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Research Article

A New Approach for Solving Fully Fuzzy Linear Programming by Using the Lexicography Method

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The fully fuzzy linear programming (FFLP) problem has many different applications in sciences and engineering, and various methods have been proposed for solving this problem. Recently, some scholars presented two new methods to solve FFLP. In this paper, by considering the L-R fuzzy numbers and the lexicography method in conjunction with crisp linear programming, we design a new model for solving FFLP. The proposed scheme presented promising results from the aspects of performance and computing efficiency. Moreover, comparison between the new model and two mentioned methods for the studied problem shows a remarkable agreement and reveals that the new model is more reliable in the point of view of optimality.

1. Introduction

Linear programming (LP) or linear optimization is one of most practical techniques in operation research, which finds the best extractable solution with respect to the constraints. Since six decades has passed from its first description and clarification, it is still useful for promoting a new approach for blending real-world problems in the framework of linear programming. Linear programming problem is in the two forms of classical linear programming (LP) and fuzzy linear programming (FLP). In real-world problems, values of the parameters in LP problem should be precisely described and evaluated. However, in real-world applications, the parameters are often illusory. The optimal solution of an LP only depends on a limited number of constraints; therefore, much of the collected information has a little impact on the solution. It is useful to consider the knowledge of experts about the parameters as fuzzy data. The concept of decision in fuzzy environment was first proposed by Bellman and Zadeh [1]. Tanaka et al. [2] proposed a new method for solving the fuzzy mathematical programming problem. Zimmermann [3] developed a method for solving LP problem using multiobjective functions. Buckley and Feuring [4] presented another method for finding the solution in fuzzy, linear programming problem by changing target function into a linear multiobjective problem. Maleki [5] proposed a method for solving LP problem with uncertain constraints using ranking function. A ranking function is a function $\mathfrak{R} : F(R) \rightarrow R$ which maps each fuzzy number into the real line, where a natural order exists. Zhang et al. [6] proposed to put forward solving of LP problem with fuzzy coefficients in target function. Hashemi et al. [7] suggested a two-phase method for solving fuzzy LP problem. Jimenez et al. [8] presented a new method using fuzzy ranking method to rank the fuzzy objective values and to deal with the inequality relation on constraints. Allahviranloo et al. [9] brought up a method for solving fully fuzzy LP problem based on a kind of defuzzification method. Ebrahimnejad and Nasseri [10] solved FLP problem with fuzzy parameters using complementary slackness property. Dehghan et al. [11] proposed some practical methods to solve a fully fuzzy linear system which are comparable to the well-known methods. Then they extended a new method employing linear programming (LP) for solving square and nonsquare fuzzy systems. Lotfi et al. [12] applied the concept of the symmetric triangular fuzzy number and obtained a new method for solving

FFLP by converting a FFLP into two corresponding LPs. MishmastNehi et al. [13] defined the concept of optimality for linear programming problems with fuzzy parameters by transforming fuzzy linear programming problems into a multiobjective linear programming problems. Kumar et al. [14] pointed out the shortcomings of the methods of [11, 12]. To overcome these shortcomings, they proposed a new method for finding the fuzzy optimal solution of FFLP problems with equality constraints. This method also had shortcomings which were corrected by Saberi Najafi and Edalatpanah [15]. Shamooshaki et al. [16] using L-R fuzzy numbers and ranking function established a new scheme for FFLP. Ezzati et al. [17] using new ordering on triangular fuzzy numbers and converting FFLP to a multiobjective linear programming (MOLP) problem presented a new method to solve FFLP; see also [18].

In this paper, we design a new model to solve fully fuzzy LP problem. Moreover, comparative results for the proposed scheme and some existing methods [14, 17] are also presented.

The rest of this paper is organized as follows: descriptions and basic operators used in the paper are stated in Section 2. In Section 3, the algorithm of the proposed method is affirmed, and also numerical example is given for illustrating the new method. Finally, conclusions are given in Section 4.

