions. We show the illustration of this mutation operation in Figure 3

Parent

4

6

3

5

7

1

8

2

offspring

4

6

7

5

3

1

8

2

Figure 3. Illustration of inversion mutation

3.2.3. Selection

When implementing GA, the way to select chromosome[175] for the next generation is also very[176] important[177] issue. It should provide a balance between exploitation and exploration to search solution[178] in search space. Here, we adopt one of the fitness-proportional methods called roulette wheel selection [2]. If the best chromosome is not selected[179] for the next generation, we select one of the chromosome[180] randomly and replace it with the best chromosome. We express our selection method as follows:

Procedure: Selection

Step 1: Calculate a cumulative probability ap for each chromosome X p ,[181] (p = 1,
252 2,⋯, pop _ size).

Step 2: Generate a random real number r in [0,1].

Step 3: If r ☞ a1 ,[182] then select the first chromosome X1 ;[183] otherwise[184] select the pth[1] chromosome X p ,[186,187] (2 ☞ p ☞ pop_ size) such that a p – 1 < r < a p .[188]

253 Step 4: Repeat Steps 2 and 3 pop_size times and obtain pop_size copies of chromosome.[189]

Step 5: If the best chromosome is not selected[190] in the next generation, replace one randomly from the new population by the best one.

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3.2.4. Overall Procedure

The overall GA procedure used in this paper is illustrated [192] as [193] in Figure 4.

Figure 4. Overall[194] procedure of proposed[195] method

4. Experimental Design and Results

To explore how well the proposed GA can solve f-SPP. we[196] have designed several numerical experiments. The proposed method was implemented by Using C language and run on PC Core i3. For the test problems, we modified the SPP test problems given [19], [2] and[197] [20]. The size of test problems and GA parameters used for these experiments are set[198] as presented in Table 1:

Table 1. Problem size and GA parameter values

Test

Number of

Crossover

Mutation

Population

Maximimum[199]

Problem

Node

Probability

Probability

Size

generation

1

20

0.4

0.2

20

100

2

10

0.4

0.2

10

100

3

25

0.4

0.2

15

100

The first experiments were cunducted [200] to see the effectiveness of GA with respect to [201] the heterogeneity of the degree of optimism. [202] To investigate this issue, for all test problems, we take a look at the variation of the degree of optimisms [203] (0, 0.1, 0.2, ..., 1). For each different degree of optimism, the experiment was done [204] 10 (ten) times. We note the best, the average and [205] the worst results. The experimental results are summarized [206] in Table 2.

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Table 2. Computational results for different alpha values

Alpha

Problem 1

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

Maximum

152,5

164,6

176,7

188,8

200,9

213

232,6

237,2

249,3

261,4

273,5

Minimum

112,5

122,1

131,7

141,3

150,9

160,5

170,1

179,7

189,3

198,9

208,5

Average

120,5

130,6

140,7

155,55

160,9

171

187,35

191,2

201,3

205,2

221,5

STDEV

16,86

17,91

18,97

22,94

21,08

22,13

27,85

24,24

25,29

19,76

27,41

Problem 2

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

Maximum

94

95,4

96,8

98,2

99,6

101

102,4

103,9

107,3

107,3

109

Minimum

92

93,7

95,4

97,1

98,8

100,5

102,2

103,8

105,2

106,6

108

Average

92,6

94,21

95,96

97,21

99,04

100,65

102,24

103,8

105,44

106,7

108,3

STDEV

0,96

0,82

0,72

0,34

0,38

0,24

0,08

0,042

0,66

0,29

0,483

Problem 3

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

Maximum

89

88,35

90,7

92,8

95,4

98

100,6

103,2

104,8

107,2

110

Minimum

85

87,6

90

92,5

94,5

96,75

99

101,3

103,5

105,8

108

Average

85,85

87,825

90,07

92,56

94,59

97

99,32

101,4

103,63

106,2

108,2

STDEV

1,31

0,36

0,22

0,12

0,28

0,52

0,67

0,617

0,41

0,67

0,632

To observe the speed of convergence of the proposed GA, we noted the objective value in each generation for the test problem 3. We compared the results for three different alpha values (0, 0.5 and [208] 1). The results are shown [209] in Figure 5.

