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A multi-criteria decision making approach for priority areas selection in membrane industry for investment promotion: a case study in Iran Marketplace

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Abstract

Membrane technologies for the separation of mixtures have gained an extensive worldwide attraction in the modern industrialized world. They have many industrial and medical applications such as water desalination, wastewater reclamation, gas separation, food and medical applications. However, even though all these applications have their own efficiency and market, the selection of priority applications is very challenging for most developing countries. On the other hand, selecting the optimal priority applications among many alternatives is a multi-criteria decision-making (MCDM) problem. This paper develops an evaluation model based on the AHP and TOPSIS methods for evaluating and ranking membrane applications effectively. The AHP is used to analyze the structure of the selection problem and to determine the weights of the evaluating criteria. It is also used for evaluating the decision-making team members to determine the relative importance of each one of them. A modified technique is proposed to improve the consistency of judgment matrices; then Individual judgments are aggregated by using the weighted geometric mean to obtain the weights of criteria. The modified technique increases the accuracy of decision-making process and saves time to obtain consistent judgment matrices. Finally, the TOPSIS method is employed to calculate the final ranking of the membrane applications. For evaluating the performance and reliability of the proposed model, it is applied in a real case in IRAN.

Keywords: Membrane applications, Multi-criteria decision-making (MCDM), AHP, TOPSIS, Iran Marketplace.

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1.Introduction

In the recent two decades, there was a growing interest about the use of membranes in chemical technology. Membranes act as a selective barrier; regulate the transport of substances between the two compartments (Adhikari and Fernando, 2006). Generally, transport selectivity, lower levels of energy consuming, lower costs and lower fouling are some advantages of membranes with respect to other alternative separation techniques. Also, their integration into other separation or reaction processes as well as downscaling and up scaling of membrane processes are easy (Gupta and Ali, 2013).

Although membrane technologies have now been industrially recognized in remarkably large scale and the markets are rather diverse (McKeen, 2012),therefore, there is a great need for most developing countries with low levels of technical experience to select one of the most important applications of membranes in order to invest on it. Hence, these communities need to turn to one of the mostly useful applications of membrane technology.

Because of the advantages and disadvantages associated with each membrane application, the selection of the optimum application forany specific area is a complicated task due to the diversity of objectivesand constraints that should be considered and satisfied simultaneously.With these types of problems, decision makers cannot go through thestandard single criteria mathematical programming techniques to findthe best option. In such situations where the decision maker confrontsmany criteria and constraints, multi-criteria decision making (MCDM)methods can offer a proper solution, as they provide techniques for comparingand rankingmany criteria and choices. Another major advantageof most MCDM techniques is their ability to analyze both quantitative and qualitative criteria together. Many techniques and methodologies are reported in the literature for MCDM (Vincke, 1992). Among most popular ones are the analytic hierarchy process (AHP), the technique for orderpreference by similarity to an ideal solution (TOPSIS), Data Envelopment Analysis (DEA), eliminationand choice corresponding to reality (ELECTRE), andanalytic network process (ANP).

The main objective of this study is to propose a systematic evaluationmodel for the selectionof an optimal membrane application among a set of available alternatives. Membrane application selection problem is a MCDM problem where manycriteria should be considered in decision-making. Therefore, this study utilizes a MCDM method (AHP) todetermine the importance weights of criteria and experts, and a TOPSIS method to obtain the final ranking of the feasible alternatives. Moreover, a modified technique was proposed to improve the inconsistency of judgment matrices.This approach is employed for four reasons: (a) TOPSIS logic isrational and understandable; (b) the computation processes arestraightforward; (c) the concept permits the pursuit of best alternativesfor each criterion depicted in a simple mathematical form,and (d) the weights are incorporated into the comparison procedures (Wang and Chang, 2007).

The main contributions of this paper are:

- Analyzing the Membrane technologies selection problem as a MCDM problem for first time, using AHP/TOPSIS. As mentioned before, to the best of author’s knowledge, there is not any reference that deals with membrane technologies selection problem with MCDM techniques.

- Proposing a modified technique to improve the consistency of judgment matrices. By using this technique, any judgment matrix with a large C.R. can be modified to a matrix with acceptable consistency (C.R. < 0.1). It should be noted that, the technique may change the values of the elements of pairwise matrices. Thus, after applying the modified technique, we should ask the decision maker (DM) to approve the new modified matrix. If DM does not approve the new matrix, then he should revise her/his opinion about the values of the elements of pairwise comparison matrix. This matter is explained in more detail in section 4.

Theperformance and reliability of the proposed modelis evaluated in a realworld case study concerning the selectionof themost suitable membrane technology in IRAN. A number of experts from different decision-making groups are used to perform the multipleattribute assessment of membrane applications in IRAN. Because the group members are not equally important, so we evaluate the experts of each group. Hence, we employ AHP to determine the relative importance of each one of them. The matter isexplained in section 4 and 5.