2. Preliminaries

In this section some basic definitions, arithmetic operations, and ranking function are reviewed.

Definition 1 (see [19]). A function, usually denoted by L (the left shape function) or R (the right shape function), is reference function of a fuzzy number if and only if $L(x) = L(-x)$, $L(0) = 1$, and L is nonincreasing on $[0, +\infty)$. Naturally, a right shape function $R(\cdot)$ is similarly defined as $L(\cdot)$.

Definition 2 (see [19]). A fuzzy number $\widetilde{M}$ is said to be a LR fuzzy number, if there exist reference functions L (for left), R (for right), and scalers $\alpha > 0$, $\beta > 0$ with

$$\mu_{\widetilde{M}}(x) = \begin{cases} L\left(\dfrac{m-x}{\alpha}\right), & x \leq m, \\[2ex] R\left(\dfrac{x-m}{\beta}\right), & x \geq m, \end{cases} \tag{1}$$

where m is the mean value of $\widetilde{M}$ and α and β are called the left and right spreads, respectively. Using its mean value and left and right spreads, and shape functions, such a LR fuzzy number $\widetilde{M}$ is symbolically written as $\widetilde{M} = (m, \alpha, \beta)_{LR}$.

Definition 3 (see [19]). Two L-R type fuzzy numbers $\widetilde{M} = (m, \alpha, \beta)_{LR}$ and $\widetilde{N} = (n, \gamma, \delta)_{LR}$ are said to be equal if and only if $m = n$ and $\alpha = \gamma$ and $\beta = \delta$.

Theorem 4 (see [19]). *Let $\widetilde{M} = (m, \alpha, \beta)_{LR}$ and $\widetilde{N} = (n, \gamma, \delta)_{LR}$ be two fuzzy numbers of LR-type. Then one has*

(1) $(m, \alpha, \beta)_{LR} \oplus (n, \gamma, \delta)_{LR} = (m + n, \alpha + \gamma, \beta + \delta)_{LR}$,

(2) $-(m, \alpha, \beta)_{LR} = (-m, \beta, \alpha)_{RL}$,

(3) $(m, \alpha, \beta)_{LR} \ominus (n, \gamma, \delta)_{LR} = (m - n, \alpha + \delta, \beta + \gamma)_{LR}$.

Remark 5. The LR-type fuzzy number $\widetilde{M} = (m, \alpha, \beta)_{LR}$ is said to be nonnegative fuzzy number if and only if $m \geq 0$, $m - \alpha \geq 0$, $m + \beta \geq 0$.

Theorem 6 (see [19]). *Under the assumptions of Theorem 4,*

(1) *for $\widetilde{M}, \widetilde{N}$ positive,*

$$(m, \alpha, \beta)_{LR} \otimes (n, \gamma, \delta)_{LR} \approx (mn, m\gamma + n\alpha, m\delta + n\beta)_{LR}, \tag{2}$$

(2) *for $\widetilde{N}$ positive and $\widetilde{M}$ negative,*

$$(m, \alpha, \beta)_{RL} \otimes (n, \gamma, \delta)_{LR} \approx (mn, n\alpha - m\delta, n\beta - m\gamma)_{RL}, \tag{3}$$

(3) *for $\widetilde{M}, \widetilde{N}$ negative*

$$(m, \alpha, \beta)_{LR} \otimes (n, \gamma, \delta)_{LR} \approx (mn, -n\beta - m\delta, -n\alpha - m\gamma)_{RL}. \tag{4}$$

Following [17], here we propose a new definition to compare two LR-type fuzzy numbers.

Definition 7. Let $\widetilde{M} = (m_1, \alpha_1, \beta_1)_{LR}$ and $\widetilde{N} = (m_2, \alpha_2, \beta_2)_{LR}$ be two arbitrary LR-type fuzzy numbers. One says that $\widetilde{M}$ is relatively less than $\widetilde{N}$, which is denoted by $\widetilde{M} \prec \widetilde{N}$, if and only if

(i) $m_1 < m_2$,

(ii) $m_1 = m_2$ and $(\alpha_1 + \beta_1) > (\alpha_2 + \beta_2)$ or,

(iii) $m_1 = m_2$, $(\alpha_1 + \beta_1) = (\alpha_2 + \beta_2)$, and $(2m_1 - \alpha_1 + \beta_1) < (2m_2 - \alpha_2 + \beta_2)$.

