Control and Optimization in Applied Mathematics (COAM)
Vol. 1, No. 1, Spring-Summer 2016(69-78), ©2016 Payame Noor University, Iran

Solving Fully Fuzzy Linear Programming Problems with Zero-One Variables by Ranking Function

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Received: June 8, 2014; Accepted: August 2, 2014.

Abstract. Jahanshahloo has suggested a method for the solving linear programming problems with zero-one variables. In this paper we formulate fully fuzzy linear programming problems with zero-one variables and a method for solving these problems is presented using the ranking function and also the branch and bound method along with an example is presented.

Keywords. Fuzzy set, Fuzzy number, Ranking function, Triangular fuzzy number, Zero-one triangular fuzzy number.
MSC. 90C70; 93C42.

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1 Introduction

The idea of decision making in the fuzzy environment was proposed by Bellman and Zadeh (See [1]). Most of researchers used this method for the solving fuzzy linear programming problems (See for more detail [3, 8, 9, 10]). The fuzzy linear programming problems in which all the parameters as well as the variables are represented by fuzzy numbers is known as FFLP problems. Each fuzzy variable can be written by the zero-one fuzzy variable. Solving the zero-one fuzzy programming problem is simple than its general form. In this paper we formulate fully fuzzy linear programming problems with zero-one variables and a method for solving these problems is presented using the ranking function. The offered method is more general than the branch and bound method (See for more details [5]). It is important to note that here we do not offer an algorithm and the only computational operation needed is the plus and minus, so this algorithm is called additive fuzzy one. This paper is organized as follows: in Section 2, some basic definitions and arithmetic between triangular fuzzy numbers are reviewed. In Section 3, formulation of FFLP problems and zero-one fully fuzzy programming problem and application of ranking function for solving these kind of problems are discussed. The Section 4 is about a suggested method to solve the zero-one fully fuzzy linear programming problem along with an example and some conclusions are discussed in Section 5.

2 Preliminaries

2.1 Basic definitions

Definition 1 (Fuzzy set)**.** If X is a collection of objects denoted generically by x then a fuzzy set $\tilde{A}$ in X is a set of ordered pairs:

$$\tilde{A} = \{(\mathrm{x}, \mu_{\tilde{\mathrm{A}}}\ (\mathrm{x})\}\mathrm{x} \in \mathrm{X}\}$$

$\mu_{\tilde{A}}(x)$ is called the membership function of x in $\tilde{A}$.

Definition 2 (Normal fuzzy set)**.** A fuzzy set $\tilde{A}$ in X is said to be normal if: $Sup_x \mu_{\tilde{A}}(x) = 1$.

Definition 3 (Convex fuzzy set)**.** A fuzzy set $\tilde{A}$ in X is said to convex fuzzy set if:

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2))$$
$$x_1, x_2 \in X, \lambda \in [0, 1]$$

Definition 4 (Fuzzy number)**.** A fuzzy number $\tilde{A}$ is a convex normalized fuzzy set $\tilde{A}$ of the real line R such that:

1. It exists exactly one $x_0 \in R$ with $\mu_{\tilde{A}}(x_0) = 1$ (x_0 is called the mean value of $\tilde{A}$).

2. $\mu_{\tilde{A}}(x_0)$ is piecewise continuous.

Definition 5 (Triangular fuzzy number). (See [2, 4]) A fuzzy number $\tilde{A} = (a, b, c)$ is said to be a triangular fuzzy number if its membership function is given by:

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-a)}{(b-a)} & a \leq x \leq b \\ \frac{(x-c)}{(b-c)} & b \leq x \leq c \\ 0 & otherwise \end{cases}$$

Our intent in the rest of the article about trinar $\tilde{A} = (a, b, c)$ is triangular fuzzy number with the following conditions, so the rest of relations makes sense.

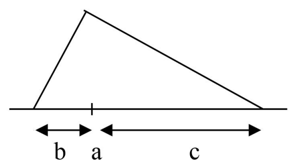

Figure 1: A triangular fuzzy number

Definition 6. A triangular fuzzy number $\tilde{A} = (a, b, c)$ is said to be non-negative fuzzy number iff : $a \geq 0$. We denote non-negative triangular fuzzy number $\tilde{A}$ by $\tilde{A} \succcurlyeq 0$.

Definition 7 (Zero-one triangular fuzzy number). We denote one triangular fuzzy number with $\tilde{1} = (1, 0, 0)$ and zero triangular fuzzy number with $\tilde{0} = (0, 0, 0)$.