The reminder of the paper is organized as follows:In section 2, the membrane technology and its applications are briefly introduced. Section 3, briefly describes the AHP, improvement inconsistency technique and TOPSIS methods. In section 4, the proposed model is presented and the stages of the proposed approach are explained in detail. In section 5, a case study related to Iran marketplace is presented to demonstrate the potential and applicability of the method. Section 6 concludes the paper and suggests for future works.

2.Membrane systems

Around 25 years ago, there were only few commercialized applications for membrane technology. Except of a few laboratory and small specialized industrial applications, most applications such as seawater desalination and reuse applications of membrane technology were not economically suitable at about the same time. Some other applications such as juice and dairy products in the food industry had high operating risks, making investors as well as practitioners, apprehensive about the use of membranes. By removing the technical and economic hurdles to widespread use of membranes during the recent two decades, membrane based applications are now commonplace in the world. Today, we are faced with different applications of membrane systems which are extensively used in the commercial, industrial and municipal markets. Although membranes have a large number of applications, from medicine to the chemical industry, the most commonplace applications can be classified into six major membrane applications, namely: water desalination, wastewater reclamation, ultrapure water, food processing application, gas separation, and medical application. These six applications are discussed briefly for introductory purposes in this section. It should be noted that some other applications of membranes are in the automobile plants for use in electro coat paint (Baker, 2004), fuel cells (Behling,2013), batteries in the biotechnology (Reis and Zydney, 2007), oil-water emulsions for metal machining operations (Baker, 2004), and some related ones (Robeson, 2012).

In water industry, membranes can generally be used to purify water, produce drinking water, and finally to remove industrial effluents from wastewater (Fane et al., 2011). Traditional water treatment methods include physical separation techniques for particle removal; biological and chemical treatments to remove suspended solids, organic matter and dissolved pollutants or toxins; and evaporative techniques and other physical and mechanical methods. Membrane separation replaces or supplements these techniques by the use of selective membranes, with pores sized to permit the passage of water molecules, but small enough to retain a wide range of particulate and dissolved compounds, depending on their nature.Membrane filters are able to enhance safety as well as quality of water by virtually removing all viruses, bacteria, and other microorganisms and contaminants (Madaeni, 1999) and have some advantages over other filtration techniques. Other methods such as heat and chemical approaches are also available for this purpose, but these methods just kill microorganisms and are not capable of eliminating them. We should also note that microorganisms can cause damage to human health whether alive or dead (Fifield and Leahy, 1983). Therefore, membranes have much priority to be used for water disinfection.

The use of membranes technology in water industry, beginning from the end of World War II, has gained a growing worldwide attraction (Baker, 2004).Increasing population numbers, a changing climate, intensive agricultural practices, economic growth and urbanizationhave a great impact on available water resources. Dry climate countries and especially, areas with insufficient water supply should be more conservative with their water usage. The reuse of treated municipal and industrial effluents provides an alternative to building new water supply dams as well as encouraging reduced or zero discharge to sensitive environments (Arnal et al., 2008). Desalination of brackish groundwater and seawater, and producing good-quality water from sewage are some alternative ways for supplying water using membranes (Baker, 2004). Another important capability of membranes is the purification of water to make ultrapure water for the electronics, medical, and power generation industries (Faneet al., 2011).

Membrane systems for gas separation processes, and demands for the separation of gas mixtures have grown extensively alongside with the development of membranes for water industry in the recent 30 years. Separation of hydrogen from nitrogen, nitrogen from air, carbon dioxide from natural gas and dehydration of alcohol are principal industrial applications of membrane gas separation systems(SpillmanR., 1995). Note that the development of such processes is of high importance for the environment. For example, hydrogen can be used as an alternative source of energy which has some environmental advantages over other sources of energy such as fossil fuels in energy security, pollution, and global climate change (Adhikari and Fernando, 2006).

Another important application of membrane technology is the development of medical separation processes for medical devices such as artificial kidneys, blood oxygenations (artificial lungs), and controlled drug delivery systems (Stamatialiset al., 2008). Membranes also play a significant role in the food industry(Lipnizki, 2010). These applications are in the dairy industry(milk protein standardization,whey protein concentration, removal of bacteria and spores from milk, whey and cheese brine, and etc.), and the production and sterilization of beverages(fruit juices, etc.).

3.Methods of Use

3.1. The AHP method

The Analytical Hierarchy Process (AHP) was introduced first by Saaty (1980) in the early 1970s in response to the scarce resources allocation and planning needs for the military. In this paper, AHP is used to derive the relative importance of criteria and attributes as well as the experts, using the pairwise comparison matrix. The definitions used in the judgment matrix for the preferences, namely the values (1, …, 9), are based on the concepts proposed by Saaty (1990). Estimating the weight priorities for the factors consists of three steps. First, a pairwise comparison matrix is constructed. Then the relative importance of the attributes is determined. Finally, a consistency inspection is carried out to ensure the reliability of the pairwise comparison.