Remark 8. It is clear from the above definition that $m_1 = m_2$, $(\alpha_1 + \beta_1) = (\alpha_2 + \beta_2)$, and $(2m_1 - \alpha_1 + \beta_1) = (2m_2 - \alpha_2 + \beta_2)$ if only and if $\widetilde{M} = \widetilde{N}$.

Definition 9. A ranking function is a function $\mathfrak{R} : F(R) \rightarrow R$, where $F(R)$ is a set of fuzzy numbers defined on set of real numbers, which maps each fuzzy number into a real line, where a natural order exists. Let $\widetilde{M} = (m, \alpha, \beta)_{LR}$ be a LR-type fuzzy number; then $\mathfrak{R}(\widetilde{M}) = m + (\beta - \alpha)/4$.

Remark 10. If $\widetilde{M} = (a, b, c)$ is a triangle fuzzy number, then $\mathfrak{R}(\widetilde{M}) = (a + 2b + c)/4$.

3. FFLP Problem Formulation and Proposed Method

FFLP problems with m fuzzy equality constraints and n fuzzy variables may be formulated as follows:

$$\begin{aligned} \max \text{ (or min) } \quad & \widetilde{C}^t \otimes \widetilde{x}, \\ \text{s.t.} \quad & \widetilde{A} \otimes \widetilde{x} = \widetilde{b}, \\ & \widetilde{x} \text{ is nonnegetive fuzzy number.} \end{aligned} \tag{5}$$

We know that $\widetilde{C}^t = [\widetilde{c}_j]_{1\times n}$, $\widetilde{x} = [\widetilde{x}_j]_{n\times 1}$, $\widetilde{A} = [\widetilde{a}_{ij}]_{m\times n}$, $\widetilde{b} = [\widetilde{b}_i]_{m\times 1}$, and $\widetilde{c}_j, \widetilde{X}_j, \widetilde{a}_{ij}, \widetilde{b}_i \in F(R)$ are all LR-type fuzzy numbers. Next, we establish the new method.

Let $\widetilde{C}^t\widetilde{x} = ((c^t x)^m, (c^t x)^l, (c^t x)^u)_{LR}$, $\widetilde{A}\widetilde{x} = ((Ax)^m, (Ax)^l, (Ax)^u)_{LR}$, $\widetilde{b} = ((b)^m, (b)^l, (b)^u)_{LR}$, and $\widetilde{x} = ((x)^m, (x)^l, (x)^u)_{LR}$, and then the steps of new method are as follows.

Step 1. With respect to fuzzy number definitions, we have

$$\begin{aligned} \max \text{ (min)} \quad & \left(\left(c^T x\right)^m, \left(c^T x\right)^l, \left(c^T x\right)^u\right)_{LR}, \\ \text{s.t.} \quad & \left((Ax)^m, (Ax)^l, (Ax)^u\right)_{LR} \\ & = \left((b)^m, (b)^l, (b)^u\right)_{LR}, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0. \end{aligned} \tag{6}$$

Equivalently, using Definition 3 we have

$$\begin{aligned} \max \text{ (min)} \quad & \left(\left(c^T x\right)^m, \left(c^T x\right)^l, \left(c^T x\right)^u\right)_{LR} \\ \text{s.t.} \quad & (Ax)^m = (b)^m, \\ & (Ax)^l = (b)^l, \\ & (Ax)^u = (b)^u, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0. \end{aligned} \tag{7}$$

