European Journal of Operational Research, Vol. 142, No. 3, 2002, pp. 625-631

Three-person Multi-objective Conflict Decision in Reservoir Flood Control

Cheng Chuntian[a,*] K.W.Chau[b]

[a] *Department of Civil Engineering, Dalian University of Technology, Dalian, 116024, P.R.China*

[b] *Department of Civil and Structural Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.*

Abstract Reservoir flood control decisions are often compromised by various parties with conflicting benefits. In this paper, a three-person multi-objective conflict decision model is presented for reservoir flood control. In order to obtain the group decision, the ideal bargaining solution is first sought by two stages satisfying programming and then the decision alternative is chosen using the fuzzy pattern recognition. The advantages of this model are simple and more adaptable to the real problem. The model is demonstrated by application to Fengman Reservoir in China.

Keywords: group decisions; three-person multi-objective decision; two stages satisfying programming, fuzzy pattern recognition; flood control

1. **Introduction**

Reservoir flood control is generally complex in practical operations as it involves a large number of uncertain factors and multiple-objectives. These factors include the intrinsic uncertainty in hydrological phenomenon, uncertainty in model assumptions, uncertainty in data or parameter values, and uncertainty in the result interpretation. The objectives are different combinations of benefits from hydropower generation, water supply for irrigation, municipal and industrial use, flood control, navigation, water quality improvement, recreation and ecology, and so on. With the complexity of the modern social structure and ever-expanding knowledge about numerous relationships among various components of a system, there exists a tendency for the change from single-objective optimization toward multi-objective analysis, especially when the system analyzed is a part of the natural environment [1]. During the past decades, there have seen a significant increase in multi-criterion decision making (MCDA) methods to water resources management. The research has focused on evaluating feasible alternatives with the aid of strong and flexible decision support systems, and on finding a satisfactory solution or a group of satisfactory solutions [2]. Bender and Simonovic[3] describe a fuzzy compromise approach to water resources systems planning under uncertainty. Despic and Simonovic[1] present a general methodology for numerical evaluation of complex qualitative criteria based on the theory of fuzzy sets. This method was suitable aggregation operators for the qualitative evaluation of flood control. Raju and Pillai [4] employ five MCDA methods to select the best reservoir

[*]Corresponding author. Tel: +86-411-4708517; Fax:+86-411-4674141; Email: ctcheng@dlut.edu.cn **(After June 15, 2001)**

[a] Now at Department. of Civil and Structural Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Email: cetcheng@polyu.edu.hk **(Before June15, 2001)**

configuration for the case study of Chaliyar river basin, Kerala, India. Cheng [2] develops a fuzzy optimal model of real time multi-reservoir operation for the flood system of the upper and middle reaches of the Yangtze River. Ko et al. [5] present a two-stage procedure combining multi-objective optimization and multi-criterion decision analysis techniques for reservoir system operational planning. The methods mentioned above put an emphasis on MCDA while there have been few studies considering multi-person multi-objective conflict decision to water resources management in group decision making problems.

It is known that flood control decisions are usually a bargaining solution compromised by different parties with conflicting benefits. A bargaining situation occurs when two or more players have a common interest to co-operate, but have conflicting interests over exactly how to co-operate. Bargaining is any process through which the players try to reach an agreement on their own [6]. Fuzzy sets theories have been developed to seek for the bargaining solution,the compromise solution or the satisfying solution. They can be found in Leung[7], Sakawa et al.[8,9], Lee and Li[10]. The approaches proposed by these investigators emphasize fuzzy multi-objective programming and puts little focus on bargaining process. After the Nash's path-breaking contributions to bargaining theory [11,12], there have been a large amount of literatures that contain theories and applications of the bargaining theory. In this paper, considering the background of the real problem, we propose a new bargaining model with three parties, i.e., Three-person Multi-objective Conflict Decision (TMCD) method by which the players get a third party to help them to determine the agreement. The method refers to the basic ideas of fuzzy multiple objective programming [7-10]. To obtain the group decision, the ideal bargaining solution is first sought through two stages satisfying programming and then the decision alternative is chosen using the fuzzy recognition model. TMCD can be used to solve this class of problem with conflicts and limited alternatives. The model is simple and effective, more adaptable to the real multi-person multi-objective decision.