Objectiveval

□

200

180

160

140

120

100

80

60

40

20

0

Alpha = 0

alpha =0,5

Aplha = 1

254 1 11 21 31 41 51 61 71 81 91

Generation

Figure 5. The comparative convergence behavior for different alpha values

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We noted from the above results that, GA is very sensitive for overall optimization degrees. For different[211] degree[212] of optimism (alpha), GA can give different objective value[213] all of the times[214]. Thus by giving different alpha value[215], GA would be able to give decision[216] maker[217] solution for the problem. The above results also show that GA can[218] convergence to the best solution very fast.

5. Conclusion

The contribution of this paper consists of introducing the model of shortest[219]
path problem with fuzzy[220] coefficient (fSPP)[221] and providing GA-based[222] algorithm to
solve it. Here, the proposed method use[223] the fuzzy ranking strategy based on
255 the alpha value/degree of optimism. The performance of the proposed method
256 was evaluated[224] by using modified several test problems given in the literature.
The findings reported in this study show that,[225] GA is very sensitive for overall
degrees of optimism. Thus, the decision makers[226] can have their solution based
on their degree of optimism. Moreover, the results also show that GA can[227]
convergence to the best solution very fast (less than 50 generations).

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Appendix: Test Problems

Figure 6. Test Problem 1 (modified from [19])

Figure 7 Test Problem 2 (modified from [2])

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Figure 8 Test Problem 3 (modified from [20])

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1.	~~doi~~ → DOI	Misspelled Words	Correctness
2.	the well-studied	Determiner Use (a/an/the/this, etc.)	Correctness
3.	of Operations	Wrong or Missing Prepositions	Correctness
4.	*been applied*	Passive Voice Misuse	Clarity
5.	~~for~~ → to	Wrong or Missing Prepositions	Correctness
6.	the path	Determiner Use (a/an/the/this, etc.)	Correctness
7.	~~deteministic~~ → deterministic	Misspelled Words	Correctness
8.	~~real world~~ → real-world	Misspelled Words	Correctness
9.	~~properly~~ → accurately	Word Choice	Engagement
10.	a fuzzy	Determiner Use (a/an/the/this, etc.)	Correctness
11.	the Genetic	Determiner Use (a/an/the/this, etc.)	Correctness
12.	*are represented*	Passive Voice Misuse	Clarity
13.	~~adopts~~ → adopt	Faulty Subject-Verb Agreement	Correctness
14.	~~decision maker~~ → decision-maker	Misspelled Words	Correctness
15.	*This*	Intricate Text	Clarity
16.	a decision	Determiner Use (a/an/the/this, etc.)	Correctness
17.	~~the~~ real	Determiner Use (a/an/the/this, etc.)	Correctness
18.	~~real world~~ → real-world	Misspelled Words	Correctness

19.	. Simulation	Improper Formatting	Correctness
20.	*is noted*	Passive Voice Misuse	Clarity
21.	~~capable~~ → capably	Misuse of Modifiers	Correctness
22.	capable of	Wrong or Missing Prepositions	Correctness
23.	~~good~~ → right	Word Choice	Engagement
24.	~~degree~~ → degrees	Incorrect Noun Number	Correctness
25.	~~important~~ → vital	Word Choice	Engagement
26.	*are expressed*	Passive Voice Misuse	Clarity
27.	~~disscused~~ → discussed	Misspelled Words	Correctness
28.	a wide	Determiner Use (a/an/the/this, etc.)	Correctness
29.	, including	Punctuation in Compound/Complex Sentences	Correctness
30.	, and	Punctuation in Compound/Complex Sentences	Correctness
31.	~~weighed~~ → weighted	Confused Words	Correctness
32.	*and so on*	Inappropriate Colloquialisms	Delivery
33.	~~good~~ → right	Word Choice	Engagement
34.	~~very important~~ → significant	Word Choice	Engagement
35.	~~and/or~~ → and, or	Inappropriate Colloquialisms	Delivery
36.	~~difficult~~ → tricky	Word Choice	Engagement
37.	, including	Punctuation in Compound/Complex Sentences	Correctness