The distribution of the weights should be reasonable when constructing the judgment matrix. Thus, the consistency index (CI), proposed by Saaty (1980), and was used as described in Equation 1.

$$CI = \frac{\lambda_{\max} - n}{n-1}, \tag{1}$$

where$\lambda_{\max}$ is the maximum Eigenvalue of the pairwise comparison matrix, calculated in Equation (2).

$$Aw = \lambda w \tag{2}$$

where$w$ is the principal Eigenvector of the matrix. Finally, the consistency ratio (CR) is calculated as follows:

$$CR = \frac{CI}{RI}, \tag{3}$$

Values for the random index (RI), namely the average consistency rate, are listed in Table 1. When the value for the CR is less than 0.1, the judgment matrix is named consistent and considered to be satisfactory.

Table 1.The random consistency index (RI) for n ≤ 10

Matrix order (n)	3	4	5	6	7	8	9	10
Random Index (RI)	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In the literature, AHP, has been widely used in solving many complicated decision-making problems (Chan and Kumar, 2007; DagdevirenandYüksel, 2008; Kulak andKahraman, 2005;Dagdeviren et al., 2009;Amiri, 2010;KilincciandOnal, 2011).

3.2. Improving consistency in the AHP

In the literature of decision-making, there exist a number of methods to improve the consistency of decision matrices (Harker, 1987; Genets and Zhung, 1996; Saaty, 2003; Dahl, 2005). This is possible only by modifying the components of a reciprocal pairwise comparison matrix in such a way that it approaches a consistent matrix. In this paper a new approach is used to improve the consistency of the judgment matrices by constructing a sequence of modified matrices (Rahmani and Navidi, 2009). This method increases the accuracy of decision-making process and saves much time and consequently, budget for the project in comparison with other modifying techniques. Note that this method relies on the generalized Purcell method for solving a system of homogenous linear equations.

In order to describe the algorithm to improve the consistency of the judgment matrix, firstlet s_k be the sum of the components of the column *k* of the reciprocal matrix A. We use $\sum s_i^{-1}$ and a new matrix (denoted by $\tilde{A}$) obtained from multiplying each column *k* of A by the s_k^{-1} to verify the consistency of A as the following theorem.

Theorem 1. Let A be a reciprocal matrix with s_j the sum of column *j*. Then

1. $\sum s_j \leq 1$.
2. The reciprocal matrix A is consistent if only if $\sum s_j = 1$.
3. The consistent reciprocal matrix has $\lambda_{\max} = n$ and its rank is one.

Let us assume that the judgment matrix A is obtained as a small perturbation of an underlying consistent matrix constructed from a ratio scale $w = (w_1, \cdots, w_n)$. A near consistent matrix is a small reciprocal multiplicative perturbation of a consistent matrix. It is given that $A = (\frac{w_i}{w_j} \varepsilon_{ij})$ where $\varepsilon_{ji} = \varepsilon_{ij}^{-1}$, and all elements of (ε_{ij}) are close to 1 (Saaty, 2003). To obtain a consistent matrix, we identify the most inconsistent entries of the near consistent matrix A and sequentially correct them, in such a way that its eigenvalue approaches *n*.Hence, a sequence of near consistent matrices $A^{(0)}, A^{(1)}, A^{(2)}, \cdots$ is constructed, such that

$$\lambda_{\max}(A^{(0)}) \geq \lambda_{\max}(A^{(1)}) \geq \lambda_{\max}(A^{(2)}), \cdots \tag{4}$$

and

$$\lim_{i \to \infty} \lambda_{\max}(A^{(i)}) = n.$$

Theorem 2: Let $\{A^{(i)}\}$ be a convergent sequence of near consistent matrices such that $\overline{A} = \lim_{i \to \infty} A^{(i)}$ and $\lambda_{\max}(\overline{A}) = n$. Thus $\overline{A}$ is a consistent matrix.

In practice, we try to find a nonzero solution of near homogenous equations $(A^{(i)} - nI)x \approx 0$ by the row pivoting method. If $x^{(i)}$ be such a solution, then set $\beta_i = \|(A^{(i)} - nI)x^{(i)}\|_2$. Now, by modifying the entries of $A^{(i)}$ under positive reciprocal condition, we expect that the sequence β_i satisfies $\beta_0 \geq \beta_1 \geq \beta_2 \geq \cdots$ and $\lim_{i \to \infty} \beta_i = 0$.

Corollary 1. If the sequence $A^{(i)}$ is near consistent matrices and $\lim_{i \to \infty} \beta_i = 0$ then $\overline{A}$ is consistent matrix and $w = \lim_{i \to \infty} x^{(i)}$ is its principal eigenvector.