Step 2. Regarding Definition 7, we convert problem (7) into the following multiobjective LP problem:

$$\begin{aligned} \max \text{ (min)} \quad & \left(c^T x\right)^m, \\ \min \text{ (max)} \quad & \left(c^T x\right)^u + \left(c^T x\right)^l, \\ \max \text{ (min)} \quad & 2\left(c^T x\right)^m - \left(c^T x\right)^l + \left(c^T x\right)^u, \\ \text{s.t.} \quad & (Ax)^m = (b)^m, \\ & (Ax)^l = (b)^l, \\ & (Ax)^u = (b)^u, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0. \end{aligned} \tag{8}$$

Step 3. In terms of the preference of objective functions, the lexicographic method will be used to obtain a lexicographically optimal solution of problem (8). So, we have

$$\begin{aligned} \max \text{ (min)} \quad & \left(c^T x\right)^m \\ \text{s.t.} \quad & (Ax)^m = (b)^m, \\ & (Ax)^l = (b)^l, \\ & (Ax)^u = (b)^u, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0. \end{aligned} \tag{9}$$

If problem (9) has optimal solution $\widetilde{x}^* = ((x^*)^m, (x^*)^l, (x^*)^u)_{LR}$, then it is an optimal solution of problem (6) and stop. Otherwise go to Step 4.

Step 4. We solve the following problem using optimal solutions that are obtained in Step 3:

$$\begin{aligned} \min \text{ (max)} \quad & \left(c^T x\right)^u + \left(c^T x\right)^l \\ \text{s.t.} \quad & \left(c^T x\right)^m = s^* \\ & (Ax)^m = (b)^m, \\ & (Ax)^l = (b)^l, \\ & (Ax)^u = (b)^u, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0, \end{aligned} \tag{10}$$

in which s^* is optimal value of problem (9). If problem (10) has exclusive solution of $\widetilde{x}^* = ((x^*)^m, (x^*)^l, (x^*)^u)$, it is optimal solution of problem (6) and we stop; otherwise proceed to Step 5.

Table 1: The solution of Example 11 by the proposed method.

Proposed method (L-R number)	Multipurpose function
16	$(c^T x)^m$
28	$(c^T x)^u + (c^T x)^l$
42	$2(c^T x)^m - (c^T x)^l + (c^T x)^u$

Step 5. We solve the following problem using optimized solution in Step 4:

$$\begin{aligned} \max\ (\min)\quad & 2\left(c^T x\right)^m - \left(c^T x\right)^l + \left(c^T x\right)^u, \\ \text{s.t.}\quad & \left(c^T x\right)^u + \left(c^T x\right)^l = n^* \\ & \left(c^T x\right)^m = s^* \\ & (Ax)^m = (b)^m, \\ & (Ax)^l = (b)^l, \\ & (Ax)^u = (b)^u, \\ & (x)^m \geq 0, \\ & (x)^m - (x)^l \geq 0, \\ & (x)^m + (x)^u \geq 0, \end{aligned} \tag{11}$$

in which n^* is optimal value of problem (10). Thus, optimal solution of problem (6) is in the form of $\widetilde{x}^* = ((x^*)^m, (x^*)^l, (x^*)^u)$ obtained by solving problem (11).

Next, we illustrate the proposed method using an example. To solve the following problem, a mathematical programming solver called Lingo will be used.

Example 11. Let us consider the following FFLP and solve it by the proposed method (Table 1)

$$\begin{aligned} \max\quad & \left((2,1,1)_{LR}\right)\widetilde{x}_1 \oplus \left((3,1,1)_{LR}\right)\widetilde{x}_2 \\ \text{s.t.}\quad & \left((1,1,1)_{LR}\right)\widetilde{x}_1 \oplus \left((2,1,1)_{LR}\right)\widetilde{x}_2 = (10,8,14)_{LR} \\ & \left((2,1,1)_{LR}\right)\widetilde{x}_1 \oplus \left((1,1,1)_{LR}\right)\widetilde{x}_2 = (8,7,13)_{LR} \\ & \widetilde{x}_1, \widetilde{x}_2 \text{ are nonnegetive fuzzy numbers.} \end{aligned} \tag{12}$$

With regard to proposed scheme we will have the following.