38.	the Dijkstra	Determiner Use (a/an/the/this, etc.)	Correctness
39.	*be used*	Passive Voice Misuse	Clarity
40.	~~licence~~ → license	Mixed Dialects of English	Correctness
41.	, and	Comma Misuse within Clauses	Correctness
42.	~~licence~~ → license	Mixed Dialects of English	Correctness
43.	~~doi~~ → DOI	Misspelled Words	Correctness
44.	*was investigated*	Passive Voice Misuse	Clarity
45.	~~modelled~~ → modeled	Mixed Dialects of English	Correctness
46.	~~real world~~ → real-world	Misspelled Words	Correctness
47.	time,	Punctuation in Compound/Complex Sentences	Correctness
48.	*been discussed*	Passive Voice Misuse	Clarity
49.	~~recent~~ → new	Word Choice	Engagement
50.	the Genetic	Determiner Use (a/an/the/this, etc.)	Correctness
51.	*been known*	Passive Voice Misuse	Clarity
52.	the effective	Determiner Use (a/an/the/this, etc.)	Correctness
53.	an optimal	Determiner Use (a/an/the/this, etc.)	Correctness
54.	~~near optimal~~ → near-optimal	Misspelled Words	Correctness
55.	~~solution~~ → solutions	Incorrect Noun Number	Correctness
56.	~~In addition~~ → Also, Besides	Wordy Sentences	Clarity

57.	hill-climbing,	Punctuation in Compound/Complex Sentences	Correctness
58.	~~neighbourhood~~ → neighborhood	Mixed Dialects of English	Correctness
59.	is:	Misuse of Semicolons, Quotation Marks, etc.	Correctness
60.	~~latter~~ → recent, last	Word Choice	Engagement
61.	*This*	Intricate Text	Clarity
62.	~~very good~~ → perfect, excellent, outstanding	Word Choice	Engagement
63.	a new	Determiner Use (a/an/the/this, etc.)	Correctness
64.	the fuzzy	Determiner Use (a/an/the/this, etc.)	Correctness
65.	*are represented*	Passive Voice Misuse	Clarity
66.	~~major~~ → significant	Word Choice	Engagement
67.	the ~~the~~ rangking	Misspelled Words	Correctness
68.	~~rangking~~ → ranking	Misspelled Words	Correctness
69.	~~ranking Fuzzy~~ → Fuzzy ranking	Misplaced Words or Phrases	Correctness
70.	~~decision maker~~ → decision-maker	Misspelled Words	Correctness
71.	*is organized*	Passive Voice Misuse	Clarity
72.	*is given*	Passive Voice Misuse	Clarity
73.	*The remainder of this paper is organized as follows: The description of the mathematical formulation of the f-SPP is given in Section 2.*	Wordy Sentences	Clarity