In order to obtain a consistent matrix, an experimental approach based on minimizing the maximum error is given to improve the elements of near consistent matrix $A^{(i)}$.Let w and v be the solution of near homogenous equations $(A^{(i)} - nI)x \approx 0$ and $(A^{(i)} - nI)^T x \approx 0$, respectively. Then, we can set $a_{ij} \approx \frac{w_i}{w_j}\varepsilon_{ij}$ and $a_{ij} \approx \frac{v_j}{v_i}\varepsilon_{ij}$ or

$$(\varepsilon_{ij}) \approx \tfrac{1}{2}(a_{ij}\frac{w_j}{w_i} + a_{ij}\frac{v_i}{v_j}) = \tfrac{1}{2}a_{ij}(\frac{w_j}{w_i} + \frac{v_i}{v_j}) \tag{5}$$

Let $B = 2\varepsilon$, then

$$B = A^{(i)} \circ (vv^{-T} + w^{-1}w^T) \tag{6}$$

in which $\circ$ implies the Hadamard product. Now we select $kl = \arg\max_{ij} b_{ij}$. If $A^{(i)}$ be consistent then $b_{kl} = 2$, else inconsistency of a_{kl} is greater than other elements of $A^{(i)}$. To improve a_{kl}, we replace a_{kl} in $A^{(i+1)}$ by geometric means of $\frac{w_k}{w_l}$ and $\frac{v_l}{v_k}$ i.e. $\sqrt{(w_k v_l)/(w_l v_k)}$, and continue the process. This algorithm is presented in Table 2.

Table 2. The algorithm for improving the elements of near consistent matrix

Step 1. *Compute vectors* $w \neq 0$ *and* $v \neq 0$ *such that* $(A^{(i)} - nI)w \approx 0$ *and* $(A^{(i)} - nI)^T v \approx 0$.
Step 2. *Set* $kl = \arg\max_{ij} a_{ij}(\frac{v_i}{v_j} + \frac{w_j}{w_i})$.
Step 3. *Set* $a_{kl} = \min(\max(\sqrt{(w_k v_l)/(w_l v_k)}, 1/M), M)$ *and* $a_{lk} = 1/a_{kl}$ *in matrix* $A^{(i+1)}$, *where* $1 \leq M \leq 9$ *is a problem-specific bound.*
Step 4. *If* $\lim_{i\to\infty}\beta_i \approx 0$, *set* $\overline{A} = A^{(i+1)}$ *and stop, else set* $i = i+1$ *and go to step 1, where* $$\beta_i = \min \left\|(A^{(i)} - nI)w\right\|_2 .$$

3.3. The TOPSIS method

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is based upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative solution (Chen and Hwang, 1992; Hwang and Yoon, 1981; Jahanshahloo et al., 2006). The positive-ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang &Elhag, 2006). There have been lots of studies in the literature using TOPSIS for the solution of MCDM problems. (Chen, 2000; Chu, 2002; Chu andLin, 2002; Wang et al., 2005; Chamodrakas et al., 2009).

The TOPSIS method consists of the following steps (Shyurand Shih, 2006):

Step 1. Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_J \end{array} \begin{array}{c} \begin{array}{cccccc} F_1 & F_2 & \cdots & F_j & \cdots & F_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{J1} & f_{J2} & \cdots & f_{Jj} & \cdots & f_{Jn} \end{bmatrix} \end{array} \tag{7}$$

Where A_j denotes the alternatives j, j= 1,2,.. .,J; F_i represents ith attribute or criterion, i=1, 2,..., n, related to ith alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j.

Step 2. Calculate the normalized decision matrix R(=[r_{ij}]). The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^{\,2}}}; \quad i = 1,2,...,n; \quad j = 1,2,...,J \tag{8}$$

Step 3.Calculate the weighted normalized decision matrix bymultiplying the normalized decision matrix by its associatedweights. The weighted normalized value $v_{ij}$is calculatedas:

$$V_{ij} = w_i \times r_{ij}, \quad j = 1,2,...,J; \quad i = 1,2,...,n. \tag{9}$$

wherew_i represents the weight of the ith attribute orcriterion.

Step 4. Determine the positive-ideal and negative-idealsolutions.

$$A^* = \{v_1^*, v_2^*, ..., v_i^*\}; \quad A^- = \{v_1^-, v_2^-, ..., v_i^-\} \tag{10}$$

Step 5. Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternativefrom the positive-ideal solution is given as:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^*)^2} \qquad j = 1,2,...,J \tag{11}$$

Similarly, the separation of each alternative from the negative-ideal solution is as follows:

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \qquad j = 1,2,...,J \tag{12}$$

Step 6. Calculate the relative closeness to the idea solution andrank the performance order. The relative closeness ofthe alternative A_j can be expressed as:

$$CC_j^* = \frac{D_j^-}{D_j^* + D_j^-} \qquad j = 1,2,...,J. \tag{13}$$

Where the CC_j^* index value lies between 0 and 1. The largerthe index value means the better the performance of thealternatives.