2. Description of the Problem

The multi-person multi-objective decision problem composing of three parties *A*, *B* and *C* is considered. *A* and *B* are two conflicting parties required to recommend alternatives and to provide information to *C*. *C*, being the higher authority (or arbitrator), can make decision according to his own priority from the information provided by *A* and *B*. The recommended alternatives provided by the players A and B can be obtained by multi-criterion decision-making analysis with the aid of strong and flexible decision making support systems, which are only the first step in the whole decision process. The crucial problem is how to get the bargaining solution from these recommended alternatives. In fact, our problem is a TMCD problem with limited alternatives.

Let the chosen objectives be denoted by $x_1,\cdots,x_m (m \ge 2)$. From those methods of multi-objective decision such as ideal point method and weight coefficient method, a set of satisfying alternatives can be obtained for A and B reflecting their priority structure. Supposing *C* demands that both *A* and *B* provide *n* alternatives, and the objective value matrixes corresponding to the above alternatives are $A_n = (a_{ij})_{n\times m}, B_n = (b_{ij})_{n\times m}$ respectively, where a_{ij} and b_{ij} are the j th objective value of i th alternative provided by *A* and *B* respectively. Among the *m* objectives considered by both *A* and *B*, some are unanimous while others are in conflict. The alternatives sets provided by A and B constitute a multi-objective conflict decision with limited alternatives (total number is $2n$).

3. Ideal bargaining solution from two stage programming

According to the features of the above problem, three parties A, B and C can be regarded to constitute a definite arbitrated situation, which is denoted by $M=(A,B;x_1,\cdots,x_m;C)$. Fuzzy compromise programming [7-10] seeks the compromise solution among the various objectives of a multi-criteria decision making problem with the maximization of the membership functions for the objectives in the first phase and the averaging the membership functions for the objectives in the second phase. The arbitrating solution, which is called the ***ideal bargaining solution*** in this paper, is obtained by two stages satisfying programming similar to reference [7-10].

The first stage programming is to obtain

$$\max SF_B(X)$$
$$\text{s.t.}\begin{cases} SF_A(X)=SF_B(X) \\ X\in S \end{cases} \tag{1}$$

and the second stage programming is to attain

$$\max SF_A(X)+SF_B(X)$$
$$\text{s.t.}\begin{cases} SF_A(X)\ge SF_A(X_0) \\ SF_B(X)\ge SF_B(X_0) \\ X\in S \end{cases} \tag{2}$$

where $SF_A()$ and $SF_B()$ are the satisfying functions of A and B respectively, X is m-dimensional vector and S is the constraint condition. Equation (1) represents maximizing the satisfying function of A in order to seek for an initial ideal solution X_0 under the same satisfying function of both A and B. Equation (2) represents maximizing the sum of the satisfying functions of both A and B in order to obtain the ideal solution X^* with improvement in both the satisfying functions of A and B. The satisfying functions $SF_A(x_j)$ and $SF_B(x_j)$ can be constructed through equations (3) and (4) respectively. For the objective that the larger value represents the better,

$$SF_A(x_j)=\frac{x_j-\bigwedge_{i=1}^{n}a_{ij}}{\bigvee_{i=1}^{n}a_{ij}-\bigwedge_{i=1}^{n}a_{ij}},\ SF_B(x_j)=\frac{x_j-\bigwedge_{i=1}^{n}b_{ij}}{\bigvee_{i=1}^{n}b_{ij}-\bigwedge_{i=1}^{n}b_{ij}} \tag{3}$$

For the objective that the smaller value represents the better,

$$SF_A(x_j)=\frac{\bigvee_{i=1}^{n}a_{ij}-x_j}{\bigvee_{i=1}^{n}a_{ij}-\bigwedge_{i=1}^{n}a_{ij}},\ SF_B(x_j)=\frac{\bigvee_{i=1}^{n}b_{ij}-x_j}{\bigvee_{i=1}^{n}b_{ij}-\bigwedge_{i=1}^{n}b_{ij}} \tag{4}$$