74.	the algorithm	Determiner Use (a/an/the/this, etc.)	Correctness
75.	~~ranking Fuzzy~~ → Fuzzy ranking	Misplaced Words or Phrases	Correctness
76.	, and	Punctuation in Compound/Complex Sentences	Correctness
77.	*Section 3 describes a brief discussion design of algorithm. It includes ranking Fuzzy numbers, representation of chromosome, genetic operations and selection method. Section 4 presents the numerical experiments and results obtained by the proposed method.*	Monotonous Sentences	Engagement
78.	*are given*	Passive Voice Misuse	Clarity
79.	*are given*	Passive Voice Misuse	Clarity
80.	~~thr~~ → the	Misspelled Words	Correctness
81.	~~lenght~~ → length	Misspelled Words	Correctness
82.	~~actually~~	Wordy Sentences	Clarity
83.	a path, or the path	Determiner Use (a/an/the/this, etc.)	Correctness
84.	~~of f~~ → off	Confused Words	Correctness
85.	*be stated*	Passive Voice Misuse	Clarity
86.	a link, or the link	Determiner Use (a/an/the/this, etc.)	Correctness
87.	~~i,~~ → i,	Improper Formatting	Correctness
88.	*is included*	Passive Voice Misuse	Clarity
89.	*ij*	Unknown Words	Correctness

90.	~~representing~~ → Representing	Improper Formatting	Correctness
91.	~~1~~ → one	Improper Formatting	Correctness
92.	, respectively	Punctuation in Compound/Complex Sentences	Correctness
93.	*is defined*	Passive Voice Misuse	Clarity
94.	*The length of a path is defined as the sum of the lengths of all individual arcs comprising the path.*	Wordy Sentences	Clarity
95.	*are represented*	Passive Voice Misuse	Clarity
96.	~~a very important~~ → a critical, a crucial, a significant, a vital	Word Choice	Engagement
97.	~~ranking fuzzy~~ → fuzzy ranking	Misplaced Words or Phrases	Correctness
98.	an integral	Determiner Use (a/an/the/this, etc.)	Correctness
99.	~~".~~ → ."	Misuse of Semicolons, Quotation Marks, etc.	Correctness
100.	~~decision maker~~ → decision-maker	Misspelled Words	Correctness
101.	, respectively	Punctuation in Compound/Complex Sentences	Correctness
102.	, as	Punctuation in Compound/Complex Sentences	Correctness
103.	A triplet denotes a TFN	Passive Voice Misuse	Clarity
104.	~~where~~ → Where	Improper Formatting	Correctness
105.	~~a1 ,~~ → a1,	Improper Formatting	Correctness
106.	~~2 ,~~ → 2,	Improper Formatting	Correctness

107.	i.e.,	Comma Misuse within Clauses	Correctness
108.	~~value~~ → Value	Improper Formatting	Correctness
109.	~~A,~~ → A,	Improper Formatting	Correctness
110.	~~doi~~ → DOI	Misspelled Words	Correctness
111.	continuous.	Closing Punctuation	Correctness
112.	~~So we~~ → So we	Improper Formatting	Correctness
113.	~~can compute~~ → can compute	Improper Formatting	Correctness
114.	~~compute its~~ → compute its	Improper Formatting	Correctness
115.	*I*	Inappropriate Colloquialisms	Delivery
116.	~~dy~~ → by	Misspelled Words	Correctness
117.	*I*	Inappropriate Colloquialisms	Delivery
118.	~~dy~~ → by	Misspelled Words	Correctness
119.	*I*	Inappropriate Colloquialisms	Delivery
120.	*is used*	Passive Voice Misuse	Clarity
121.	~~in relation to~~ → about, to, with, concerning	Wordy Sentences	Clarity
122.	~~number~~ → Number	Improper Formatting	Correctness
123.	~~following~~ → I am following, you are following	Incomplete Sentences	Correctness
124.	~~Aj~~ → Aj	Confused Words	Correctness
125.	*I*	Inappropriate Colloquialisms	Delivery
126.	~~Aj~~ → Aj	Confused Words	Correctness