4. Methodology

The proposed model for priority areas selection in membrane industry, composed of the AHP, the modified technique and TOPSIS methods, consists of four basic stages: (1) identification of the criteria, sub-criteria and alternatives to be used in developing the decision hierarchy structure, (2) establishment of pairwise comparison matricesusing AHP method for all criteria and experts, (3) improving inconsistency in comparison matrices and calculating the weights of experts and criteria by using AHP, (4) evaluation of the alternatives and determination of the final ranking by TOPSIS. These stages are explained in more detail in bellow.

Stage 1. Developing the decision hierarchy structure

In the first stage of proposed method, alternative membrane applications, criteria and sub-criteria which will be used in their evaluationare selected and the decision hierarchy is formed. AHP modelis structured such that the objective is in the first level, criteriaare in the second level, sub-criteria are in the third level and alternative membrane applications are on the fourth level.In the last step of the first stage, the decision hierarchy (criteria, sub-criteria and alternatives)should be approved by the decision-making team.

A number of experts from different decision-making groups (industry, academic experts and governmental institutes) are used to perform the multiple attribute assessment of membrane applications.

Stage 2. Establishment of pairwise comparison matrices

After the approval of decision hierarchy, pairwise comparison matricesfor all criteria, sub-criteria (used in membrane applications selection) and experts are formed. Experts make individual evaluations to determine the values of the elements of pairwise comparison matrices. In this case it is supposed that the weights of these three groups are equal, but the members of each group are not equally important. So, we asked another expert in each group to evaluate the experts of groups. Obviously, experts with high weight have more impact oncriteria weights and on ranking the alternatives.It should be noted that, the weights of all experts can be supposed equal in other application or in other decision team.

Stage 3. Improving inconsistency and calculating the weights of experts and criteria

Afterdetermining the pairwise comparison matrices for all criteria and experts,the explainedapproach in section 3.2 will be employed to improve theinconsistent judgment matrices to the consistent matrices.The consistency, however hardly ever achievable,has been widely considered as a desirableproperty of preferences in decision making problems.Being consistent in expressing preferences means being rational in discriminating among alternatives. Although one might claim that consistency does not necessarily indicate expertise of the decision maker (consistent preferences can possibly be achieved randomly), it is undebatable that a good expert must always be able to state his preferences in a non-contradictory way. Therefore, although consistency alone does not guarantee the expertise of a decision maker, the presence of inconsistencies should be symptomatic of the decision maker's scarce preparation or lack of knowledge of the problem (for more study seeBrunelli&Fedrizzi, 2015). By using the modifying technique, any judgment matrix with a large C.R. can be modified to a matrix with acceptable consistency (C.R. < 0.1).This technique increases the accuracy of decision-making process and saves time to obtain consistentjudgmentmatrices.

Obviously, the modifying technique may change the values of the elements of pairwise matrices that leads to changing the ranking order. Thus, after applying the modifying technique the decision maker (DM) should be asked to approve the new modified matrix. If DM does not approve the modified matrix, then he should revise his/her opinion about the values of the elements of pairwise matrix. This matter has been shown in schematic diagram of the proposed model (figure 1).

At the end ofthisstage, the weights of experts are calculatedbased on the final consistent comparison matrix. After calculating the experts' weights, Individual consistent judgments aggregated by using the weighted geometric mean to obtain the weights of the criteria. In the end, calculated weights of the criteria are approved by decision making team.

Stage 4. Determination of the final ranking

After establishing a decision matrix for ranking the alternatives according to the first step in section 3.3, the extracted weights from previousstage are used to calculate the weighted normalized decision matrix in TOPSIS method (according to the explained steps in section 3.3). It should be noted that the decision matrix in this step are calculated from individual decision matrixby using the weighted geometric mean (by usingthe calculatedweight for experts in stage 3).

After calculating the weighted normalized decision matrix, membrane applications ranks are determined by using TOPSIS method in this stage. The application having the high rank is determined asthe most appropriatemembrane application according to the calculations by TOPSIS.Ranking of the other membrane applications is determined according to the output of the TOPSIS method.

The schematic diagram of the proposed model for membrane application selection is provided in figure 1.