Using Step 2,

$$\begin{aligned} \max\quad & \left(2x_1 + 3x_2\right) \\ \min\quad & \left(2z_1 + x_1 + 3z_2 + x_2\right) + \left(2y_1 + x_1 + 3y_2 + x_2\right) \\ \max\quad & 2\left(2x_1 + 3x_2\right) - \left(2y_1 + x_1 + 3y_2 + x_2\right) \\ & \quad + \left(2z_1 + x_1 + 3z_2 + x_2\right) \\ \text{s.t.}\quad & x_1 + 2x_2 = 10, \\ & x_1 + x_2 + y_1 + 2y_2 = 8, \\ & x_1 + x_2 + z_1 + 2z_2 = 14 \\ & 2x_1 + x_2 = 8 \\ & x_1 + x_2 + 2y_1 + y_2 = 7 \\ & x_1 + x_2 + 2z_1 + z_2 = 13 \\ & x_1 \geq 0, \\ & x_1 \geq 0, \\ & x_1 - y_1 \geq 0, \\ & x_1 - y_1 \geq 0, \\ & z_1 + x_1 \geq 0, \\ & z_1 + x_1 \geq 0. \end{aligned} \tag{13}$$

Using Step 3,

$$\begin{aligned} \max\quad & 2x_1 + 3x_2 \\ \text{s.t.}\quad & x_1 + 2x_2 = 10, \\ & x_1 + x_2 + y_1 + 2y_2 = 8, \\ & x_1 + x_2 + z_1 + 2z_2 = 14, \\ & 2x_1 + x_2 = 8, \\ & x_1 + x_2 + 2y_1 + y_2 = 7, \\ & x_1 + x_2 + 2z_1 + z_2 = 13, \\ & x_1 \geq 0, \\ & x_1 \geq 0, \\ & x_1 - y_1 \geq 0, \\ & x_1 - y_1 \geq 0, \\ & z_1 + x_1 \geq 0, \\ & z_1 + x_1 \geq 0. \end{aligned} \tag{14}$$

So, the solution of the above problem is

$$\{16, \{x_1 \longrightarrow 2, x_2 \longrightarrow 4, y_1 \longrightarrow 0, y_2 \longrightarrow 1, z_1 \longrightarrow 2, z_2 \longrightarrow 3\}\}. \tag{15}$$

Using Step 4,

$$\begin{aligned}
\min\quad & (2z_1 + x_1 + 3z_2 + x_2) + (2y_1 + x_1 + 3y_2 + x_2)\\
\text{s.t.}\quad & 2x_1 + 3x_2 = 16,\\
& x_1 + 2x_2 = 10,\\
& x_1 + x_2 + y_1 + 2y_2 = 8,\\
& x_1 + x_2 + z_1 + 2z_2 = 14,\\
& 2x_1 + x_2 = 8,\\
& x_1 + x_2 + 2y_1 + y_2 = 7,\\
& x_1 + x_2 + 2z_1 + z_2 = 13,\\
& x_1 \geq 0,\\
& x_1 \geq 0,\\
& x_1 - y_1 \geq 0,\\
& x_1 - y_1 \geq 0,\\
& z_1 + x_1 \geq 0,\\
& z_1 + x_1 \geq 0.
\end{aligned} \tag{16}$$

The solution of the above problem is

$$\{28, \{x_1 \longrightarrow 2, x_2 \longrightarrow 4, y_1 \longrightarrow 0, y_2 \longrightarrow 1, z_1 \longrightarrow 2, z_2 \longrightarrow 3\}\}. \tag{17}$$