Definition 8. Two triangular fuzzy number $\tilde{A} = (a, b, c)$ and $\tilde{B} = (e, f, g)$ are said to be equal iff $a = e, b = f, c = g$.

Definition 9 (Ranking function). (See e.g. [2, 6, 7]). A ranking function is a function $\mathcal{R} : f(R) \to R$, where $f(R)$ is a set of fuzzy numbers defined on set of real numbers, which maps each fuzzy number into the real line. This ranking function, ranking fuzzy number with integral value. The method, which is independent of the type of membership function, can rank more than two fuzzy number simultaneously. It is relatively simple in computation, especially in ranking triangular and trapezoidal fuzzy number. Further, an index of optimism is used to reflect the decision makers optimistic attitude. Let $\tilde{A} = (a, b, c)$ be a triangular fuzzy number then

$$\mathcal{R}(\tilde{A}) = \frac{a + 2b + c}{4}.$$

2.2 Arithmetic operations

In this subsection, arithmetic operations between fuzzy numbers, defined on universal set of real number R, are reviewed. Let $\tilde{A} = (a, b, c)$ and $\tilde{B} = (e, f, g)$ be two triangular fuzzy number then:

i) $\tilde{A} \oplus \tilde{B} = (a, b, c) \oplus (e, f, g) = (a + e, b + f, c + g)$.

ii) $\ominus\tilde{B} = \ominus(e, f, g) = (-e, g, f)$.

iii) $\tilde{A} \ominus \tilde{B} = (a, b, c) \ominus (e, f, g) = (a - e, b + g, c + f)$.

Let $\tilde{A} = (a, b, c)$ be any triangular fuzzy number and $\tilde{B} = (e, f, g)$ be a non-negative triangular fuzzy number then:

$$\tilde{A} \otimes \tilde{B} = \begin{cases} (ae,\ af + eb,\ ag + ec) & if\ a \geq 0 \\ \\ (ae,\ eb - ag,\ ec - af) & if\ a < 0 \end{cases}$$

3 Fully Fuzzy Linear Programming Problems with Zero-one Variables

A FFLP problem with m fuzzy constraints and n fuzzy variables may be formulated as follows:

$$\begin{aligned} \max(\text{or } \min) \quad & \tilde{C}^T \otimes \tilde{X} \\ s.t: \quad & \tilde{A} \otimes \tilde{X} \leq (\geq)\ \tilde{b} \end{aligned} \tag{p1}$$

where $\tilde{X}$ is non-negative fuzzy number.

A FFLP problem with zero-one fuzzy variables with m fuzzy constraints and n zero-one fuzzy variables may have formulation as follows:

$$\begin{aligned} \min \quad & (\tilde{C}^T \otimes \tilde{X}) \\ s.t: \quad & \tilde{A} \otimes \tilde{X} \geq \tilde{b} \\ & \tilde{X} = \tilde{0}\ or\ \tilde{1}, \end{aligned} \tag{p2}$$

where

$$\tilde{C}^{\mathrm{T}} = [\tilde{c}_j]_{1\times n}, \tilde{b} = [\tilde{b}_i]_{m\times 1}, \widetilde{\mathrm{A}} = [\tilde{a}_{ij}]_{m\times n},$$
$$\widetilde{\mathrm{X}} = [\tilde{x}_j]_{n\times 1}, \tilde{a}_{ij}, \tilde{x}_j, \tilde{c}_j, \tilde{b}_i \in F(R).$$

3.1 Application of ranking function for solving FFLP problems

Suppose that $S = \{\tilde{A}_1, \tilde{A}_2, \ldots ., \tilde{A}_n\}$ is a set of convex fuzzy numbers, and that ranking function $\mathcal{R}$ is a mapping from S to the real number. By definition (9) for any distinct $\tilde{A}_i$, $\tilde{A}_j \in S$, the ranking function $\mathcal{R}$, has the following properties:

i) if $\mathcal{R}(\tilde{A}_i) < \mathcal{R}(\tilde{A}_j)$ then: $\tilde{A}_i \prec \tilde{A}_j$.

ii) if $\mathcal{R}(\tilde{A}_i) = \mathcal{R}(\tilde{A}_j)$ then: $\tilde{A}_i = \tilde{A}_j$.

iii) if $\mathcal{R}(\tilde{A}_i) > \mathcal{R}(\tilde{A}_j)$ then: $\tilde{A}_i \succ \tilde{A}_j$.