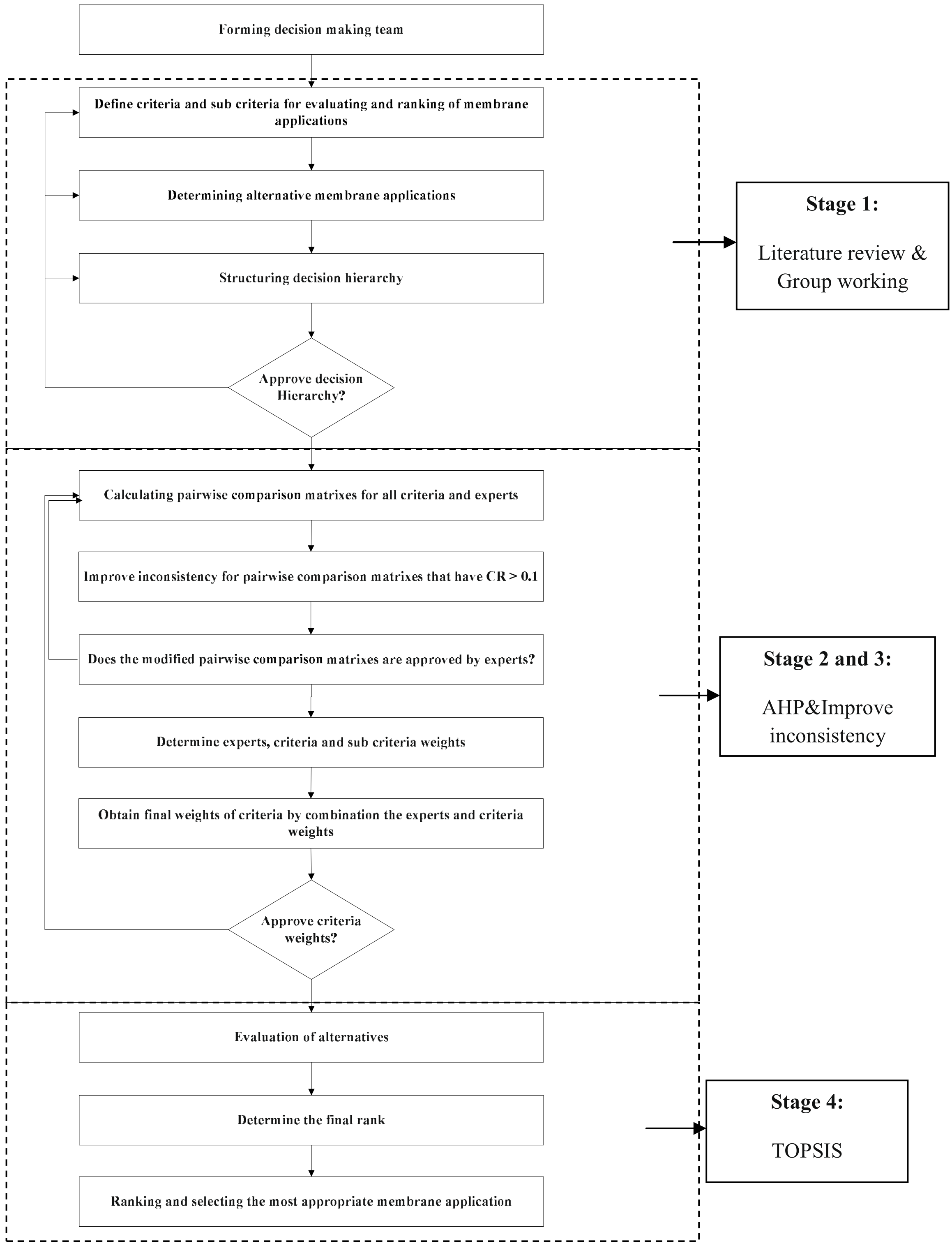

Figure 1. Schematic diagram of the proposed model for membrane applicationselection

5.Application of the proposed model

The proposed model isapplied to a real problem in membrane Industry. The aim of our specific study is to determine the most appropriate membrane application in IRAN for investment promotion and to illustrate the utilization of the proposed model for the membrane application selection problem. A number of experts from different decision-making groups (industry, academic experts and governmental institutes)are employed to perform the multiple attribute assessment of membrane applications in IRAN.

5.1.Evaluating criteria and decision hierarchy

According to Miller (1956), most decision makers are not able to analyze more than seven to nine factors simultaneously when making a decision. Thus, it is necessary to break down the complex problem into more manageable sub problems (Chan and Kumar, 2007). The criteria and sub-criteria for membrane applications selection were determined by the expert team members based on their backgrounds and experiences. The final outcome of their decision included four criteria and fifteen sub-criteria. Criteria and sub-criteria with their definitions of importance are given in Table 3. It is tried to choose the independent criteria by helping evaluating group. In the next step, availablemembrane applications were researched by the team members and six major applications were chosen to be included in this study. Decision hierarchystructured with the determined alternative membrane applications, criteria and sub-criteria is provided in Figure2.The decision hierarchy included four levels: The main objective which is placed in the first level of the hierarchy is the selection of the most appropriate membrane application. The main criteria, sub-criteria and membrane applications will be placed in the later levels.