And using Step 5,

$$\begin{aligned}
\max\quad & 2(2x_1 + 3x_2) - (2y_1 + x_1 + 3y_2 + x_2)\\
& \quad + (2z_1 + x_1 + 3z_2 + x_2)\\
\text{s.t.}\quad & 2z_1 + x_1 + 3z_2 + x_2 + 2y_1 + x_1 + 3y_2 + x_2\\
& = 28,\\
& 2x_1 + 3x_2 = 16,\\
& x_1 + 2x_2 = 10,\\
& x_1 + x_2 + y_1 + 2y_2 = 8,\\
& x_1 + x_2 + z_1 + 2z_2 = 14,\\
& 2x_1 + x_2 = 8,\\
& x_1 + x_2 + 2y_1 + y_2 = 7,\\
& x_1 + x_2 + 2z_1 + z_2 = 13,\\
& x_1 \geq 0,\\
& x_1 \geq 0,\\
& x_1 - y_1 \geq 0,\\
& x_1 - y_1 \geq 0,\\
& z_1 + x_1 \geq 0,\\
& z_1 + x_1 \geq 0.
\end{aligned} \tag{18}$$

Table 2: The solution of Example 11 by Ezzati et al. method.

Ezzati et al. method (triangle number)	Multipurpose function
16	$(c^T x)^m$
28	$(c^T x)^u + (c^T x)^l$
39	$(c^T x)^l + (c^T x)^u$

The solution of the above problem is

$$\{42, \{x_1 \longrightarrow 2, x_2 \longrightarrow 4, y_1 \longrightarrow 0, y_2 \longrightarrow 1, z_1 \longrightarrow 2, z_2 \longrightarrow 3\}\}. \tag{19}$$

The L-R fuzzy optimized solution is $(16, 9, 19)_{LR}$ and, using Definition 9, the ranking function will be 18.5.

We also solve this example using Kumar et al. and Ezzati et al. methods. Using Kumar et al. method [14], the fuzzy optimized solution is $(5, 16, 33)$ and with regard to Definition 9 and Remark 10, the ranking function will be 17.5.

Solving this method by Ezzati et al. method, we will have Table 2.

The fuzzy optimized solution here is $(5.5, 16, 33.5)$ and using Definition 9 and Remark 10, the ranking function is 17.75. By comparing the above methods, we conclude that our method offers relatively better results. Now, let us compare the methods using Definition 7. Comparing the solutions of Kumar and Ezzati et al. methods, we have

(i) $m_1 = 16 = m_2$,

(ii) $m_1 = m_2$ and $(\beta_1 - \alpha_1) = 28 = (\beta_2 - \alpha_2)$,

(iii) $m_1 = m_2$, $(\beta_1 - \alpha_1 = \beta_2 - \alpha_2)$, and $((\alpha_1 + \beta_1) = 39) < ((\alpha_2 + \beta_2) = 39)$.

Therefore,

Kumar et al. method $(5, 16, 33) <$ Ezzati et al. method $(5.5, 16, 33.5)$.

And to compare Ezzati et al. method [17] with our method, first we convert Ezzati et al. fuzzy triangular solution into L-R

$$(5.5, 16, 33.5) = (16, 10.5, 17.5)_{LR}. \tag{20}$$

Afterwards, comparing the fuzzy optimized solution of Ezzati et al.'s method, we have

(i) $m_1 = 16 = m_2$,

(ii) $m_1 = m_2$ and $(\alpha_1 + \beta_1) = 28 = (\alpha_2 + \beta_2)$ or,

(iii) $m_1 = m_2$, $(\alpha_1 + \beta_1) = (\alpha_2 + \beta_2)$, and $((2m_1 - \alpha_1 + \beta_1) = 39) < ((2m_2 - \alpha_2 + \beta_2) = 42)$.

Thus,

(5.5, 16, 33.5) Ezzati et al.'s method < proposed method $(16, 9, 19)_{LR} = (7, 16, 35)$.

As a result, with regard to the ranking function and Definition 7, our solution is more optimized than the above methods.