127.	*I*	Inappropriate Colloquialisms	Delivery
128.	*I*	Inappropriate Colloquialisms	Delivery
129.	~~A j~~ → Aj	Confused Words	Correctness
130.	*I*	Inappropriate Colloquialisms	Delivery
131.	*I*	Inappropriate Colloquialisms	Delivery
132.	~~A j~~ → Aj	Confused Words	Correctness
133.	~~j .~~ → j.	Improper Formatting	Correctness
134.	~~behaviour~~ → behavior	Mixed Dialects of English	Correctness
135.	~~important~~ → critical, crucial, essential	Word Choice	Engagement
136.	the design	Determiner Use (a/an/the/this, etc.)	Correctness
137.	the GA	Determiner Use (a/an/the/this, etc.)	Correctness
138.	, including	Punctuation in Compound/Complex Sentences	Correctness
139.	, and	Punctuation in Compound/Complex Sentences	Correctness
140.	*is well known*	Passive Voice Misuse	Clarity
141.	~~a good~~ → an excellent	Word Choice	Engagement
142.	the gene	Determiner Use (a/an/the/this, etc.)	Correctness
143.	*In this representation, the value of gene represents the priority of the node number for being included in the arc.*	Wordy Sentences	Clarity

144.	permutation.	Closing Punctuation	Correctness
145.	~~doi~~ → DOI	Misspelled Words	Correctness
146.	~~of~~ → Of	Improper Formatting	Correctness
147.	*be easily applied*	Passive Voice Misuse	Clarity
148.	~~And~~ → Moreover, Furthermore	Inappropriate Colloquialisms	Delivery
149.	~~Si with~~ → Si with	Improper Formatting	Correctness
150.	~~a1 ,~~ → a1,	Improper Formatting	Correctness
151.	~~a2 ,~~ → a2,	Improper Formatting	Correctness
152.	the path	Determiner Use (a/an/the/this, etc.)	Correctness
153.	~~i~~ → I	Misspelled Words	Correctness
154.	~~vk~~ → ok	Misspelled Words	Correctness
155.	*vk*	Unknown Words	Correctness
156.	Pk ← ~~Pk~~	Misspelled Words	Correctness
157.	*i*	Inappropriate Colloquialisms	Delivery
158.	~~i~~ → I	Misspelled Words	Correctness
159.	a chromosome	Determiner Use (a/an/the/this, etc.)	Correctness
160.	a genetic	Determiner Use (a/an/the/this, etc.)	Correctness
161.	operator,	Punctuation in Compound/Complex Sentences	Correctness
162.	a new	Determiner Use (a/an/the/this,	Correctness

		etc.)	
163.	~~Basically,~~	Wordy Sentences	Clarity
164.	~~use~~ → uses	Faulty Subject-Verb Agreement	Correctness
165.	~~important~~ → critical, crucial	Word Choice	Engagement
166.	permutation-based	Misspelled Words	Correctness
167.	as:	Misuse of Semicolons, Quotation Marks, etc.	Correctness
168.	~~Procedure :~~ → Procedure:	Improper Formatting	Correctness
169.	~~sub string~~ → substring	Confused Words	Correctness
170.	~~doi~~ → DOI	Misspelled Words	Correctness
171.	~~sub string~~ → substring	Confused Words	Correctness
172.	substring.	Closing Punctuation	Correctness
173.	the information	Determiner Use (a/an/the/this, etc.)	Correctness
174.	The mutation, or A mutation	Determiner Use (a/an/the/this, etc.)	Correctness
175.	a chromosome	Determiner Use (a/an/the/this, etc.)	Correctness
176.	a very	Determiner Use (a/an/the/this, etc.)	Correctness
177.	~~very important~~ → critical, significant, fundamental, crucial	Word Choice	Engagement
178.	~~solution~~ → solutions	Incorrect Noun Number	Correctness