According to equations (3) and (4), the synthetically satisfying functions of A and B can be obtained:

$$SF_A(X)=\sum_{j=1}^{m}\alpha_j\cdot SF_A(x_j) \tag{5}$$

$$SF_B(X)=\sum_{j=1}^{m}\beta_j\cdot SF_B(x_j) \tag{6}$$

In equations (5) and (6), α_j and β_j are weight coefficients of A and B respectively for objective j, which reflect priority structure of A and B in recommended alternatives. By substituting equations (5) and (6) into equations (1) and (2), the arbitrating solution $X^* = (x_1^*, \cdots, x_m^*)^T$ can be obtained. For the arbitrating problem with independent variables $x_1, \cdots, x_m$, the arbitrating solution is undoubtedly the bargaining solution for the conflicting problem. However, it is rather common in the real problem that there exist contradictories among multi-objectives and it is difficult to attain alternative to exactly reflect the above state of objective value. Therefore, X^* is only the ***ideal state*** and it is not possible to exist in real case. Hence, in this paper, it is called the ideal bargaining solution.

4 Choosing the decision alternative using the fuzzy pattern recognition

For the $2n$ decision alternatives consisting of the alternative sets A_n and B_n, and the ideal bargaining solution X^*, TMCD becomes how to select among them a satisfying alternative closest to the ideal bargaining solution X^*. It is a typical pattern recognition problem. To solve the pattern recognition problem, a new fuzzy pattern recognition model is proposed.

Let Y denote the matrix of the recommended alternatives that is composed of matrixes A_n and B_n, and satisfy

$$\begin{cases} y_{kj} = a_{kj},\ for \qquad k \le n \\ y_{kj} = b_{k-n,j},\ for \qquad k > n \end{cases} \tag{7}$$

where k=1,…,$2n$, j=1,…,m. From equation (7), $Y = (y_{kj})_{2n \times m}$ is a $2n \times m$ matrix. All alternatives can be represented by $Y = (Y_1, Y_2, ..., Y_{2n})^T$, where Y_k is the *kth* alternative and $Y_k = (y_{k1}, \cdots, y_{km})^T$.

The vector of objective value Y_k should be converted into the membership degree vector $R_k = (r_{k1}, \cdots, r_{km})^T$ by equations (8) and (9), and

$$r_{kj} = y_{kj} / x_j^*,\ \text{for}\ y_{kj} \le x_j^* \tag{8}$$

$$r_{kj} = x_j^* / y_{kj},\ \text{for}\ y_{kj} > x_j^* \tag{9}$$

Note here that in equations (8) and (9), if the *jth* index is the same between Y_k and X^*, $y_{kj} = 1$ and it represents that there is no difference in the *jth* index between two alternatives. If the *jth* index of Y_k is less than that of X^*, it represents that there is **negative** similarity in the *jth* index between two alternatives. If the *jth* index of Y_k is greater than that of X^*, it represents that there is **positive** similarity in the *jth* index between two alternatives. From the definition of equations (8) and (9), we can obtain the membership degree vector R^* of X^*, $R^* = (1, \cdots, 1)^T$, which describes m objective membership degree of the ideal alternative X^*. According to the definition of complementary set in fuzzy sets, the membership degree of non-ideal alternative X^{*c} should be $R^{*c} = (0, \cdots, 0)^T$.

In order to acquire the cluster structure of the alternative sets, it is natural to select an alternative closest to X^* and farthest away from X^{*c}. Similar to the fuzzy distance [14], the weighted distances are defined as

$$D(R_k, X^*) = \sqrt{\sum_{j=1}^{m}[w_j(r_{kj} - x_j^*)]^2} = \sqrt{\sum_{j=1}^{m}[w_j(r_{kj} - 1)]^2} \qquad (10)$$

$$d(R_k, X^{*c}) = \sqrt{\sum_{j=1}^{m}[w_j(r_{kj} - x_j^{*c})]^2} = \sqrt{\sum_{j=1}^{m}(w_j r_{kj})^2} \qquad (11)$$

In equations (10) and (11), w is the weighting vector, $w = (w_1, w_2, \ldots, w_m)^T$ with $\sum_{j=1}^{m} w_j = 1$, $w_j > 0, j = 1, 2, \ldots, m$. If the membership degree of alternative Y_k relative to X^* is denoted by u_k, then its counterpart relative to X^{*c} is 1-u_k. The synthetically weighted distance is defined by

$$F(u_k) = [u_k D(R_k, X^*)]^2 + [(1-u_k)d(R_k, X^{*c})]^2$$
$$= u_k^2 \sum_{j=1}^{m}[w_j(r_{kj} - 1)]^2 + (1-u_k)^2 \sum_{j=1}^{m}(w_j r_{kj})^2 \qquad (12)$$

Take $dF(u_k)/du_k = 0$, the membership degree of the *kth* alternative belonging to X^* is obtained as follows:

$$u_k = \frac{1}{1 + \left[\dfrac{\sum_{j=1}^{m}[w_j(r_{kj} - 1)]^2}{\sum_{j=1}^{m}(w_j r_{kj})^2}\right]} \qquad (13)$$

According to the maximum principle of membership degree, we can choose the decision alternative and obtain the final bargaining solution among *2n* alternatives. An overall procedure of TMCD is shown in Figure 1.