Definition 10. The fuzzy optimal solution of FFLP problem with zero-one variables (p2) will be a fuzzy number $\widetilde{\mathrm{X}}$ if it satisfies the following characteristics:

i) $\widetilde{\mathrm{X}}$ is a zero-one fuzzy number

ii) $\tilde{A} \otimes \widetilde{\mathrm{X}} = \widetilde{\mathrm{b}}$

iii) if there exist any zero-one fuzzy number $\tilde{y}$ such that $\tilde{A} \otimes \tilde{y} = \widetilde{\mathrm{b}}$, then (in case of maximization problem)

$$\mathcal{R}(\tilde{C}^T \otimes \widetilde{\mathrm{X}}) > \mathcal{R}(\tilde{C}^T \otimes \tilde{y})$$

and
(in case of minimization problem)

$$\mathcal{R}(\tilde{C}^T \otimes \widetilde{\mathrm{X}}) < \mathcal{R}(\tilde{C}^T \otimes \tilde{y}).$$

Definition 11. The Zero-one fully fuzzy linear programming primitive problem (p2) is feasible iff $\widetilde{\mathrm{b}}$ be a non-negative fuzzy number.

Definition 12. The duality of the zero-one fully fuzzy linear programming problem (p2) is feasible iff the coefficients of the objective function in primitive problem be non-negative fuzzy number.

4 Proposed Method

In this section, we proposed a method to reach an optimum solution for the zero-one fully fuzzy linear programming problems. So, in the beginning, to apply the addition fuzzy algorithm, the duality of the zero-one fuzzy problem should be feasible. Moreover, all constraints should be the kind of less-equal sign. Evident that every problem can be turn to the above mentioned form consider the following problem:

$$\begin{aligned} Min \quad & \sum_{j=1}^{n} (\tilde{c}_j \otimes \tilde{X}_j) \\ s.t: \quad & \sum_{j=1}^{n} (\tilde{a}_{ij} \otimes \tilde{X}_j) \oplus \tilde{s}_i = \tilde{b}_i \quad i = 1, ..., m \\ & \tilde{X}_j = \tilde{0} \ or \ \tilde{1} \qquad j = 1, ..., n \\ & \tilde{s}_i \succcurlyeq 0 \qquad i = 1, \dots, m, \end{aligned}$$

where $\tilde{s}_i$ $(i = 1, \dots, m)$ is the auxiliary fuzzy variable corresponding i-th constraint. The duality of above problem is feasible if for each j, $\tilde{c}_{\mathrm{j}} \succcurlyeq 0$. Each $\tilde{c}_{\mathrm{j}} \prec 0$ can be turn to the desired form by $\tilde{X}_j = \widetilde{1} \ominus \widetilde{\acute{X}_j}$ where $\widetilde{\acute{X}_j}$ is a zero-one fuzzy variable. This is possible for both of the constraints and the objective function. If the primitive problem be feasible in addition to the dualism, there remains nothing to be done because the problem is minimization and the minimum of the objective function by the new fuzzy variable is reached if we allocate $\tilde{0} = (0, 0, 0)$ value to the all of the variables. If the primitive problem is not feasible we utilize the fuzzy additive algorithm to find the fuzzy optimum solution. The suggested idea for the zero-one problem is as follow: first we logically suppose that all of the variables are at level $\tilde{0}$ because per each j, $\tilde{c}_j \succcurlyeq 0$, since some of auxiliary variables corresponding with the solution are not feasible (it may some $\tilde{S}_i$ be negative fuzzy number), so it is necessary to reach some of the variables to the $\tilde{1}$ level assuming it approaches the solution to the being feasible means that $\tilde{s}_i \succcurlyeq 0$ (for each i). For assurance of a correct choose of the variables to reach their value to $\tilde{1}$ level we need some creativity and tests. Here we explain more with a numerical example.