179.	*is not selected*	Passive Voice Misuse	Clarity
180.	~~chromosome~~ → chromosomes	Incorrect Noun Number	Correctness
181.	~~p ,~~ → p,	Improper Formatting	Correctness
182.	~~a1 ,~~ → a1,	Improper Formatting	Correctness
183.	~~X1 ;~~ → X1;	Improper Formatting	Correctness
184.	otherwise,	Punctuation in Compound/Complex Sentences	Correctness
185.	~~pth~~ → path	Misspelled Words	Correctness
186.	p ,	Punctuation in Compound/Complex Sentences	Correctness
187.	~~p ,~~ → p,	Improper Formatting	Correctness
188.	~~p .~~ → p.	Improper Formatting	Correctness
189.	a chromosome, or the chromosome	Determiner Use (a/an/the/this, etc.)	Correctness
190.	*is not selected*	Passive Voice Misuse	Clarity
191.	~~doi~~ → DOI	Misspelled Words	Correctness
192.	*is illustrated*	Passive Voice Misuse	Clarity
193.	~~as~~	Wrong or Missing Prepositions	Correctness
194.	The overall	Determiner Use (a/an/the/this, etc.)	Correctness
195.	the proposed	Determiner Use (a/an/the/this, etc.)	Correctness
196.	~~we~~ → We	Improper Formatting	Correctness
197.	, and	Punctuation in	Correctness

		Compound/Complex Sentences	
198.	*are set*	Passive Voice Misuse	Clarity
199.	~~Maximimum~~ → Maximum	Misspelled Words	Correctness
200.	~~cunducted~~ → conducted	Misspelled Words	Correctness
201.	~~with respect to~~ → concerning, for, to	Wordy Sentences	Clarity
202.	*The first experiments were cunducted to see the effectiveness of GA with respect to the heterogeneity of the degree of optimism.*	Wordy Sentences	Clarity
203.	~~optimisms~~ → optimism	Confused Words	Correctness
204.	*was done*	Passive Voice Misuse	Clarity
205.	, and	Punctuation in Compound/Complex Sentences	Correctness
206.	*are summarized*	Passive Voice Misuse	Clarity
207.	~~doi~~ → DOI	Misspelled Words	Correctness
208.	, and	Punctuation in Compound/Complex Sentences	Correctness
209.	*are shown*	Passive Voice Misuse	Clarity
210.	~~doi~~ → DOI	Misspelled Words	Correctness
211.	a different	Determiner Use (a/an/the/this, etc.)	Correctness
212.	~~degree~~ → degrees	Incorrect Noun Number	Correctness
213.	~~value~~ → values	Incorrect Noun Number	Correctness
214.	~~times~~ → time	Incorrect Noun Number	Correctness

215.	~~value~~ → values	Incorrect Noun Number	Correctness
216.	a decision	Determiner Use (a/an/the/this, etc.)	Correctness
217.	~~decision maker~~ → decision-maker	Misspelled Words	Correctness
218.	can provide, can achieve, can see, can facilitate	Incomplete Sentences	Correctness
219.	the shortest	Determiner Use (a/an/the/this, etc.)	Correctness
220.	a fuzzy	Determiner Use (a/an/the/this, etc.)	Correctness
221.	~~fSPP~~ → SPP	Misspelled Words	Correctness
222.	a GA-based, or the GA-based	Determiner Use (a/an/the/this, etc.)	Correctness
223.	~~use~~ → uses	Faulty Subject-Verb Agreement	Correctness
224.	*was evaluated*	Passive Voice Misuse	Clarity
225.	that,	Punctuation in Compound/Complex Sentences	Correctness
226.	~~decision makers~~ → decision-makers	Misspelled Words	Correctness
227.	can provide, can achieve, can see, can facilitate	Incomplete Sentences	Correctness
228.	~~acknowledge~~ → acknowledges	Faulty Subject-Verb Agreement	Correctness
229.	~~The~~ → the	Confused Words	Correctness
230.	~~M S~~ → MS	Confused Words	Correctness
231.	*Gen M and Cheng R 1997 Genetic Algorithm and Engineering Design, 2nd ed. (New York: John Willey and Sons).*	Incomplete Sentences	Correctness