Insert Figure 1 Here

5 Case study of reservoir flood control

Reservoir flood operation is a typical problem of the muiti-person multi-objective decision. Operation decision is given by synthesizing opinions of different departments. The higher hierarchy has the final decision right in different scopes and limits of authority. The flood control of Fengman Reservoir is considered as an example. Fengman Reservoir is located at the second Songhua River, one of the seven major rivers within China. It is *24 km* away from Jiling City, one of the key protection areas. The reservoir has a watershed area of *42,500* square kilometers, with a water holding capacity of up to *10,800* million cubic meters. The reservoir is mainly used for hydropower generation, flood control, as well as irrigation purposes. Because Fengman reservoir is a huge reservoir, there exists a significant degree of conflict between flood control and hydropower generation. A special administration Bureau, Beishan and Fengman Reservoirs Management Department (party C) is established to deal with the daily conflicts between the Electrical Administrative Bureau of Northeastern (party A) and Committee of Songliao Basin (party B). Most decisions are made through the bargaining among these three parties.

Three objectives related to Fengman Reservoir flood control are chosen for the alternatives evaluation. Objective 1 is maximizing the flood control volume between the design level (263.5m) and the highest level of reservoir during reservoir routing. In general, the greater is the objective value, the safer is the dam and but it is harmful to hydropower generation during flooding events. So, party B will choose the strategy of controlling the lower maximum water lever as far as possible, which is contrary to party A. Objective 2 is minimizing the storage volume between the terminal level of reservoir and the desired terminal level (262.5m). It implies that the desired performance level is known and that the deviation from the target level results in losses or damage on the next flood operation. However, the higher terminal level is beneficial to hydropower generation. Objective 3 is minimizing the spilling volume overflow discharge for power generation. It is obvious that there is no conflict in this objective. Party B will choose the safe outflow as far as possible. The outflow is often far away from the maximum hydropower generation desired by Party A. In order to reach an agreement, party B will choose those alternatives with lesser values for objective 3. From the above-mentioned description, party A desires that three objectives are all smaller; while party B wishes that the two proceeding objectives are larger and the last one is smaller.

For an actual flood in 1991, A and B can utilize the fuzzy optimal model for the flood control system developed by Cheng and Chau [13] to obtain a group of alternatives respectively. These alternatives and their weights of objective are then provided to C. The followings are the objective characteristics value matrixes of five alternatives from A and B respectively:

$$A_5 = \begin{bmatrix} 10.01 & 8.75 & 21.60 \\ 10.53 & 8.23 & 22.12 \\ 11.57 & 6.15 & 24.19 \\ 12.61 & 4.42 & 25.92 \\ 12.00 & 6.06 & 24.28 \end{bmatrix}, \quad B_5 = \begin{bmatrix} 12.78 & 7.52 & 22.81 \\ 12.52 & 7.78 & 22.55 \\ 12.09 & 8.22 & 22.12 \\ 11.40 & 8.91 & 21.43 \\ 14.17 & 3.21 & 27.13 \end{bmatrix}$$

and corresponding weight vectors are $\alpha = (0.30, 0.40, 0.30)^T$, $\beta = (0.50, 0.40, 0.10)^T$. According to equations (3)~(6), the satisfying functions of A and B are

$$SF_A(X) = 4.064 - 0.1154x_1 - 0.0924x_2 - 0.0694x_3$$

and

$$SF_B(X) = 0.1805x_1 + 0.0702x_2 - 0.0175x_3 - 1.7993$$

From equation (1), the first stage programming can be described as

$$\max\ 0.1805x_1 + 0.0702x_2 - 0.0175x_3 - 1.7993$$

$$\text{s.t.} \begin{cases} 0.2959x_1 + 0.1626x_2 + 0.0519x_3 = 5.8626 \\ x_1 \geq 10.01, x_1 \leq 14.17 \\ x_2 \geq 3.21, x_2 \leq 8.91 \\ x_3 \geq 21.43, x_3 \leq 27.13 \end{cases} \tag{14}$$