4. Conclusions

In the present paper, a method of solving the fully fuzzy programming problem with *L-R* fuzzy numbers has been proposed. The FFLP problem is converted into an MOLP problem using fuzzy calculus and solved by lexicography method and linear programming methods. The proposed scheme presented promising results from the aspects of computing efficiency and performance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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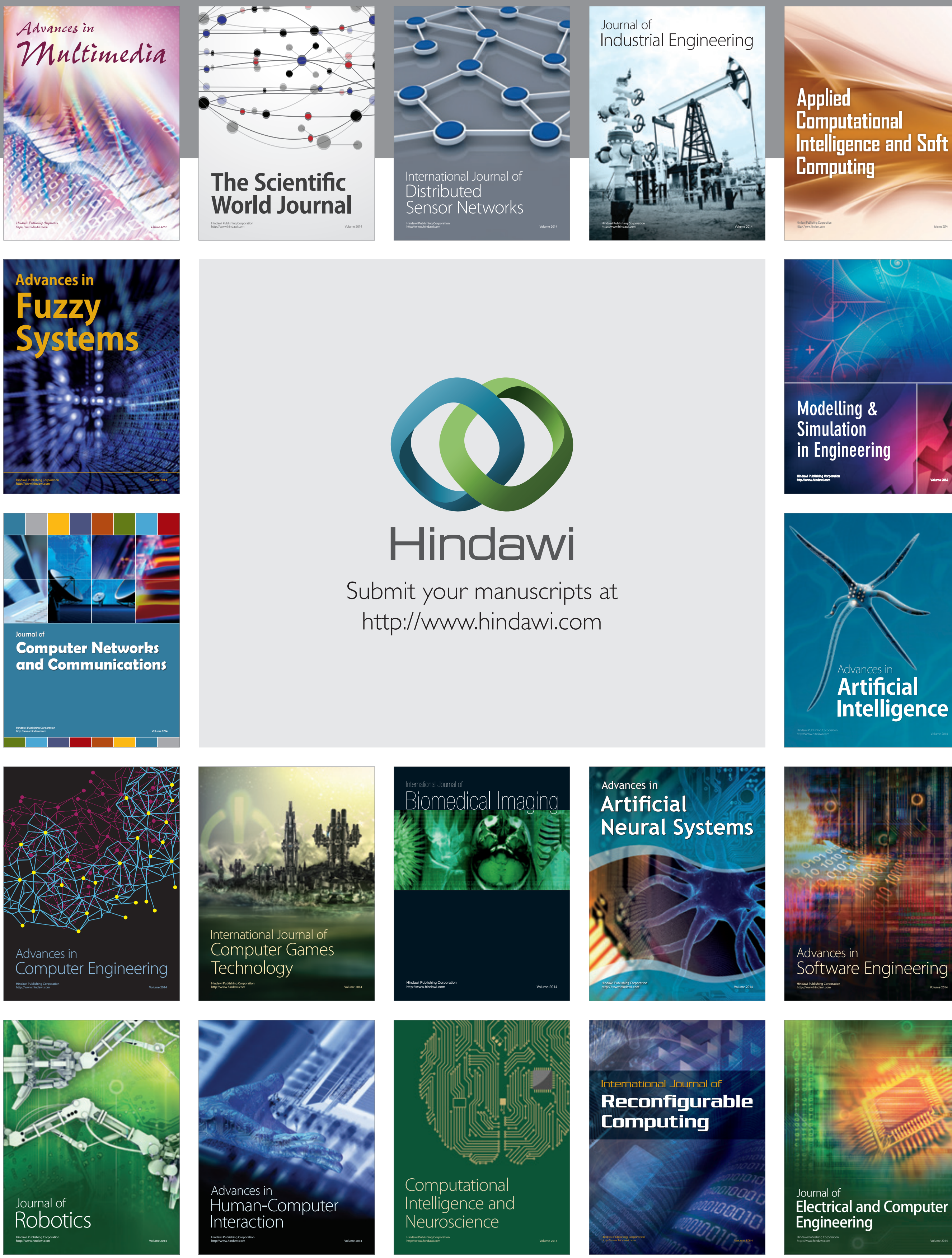

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