232.	~~E W~~ → EW	Confused Words	Correctness
233.	, and	Comma Misuse within Clauses	Correctness
234.	~~Sosiety~~ → Society	Misspelled Words	Correctness
235.	~~Y S~~ → YS	Confused Words	Correctness
236.	, and	Punctuation in Compound/Complex Sentences	Correctness
237.	~~Two Stage~~ → Two-Stage	Misspelled Words	Correctness
238.	Based on	Wrong or Missing Prepositions	Correctness
239.	, and	Punctuation in Compound/Complex Sentences	Correctness
240.	~~doi~~ → DOI	Misspelled Words	Correctness
241.	~~Concernig~~ → Concerning	Misspelled Words	Correctness
242.	~~Koufman~~ → Kaufman	Misspelled Words	Correctness
243.	, and	Punctuation in Compound/Complex Sentences	Correctness
244.	~~Hashier~~ → Cashier	Misspelled Words	Correctness
245.	~~doi~~ → DOI	Misspelled Words	Correctness
246.	~~doi~~ → DOI	Misspelled Words	Correctness
247.	*Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.*	Quantifying the consensus on anthropogenic global warming ... https://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024/pdf	Originality
248.	*The remainder of this paper is*	Information | Free Full-Text |	Originality

	organized as follows:	Traveling-Salesman-Problem ... https://www.mdpi.com/2078-2489/10/1/7/html	
249.	*Finally, some concluding remarks are given in Section 5. 2. Mathematical Model*	PERFORMANCE EVALUATION OF VARIOUS GENETIC ALGORITHM ... http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0416_4013.pdf	Originality
250.	*For any two vertices, s and t in*	Removable paths and cycles with parity constraints ... https://www.sciencedirect.com/science/article/pii/S0095895614000069	Originality
251.	*Crossover is known as the most important recombination operator in GA.*	PERFORMANCE EVALUATION OF VARIOUS GENETIC ALGORITHM ... http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0416_4013.pdf	Originality
252.	*pop _ size). Step 2: Generate a random real number r in [0,*	A robust optimization model for green regional logistics ... https://journals.sagepub.com/doi/full/10.1177/1687814015620518	Originality
253.	*Step 4: Repeat Steps 2 and 3 pop_size times and obtain pop_size copies of*	A robust optimization model for green regional logistics ... https://journals.sagepub.com/doi/full/10.1177/1687814015620518	Originality
254.	*1 11 21 31 41 51 61 71 81 91*	Kingston Waterfront Real Estate - Neil Swanson Properties http://neilswansonproperties.com/	Originality
255.	*The performance of the proposed method was evaluated by*	A Functional Specialization-Based Multiobjective ... https://onlinelibrary.wiley.com/doi/abs/10.1002/ecj.12030	Originality
256.	*The findings reported in this study show that,*	Gender, Spousal Caregiving, and Depression: Does Paid Work Matter?	Originality

257.	*2nd ed. (New York: John Wiley and Sons*	Airborne Transmission of Viral Respiratory Pathogens: Don't Stand So Close to Me?	Originality
258.	*Holland J 1975 Adaptation in Natural and Artificial Systems*	Emergence of Swarming Behavior: Foraging Agents Evolve Collective Motion Based on Signaling	Originality
259.	*Syarif A, Yun Y S and Gen M 2002 Study on Multi-stage*	PERFORMANCE EVALUATION OF VARIOUS GENETIC ALGORITHM ... http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0416_4013.pdf	Originality
260.	*Syarif A and Gen M 2003 Solving Exclusionary Side*	PERFORMANCE EVALUATION OF VARIOUS GENETIC ALGORITHM ... http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0416_4013.pdf	Originality
261.	*Syarif A and Gen M 2003 Double Spanning*	PERFORMANCE EVALUATION OF VARIOUS GENETIC ALGORITHM ... http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0416_4013.pdf	Originality