After solving the LP of equation (14), $X_0 = (14.1700, 3.4285, 21.4300)^T$. Correspondingly, the second stage programming can be represented by

$$\max 0.0651x_1 - 0.0222x_2 - 0.0869x_3 + 2.2640$$

$$\text{s.t.} \begin{cases} 0.1805x_1 + 0.0702x_2 - 0.0175x_3 \geq 2.4233 \\ 0.1154x_1 + 0.0924x_2 + 0.0694x_3 \leq 3.4393 \\ x_1 \geq 10.01, x_1 \leq 14.17 \\ x_2 \geq 3.21, x_2 \leq 8.91 \\ x_3 \geq 21.43, x_3 \leq 27.13 \end{cases} \tag{15}$$

After solving the LP of equations (15), $X^* = (14.1700, 3.4219, 21.4300)^T$. If the objective weight of C is (0.45,0.30,0.25), then with equations (7)~(13), the membership degree of each alternative belonging to X^* are

(0.7766,0.8086,0.8935,0.9667,0.9079,0.8922,0.8819,0.8636,0.8319,0.9903)

According to the maximum principle of membership degree, C is confident to choose the fifth alternative recommended by B as the decision alternative. In fact, the selected decision alternative is reasonable because the lower maximum water level with is safer for dam. The smaller deviation from the target level in terminal level is beneficial to hydropower generation and satisfies the flood control also. Relatively, the loss of hydropower generation is higher for this flood control operation, but the objective 2 is more beneficial than objective 3 in hydropower generation because the higher level can generate more energy.

6 Conclusions

Most bargaining theories are too complex and theoretical to be understood by decision makers, there exists a gap between the theory and application. The paper is devoted to develop a feasible and simple model of the three-person multi-objective conflict decision based on reservoir flood control. However, the model is a general methodology for the problem of the multi-person multi-objective conflict decision involving three players and hence can be applied to other fields as well.

Acknowledgments

This research was supported by "The Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutions of Ministry of Education, P.R.C" (No.200026), "Fok Ying Tung Education Foundation, P.R.C"(No.71072), the National Natural Science Foundation of China (No. 60073037), and the Research Grants Council of Hong Kong (PolyU5084/97E).

References

[1] Ozren Despic, Slobodan P.Simonovic. Aggregation operators for soft decision making in water resources. *Fuzzy Sets and Systems* 115(2000) 11-33

[2] Cheng Chuntian**.** Fuzzy optimal model for the flood control system of upper and middle reaches of the Yangtze River. *Hydrological Sciences Journal* 44(1999) 573~582

[3] Michael J.Bender, Slobodan P.Simonovic. A fuzzy compromise approach to water resources systems planning under uncertainty. *Fuzzy Sets and Systems* 115(2000) 35-44

[4] Komaragiri Srinivasa Raju, C.R.S. Pillai. Multicriterion decision making in river basin planning and development. *European Journal of Operational Research* 112(1999) 249-257

[5] Seok-Ku Ko, Darrell G. Fontane and Jure Margeta. Multiple reservoir system operational planning using multi-criterion decision analysis. European *Journal of Operational Research* 76(1994) 428-439

[6] Abhinay Muthoo. Bargaining theory with application. Cambridge University Press, 1999

[7] Y.Leung. Compromise programming under fuzziness. *Control and Cybernetics* 13 (1984) 203-214

[8].M.Sakawa, H.Yano and T.Yumine. An interactive fuzzy satisfying method for multiobjective linear programming problems and its applications, *IEEE Trans.Systems Man Cybernet* 17(1987) 654-661.