Table 3. Membrane applications evaluation criteria, sub-criteria and definition

Criteria	Sub-criteria	Definition
Logistic	Human resources	Expert team members to implement the membrane
	Management efficiency	To what extent technical staff is ready to navigate the membrane?
	Time requirements	Ability to set up the membrane in the specified time.
	Economic sanctions	To what extent the economic sanctions affect to buy the membrane?
Economic	Cost of purchase	Cost of equipment required for the membrane preparation.
	Possible income	What will be the size of the project revenues?
	Variety of consumptions	Is there a variety of applications?
	Useless costs	What is the size of loss due to non-use?
Strategic	Strategic dependency	The dependence of country on membrane
	Current needs	The required size of the membrane.
	Membrane's supply	Is there possibility to buy the membrane for the country?
	Future needs	The needs of country to the membrane in future.
Technical	Set-up easiness	Is it possible to provide the tools, equipment, and the necessary conditions easily?
	Complexity of operations	To what extent, the affective factors and parameters are complex?
	Maintenance	Is it possible to Maintenance and washing the membrane easily?

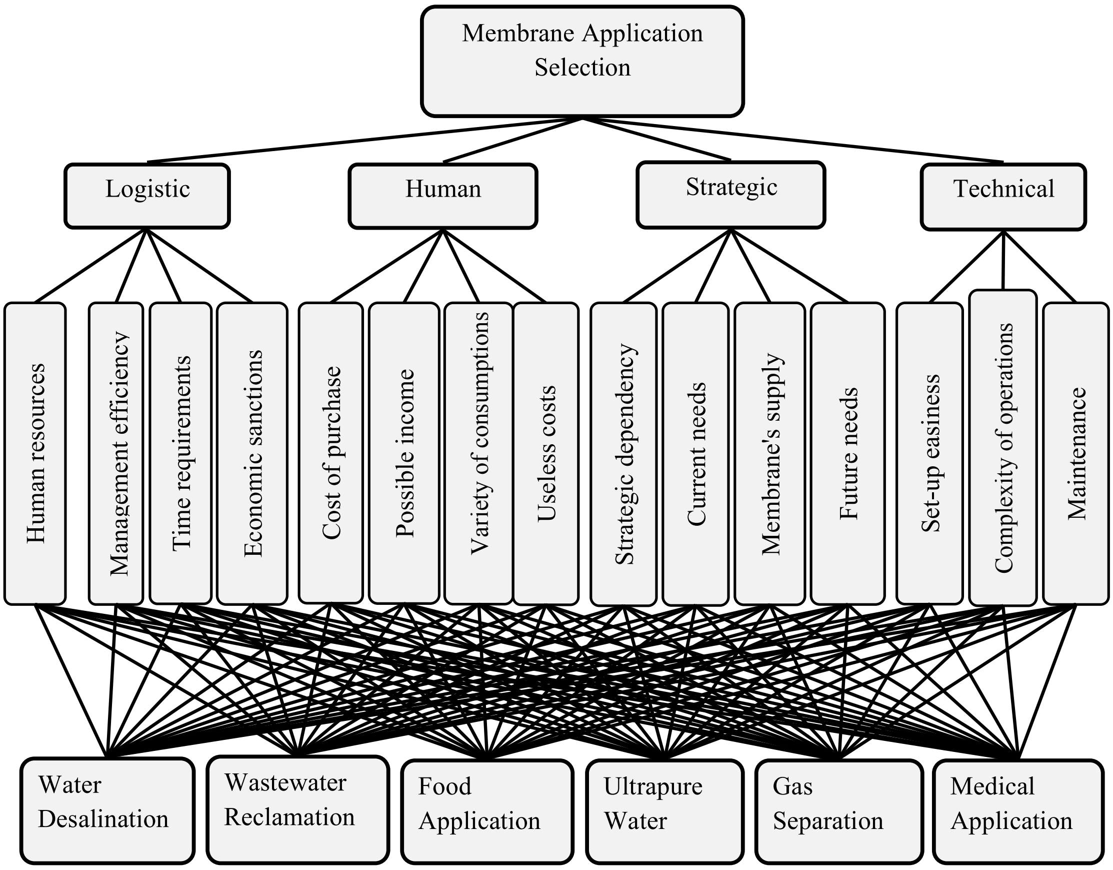

Figure 2. The decision hierarchy of membrane application selection.

5.2.Weights of experts and criteria

After forming the decision hierarchy for the membrane application selection problem, theweights of the criteria to be used in evaluation process are calculated by using the AHP method. In this phase, the experts in the expertteamfrom different decision groups: industry, academic experts and governmental institutes,each with seven expertsdenoted by E_l (where, l = 1, 2, …, 21) are given the task of forming individual pairwise comparison matrices.