Example 1. In this problem $\tilde{S}_i$ $(i = 1, 2, 3)$ are the auxiliary fuzzy variables correspond with the i-th constraint.

$$\begin{aligned}
Min \quad w =&\big((3,4,5)\otimes\tilde{X}_1\big)\oplus\\
&\big((2,3,4)\otimes\tilde{X}_2\big)\oplus\big((5,21,33)\otimes\tilde{X}_3\big)\oplus\big((2,3,4)\otimes\tilde{X}_4\big)\oplus\big((3,4,5)\otimes\tilde{X}_5\big)\\
s.t: \quad &\big((-1,1,2)\otimes\tilde{X}_1\big)\oplus\big((-1,1,2)\otimes\tilde{X}_2\big)\oplus\big((1,2,3)\otimes\tilde{X}_3\big)\oplus\big((2,3,4)\otimes\\
&\tilde{X}_4\big)\oplus\big((-1,1,2)\otimes\tilde{X}_5\big)\oplus\tilde{s}_1=(1,2,5)\\
&\big((-7,4,5)\otimes\tilde{X}_1\big)\oplus\big((3,7,9)\otimes\tilde{X}_3\big)\\
&\oplus\big((-4,2,3)\otimes\tilde{X}_4\big)\oplus\big((-3,3,5)\otimes\tilde{X}_5\big)\oplus\tilde{s}_2=(-2,2,6)\\
&\big((10,11,13)\otimes\tilde{X}_1\big)\oplus\big((-6,14,34)\otimes\tilde{X}_2\big)\oplus\\
&\big((-3,3,5)\otimes\tilde{X}_4\big)\oplus\big((-3,3,5)\otimes\tilde{X}_5\big)\oplus\tilde{s}_3=(-1,1,4)\\
&\widetilde{X}_j=\tilde{0}\ \text{ or } \tilde{1} \qquad j=1,\ldots,5\\
&\widetilde{s}_j\succcurlyeq 0 \qquad i=1,2,3
\end{aligned}$$

The Table 1 show the above problem:

Table 1: Simplex table corresponding to Example 1

$\widetilde{X}_5$	$\widetilde{S}_3$	$\widetilde{S}_2$	$\widetilde{S}_1$	RHS		$\widetilde{X}_4$	$\widetilde{X}_3$	$\widetilde{X}_2$	$\widetilde{X}_1$
(3,4,5)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	W	(2,3,4)	(5,21,33)	(2,3,4)	(3,4,5)
(-1,1,2)	(0,0,0)	(0,0,0)	(1,0,0)	(1,2,5)	$\widetilde{S}_1$	(2,3,4)	(1,2,3)	(-1,1,2)	(-1,1,2)
(-3,3,5)	(0,0,0)	(1,0,0)	(0,0,0)	(-2,2,6)	$\widetilde{S}_2$	(-4,2,3)	(3,7,9)	(0,0,0)	(-7,4,5)
(-3,3,5)	(1,0,0)	(0,0,0)	(0,0,0)	(-1,1,4)	$\widetilde{S}_3$	(-3,3,5)	(0,0,0)	(-6,14,34)	(10,11,13)

Because $\tilde{X}_j = \tilde{0}$ for each j: (The zero index show the beginning step).

$$(\tilde{S}_1^0, \tilde{S}_2^0,\ \tilde{S}_3^0) = ((1, 2, 5)\,,\ (-2, 2, 6)\,,\ (-1, 1, 4))$$

The corresponding value with the objective function is:

$$w^0 = \mathcal{R}\left\{\sum_{j=1}^{5}(\widetilde{c}_j \otimes \widetilde{x}_j)\right\} = \mathcal{R}\{(0, 0, 0)\} = 0$$

The primitive solution is not feasible because $\tilde{s}_2^0$, $\tilde{s}_3^0$ are negative fuzzy value. So that one of $\tilde{\mathrm{x}}_{\mathrm{j}}$ $(j = 1, \ldots, 5)$ variables should be reached to the $\tilde{1}$ level. Such a variable should approaches the solution toward being feasible. Considering the variables in the $\tilde{0}$ level we find that all of the $\tilde{\mathrm{x}}_3$ coefficients in the constraints corresponding with negative auxiliary variables $\{\tilde{S}_2, \tilde{S}_3\}$, are non-negative fuzzy numbers, so increasing $\tilde{\mathrm{x}}_3$ to $\tilde{1}$ level worsen the feasible solution:

$$(-2, 2, 6) \ominus ((3, 7, 9) \otimes (1, 0, 0)) = (-5, 11, 13)$$

$$(-1, 1, 4) \ominus ((0, 0, 0) \otimes (1, 0, 0)) = (-1, 1, 4)$$

As a result $\tilde{\mathrm{x}}_3$ should be remain in the $\tilde{0}$ level. Regarding to the coefficients of the$\tilde{X}_1, \tilde{X}_2$ and $\tilde{X}_4$ in the constraints corresponding with the negative auxiliary variables, although none of them bring about a feasible solution for the problem but it may that this matter accomplished by a combination of these at $\tilde{1}$ level. But still we can not remove these variables as it for $\tilde{X}_3$. On the other hand if we increase $\tilde{X}_5$ to the $\tilde{1}$ level we achieve a feasible solution. We equal $\tilde{\mathrm{X}}_5$ to $\tilde{1} = (1, 0, 0)$:

$$\begin{aligned}(\tilde{S}_1^1,\ \tilde{S}_2^1, \tilde{S}_3^1) =& (\tilde{S}_1^0 \ominus ((-1, 1, 2) \otimes (1, 0, 0)),\\ & \tilde{S}_2^0 \ominus ((-3, 3, 5) \otimes (1, 0, 0)),\\ & \tilde{S}_3^0 \ominus ((-3, 3, 5) \otimes (1, 0, 0)))\\ =& ((2, 4, 6), (1, 7, 9), (2, 6, 7))\end{aligned}$$

And the value of the objective function is equal:

$$w^1 = \mathcal{R}\left\{\tilde{C}_5 \otimes \tilde{X}_5\right\} = \mathcal{R}\left\{(3, 4, 5) \otimes (1, 0, 0)\right\} = 4.$$

Because this solution is a feasible solution we get it as the best solution until this level, $\overline{w} = w^1 = 4$ would be the upper bound for the next problem, or it can be said that from this level on, we search for the feasible solution which give a value less than 4 to the objective function. Now, we state the above trend as the branch and bound method. In Figure 2 the node (0) shows a condition in which $\tilde{X}_{\mathrm{j}} = \tilde{0}$ (per each j), this node spilt into two branch which correspond to the $\tilde{X}_5 = \tilde{0}$ and $\tilde{X}_5 = \tilde{1}$. If we put $\tilde{X}_5 = \tilde{1}$ we achieve a feasible solution in the node (1) which we get $\overline{w} = 4$ by it. Because all of the coefficients of the objective function are non-negative fuzzy numbers and it is a minimization problem, with the attention to the Definition 9 and part (b) in Subsection 2.2, none of the branch from node (1) does not give a better solution, so we leave this branch. Because $\tilde{X}_5 = \tilde{0}$ is the only rest branch, we should consider its corresponding solution. So we have the node (2) which its solution equal:

$$(\tilde{S}_1^2,\ \tilde{S}_2^2,\ \tilde{S}_3^2) = ((1, 2, 5), (-2, 2, 6), (-1, 1, 4))$$

$w^2 = 0$ and all the $\tilde{X}_{\mathrm{j}}$ $(j = 1, \ldots, 5)$ are at the $\tilde{0}$ level. Regarding that the value of $\tilde{X}_{\mathrm{j}}$ $(j = 1, \ldots 5)$ and the value of the objective function for the node of (0) and (2) are equal, maybe we think that there is no difference between these two nodes. But the important difference is that at the node (0) all of the $\tilde{X}_{\mathrm{j}}$ $(j = 1, \dots, 5)$ are free and can get the value of $\tilde{0}$ and $\widetilde{1}$, but in the node (2) the value of $\tilde{X}_5$ is constant and equal $\tilde{0}$. So for the selection variable branch at the node (2) we consider $\tilde{X}_1, \tilde{X}_2, \tilde{X}_3$ and $\tilde{X}_4$ only. The logic for raising variable branch in the node (2) to the $\widetilde{1}$ level, is the same for that on the node (0) with the additional information that each variable in the $\widetilde{1}$ level which create an objective function with the value greater or equal to $\overline{w}= 4$ should remain at the $\tilde{0}$ level. So raising $\tilde{X}_3$ to the $\widetilde{1}$ level do not produce a good result because it worsen both the optimization and feasibility of the solution (the value of objective function increase to 20 and the auxiliary variables become negative). We leave the $\tilde{X}_1$ Because $\tilde{c}_1 = \tilde{c}_5$ and even if raising $\tilde{X}_1$ to $\widetilde{1}$ level produce one feasible solution, still the value of the objective function do not improve. So, we should choose between $\tilde{X}_2$ and $\tilde{X}_4$. Regarding to the coefficients of the $\tilde{X}_2$ and $\tilde{X}_4$ in the constraints corresponding the auxiliary negative variables, none of the $\tilde{X}_2$ and $\tilde{X}_4$ variables can not alone create the feasible solution, so in this case the selection should be based on an experimental value. For every free variable of $\tilde{X}_{\mathrm{j}}$ define:

$$\tilde{k}_{ij} = \{\tilde{S}_{\mathrm{i}} \ominus \left(\tilde{a}_{\mathrm{ij}} \otimes \widetilde{1}\right)\}$$