[9] M.Sakawa, H.Yano. An interactive fuzzy satisfying method for generalized

multiobjective linear programming problems with fuzzy parameters. *Fuzzy Sets and Systems* 35(1990) 125-142
[10].E.Stanley Lee and R.J.Li. Fuzzy multiple objective programming and compromise programming with pareto optimum, *Fuzzy Sets and Systems* 53(1993) 275-288.
[11] Nash J. The bargaining problem. *Econometrica* 18(1950) 155~162
[12] Nash J. Two-person cooperative games. *Econometrica* 21(1953) 128~140
[13] Cheng Chuntian, K.W.Chau(2001). “Fuzzy iteration methodology for reservoir flood control operation”, *Journal of American Water Resources Association* (to appear)
[14] D.Dumitrescu, A.Dumitrescu. A unified approach to fuzzy pattern recognition. European *Journal of Operational Research* 96(1997) 471-478

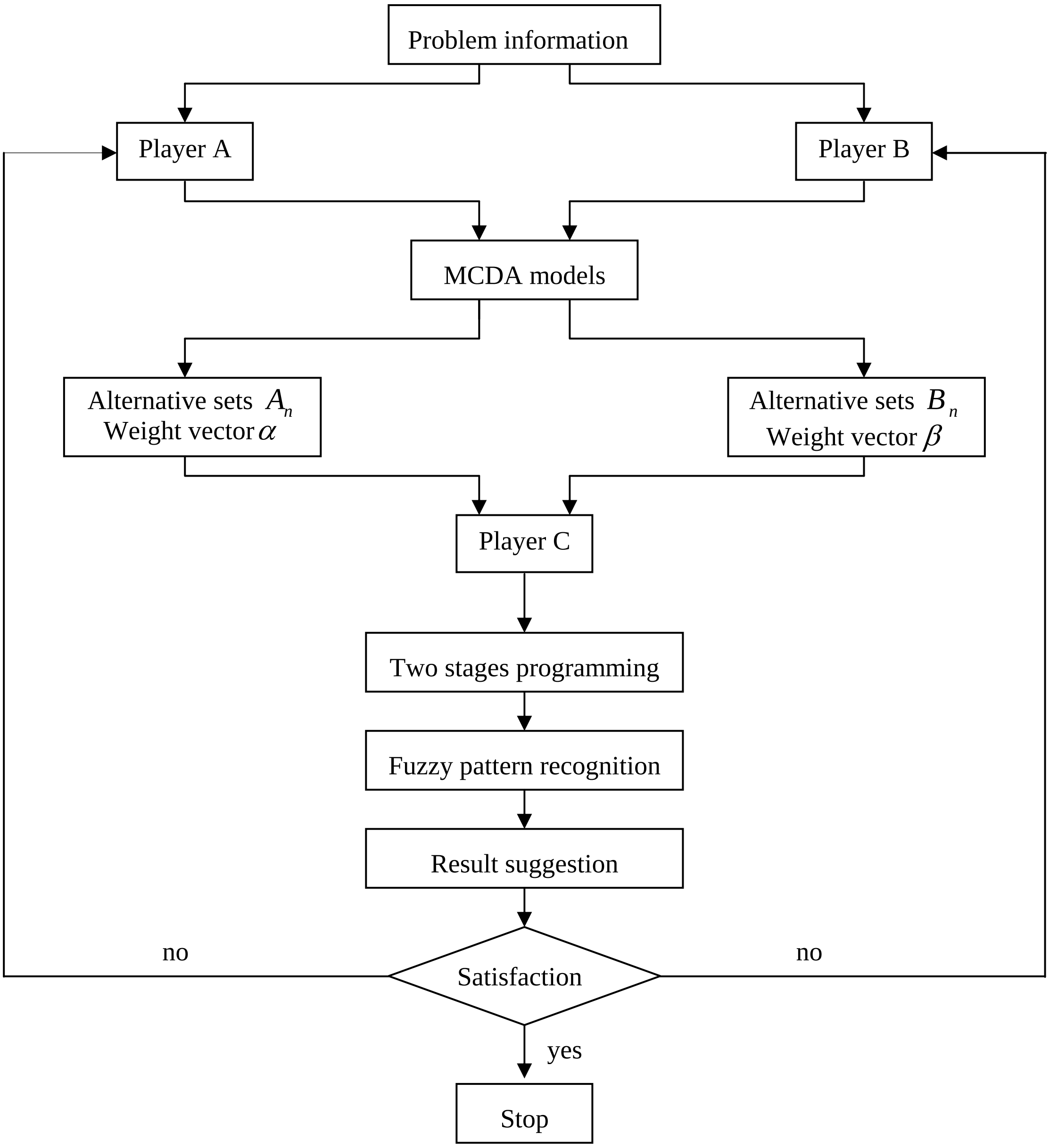

Figure 1 The overall procedure of TMCD