Because $\tilde{k}_{ij}$ is a triangular fuzzy number, we show it as follow:

$$\tilde{k}_{\mathrm{ij}} = (k_{ij}^{(1)},\ k_{ij}^{(2)},\ k_{ij}^{(3)})$$

And we define V_j number per each $\tilde{X}_{\mathrm{j}}$ as follow:

$$V_j = \sum_i \min\{0, k_{ij}^{(1)}\}$$

The value of V_j can be taken as the rate of unfeasibility resulted from raising the free variables to the $\widetilde{1}$ level. The chose branching variable is the one which has the least modulus V value.

Let compute the V value for $\tilde{X}_2$ and $\tilde{X}_4$:

$$V_2 = -2, V_4 = -1$$

So we chose $\tilde{X}_4$ as the branch variable and $\tilde{X}_4 = (1, 0, 0)$ produced the node (3) in figure 2 where $w^3 = 3$ and

$$(\tilde{S}_1^3,\ \tilde{S}_2^3,\ \tilde{S}_3^3) = ((-1, 6, 8), (2, 5, 8), (2, 6, 7)).$$

On the node (3) we have:

$$\tilde{X}_4 = (1, 0, 0) \text{ and } \tilde{X}_5 = (0, 0, 0).$$

Thus $\tilde{X}_1, \tilde{X}_2$ and $\tilde{X}_3$ are the only free variables on the node (3). According to the value of $\tilde{c}_j$ $(j = 1, 2, 3)$, raising $\tilde{X}_1, \tilde{X}_2$ and $\tilde{X}_3$ to the $\tilde{1}$ level, do not produce a better value for the objective function because per raising $\tilde{X}_1, \tilde{X}_2$and $\tilde{X}_3$ to the $\tilde{1}$ level the values for the objective function are respectively: 4+3, 3+3 and 20+3.

Because none of the free variables are promising, no more branch on the node (3) is possible so it is cut. The only rest node is the node (4) in which $\tilde{X}_4$=$\tilde{X}_5$=$(0,0,0)$, w^4= 0 and

$$(\tilde{s}_1^4,\ \tilde{s}_2^4,\ \tilde{s}_3^4) = ((1,2,5)\,,(-2,2,6)\,,(-1,1,4)).$$

On the node (4) there is also the free variables of $\tilde{X}_1, \tilde{X}_2$ and $\tilde{X}_3$. The $\tilde{X}_3$ variable is not also promising in that optimization and feasibility. The $\tilde{X}_1$ and $\tilde{X}_2$ variables also can not produce the feasible solution on the node (4), so there is no branch on the nod (4) and cut. The achieved solution in the node (1) with $\tilde{X}_5 = (1,0,0)$, w^1= 4 and $\widetilde{X_j} = \tilde{0}$ $(j = 1,2,3,4)$ is the desired solution.

5 Conclutions

In this paper we formulate fully fuzzy linear programming problems with zero-one variables and a method for solving these problems is presented using the ranking functions and also the branch and bound method along with an example is presented.

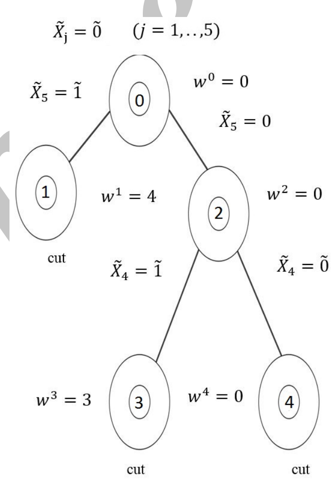

Figure 2: The tree of numerical Example 1

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حل مسائل برنامه‌ریزی خطی کاملاً فازی صفر-یک با استفاده از توابع رتبه‌بندی

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چکیده
جهانشاهلو یک روش برای حل مسائل برنامه‌ریزی خطی صفر و یک ارائه کرده است. در این مقاله، مسائل برنامه‌ریزی خطی کاملاً فازی صفر و یک، فرمول‌بندی شده و با استفاده از تابع رتبه‌بندی، روشی برای حل این مسائل معرفی شده است و هم‌زمان روش انشعاب و کران همراه با یک مثال عددی برای تشریح روش پیشنهادی ارائه شده است.

کلمات کلیدی
مجموعه فازی، عدد فازی، تابع رتبه‌بندی، عدد فازی مثلثی، عدد فازی مثلثی صفر و یک.