As explained before, our intention here is to evaluate the experts of each group. Hence, we employ AHP to determine the relative importance of each one of them.Tables 4-6 show pairwise comparison matrices for each group i.e., industrial, academic and governmental experts, respectively. We also employ the modifying technique that has been explained in section 3.2 to modify the judgment matrix in such a way that it approaches a consistent matrix.

Table 4.pairwise comparison matrix for industrial experts

	E_1	E_2	E_3	E_4	E_5	E_6	E_7
E_1	1.00	1.00	0.50	0.14	0.20	0.14	0.11
E_2	1.00	1.00	0.33	0.11	0.14	0.14	0.20
E_3	2.00	3.00	1.00	0.33	1.00	0.25	0.20
E_4	7.00	9.00	3.00	1.00	5.00	5.00	0.20
E_5	5.00	7.00	1.00	0.20	1.00	1.00	0.14
E_6	7.00	7.00	4.00	0.20	1.00	1.00	0.33
E_7	9.00	5.00	5.00	5.00	7.00	3.00	1.00

Table 5.pairwise comparison matrix for academic experts

	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}	E_{14}
E_8	1.00	4.00	0.20	0.33	0.14	1.00	3.00
E_9	0.25	1.00	0.20	0.33	1.00	3.00	5.00
E_{10}	5.00	5.00	1.00	5.00	0.33	5.00	6.00
E_{11}	3.00	3.00	0.20	1.00	1.00	4.00	5.00
E_{12}	7.00	1.00	3.00	1.00	1.00	5.00	3.00
E_{13}	1.00	0.33	0.20	0.25	0.20	1.00	0.20
E_{14}	0.33	0.20	0.17	0.20	0.33	5.00	1.00

Table 6.pairwise comparison matrix for governmental institutes

	E_{15}	E_{16}	E_{17}	E_{18}	E_{19}	E_{20}	E_{21}
E_{15}	1.00	6.00	3.00	5.00	7.00	0.50	3.00
E_{16}	0.17	1.00	0.33	3.00	5.00	1.00	3.00
E_{17}	0.33	3.00	1.00	5.00	8.00	1.00	3.00
E_{18}	0.20	0.33	0.20	1.00	1.00	0.20	3.00
E_{19}	0.14	0.20	0.13	1.00	1.00	0.20	0.33
E_{20}	2.00	1.00	1.00	5.00	5.00	1.00	5.00
E_{21}	0.33	0.33	0.33	0.33	3.00	0.20	1.00

The relative importance of industrial experts after applying the modifying technique is calculated by AHP in Table 7. It should be noted that the modified comparison matrices are approved by experts. Table 7 alsoimproves consistency of thejudgment matrix and shows the first eight sequence of improvement in the comparison matrix along with changes to other specifications of the judgment matrix including the importance weights of experts, $\lambda_{\max}$and consistency ratio (C.R.). As can be seen from Table 7, while $\sum s_i^{-1}$ increases and monotonically approaches to one as the number of improving iterations increases, the consistency ratio (C.R.) decreases from 0.123 to 0.066. The most inconsistent entry of the comparison matrix that should be modified at each step of the algorithm for improving consistency is also identified and given in Table 7.

Table 7.improvement in pairwise comparison matrix for industrial experts

	Eigenvector	Iteration 1.	Iteration 2.	Iteration 3.	Iteration 4.	Iteration 5.	Iteration 8.
E_1	0.059	0.025	0.026	0.027	0.027	0.027	0.027
E_2	0.063	0.028	0.028	0.029	0.029	0.029	0.030
E_3	0.142	0.062	0.064	0.066	0.067	0.062	0.061
E_4	0.600	0.208	0.188	0.180	0.183	0.183	0.168
E_5	0.208	0.083	0.097	0.101	0.095	0.100	0.107
E_6	0.301	0.132	0.140	0.154	0.165	0.165	0.171
E_7	1.000	0.449	0.449	0.451	0.450	0.448	0.449
λ_{max}	7.974	7.780	7.666	7.624	7.586	7.564	7.530
$C.R.$	0.123	0.098	0.084	0.078	0.074	0.071	0.066
$\sum s_i^{-1}$	0.889	0.919	0.928	0.938	0.943	0.942	0.948
The most inconsistent element	**-------**	**(4,5)**	**(4,6)**	**(5,6)**	**(3,5)**	**(4,5)**	**(3,5)**

Similar to the industrial experts, the importance weights of academic and governmental experts along with their eight sequence iterations on improving consistency of decision matrices are given in Tables 8 and 9, respectively.

Table 8.improvement in pairwise comparison matrix for academic experts

	Eigenvector	Iteration 1.	Iteration 2.	Iteration 3.	Iteration 4.	Iteration 5.	Iteration 8.
E_8	1.803	0.088	0.050	0.068	0.066	0.055	0.056
E_9	1.906	0.091	0.099	0.086	0.073	0.075	0.081
E_{10}	5.796	0.338	0.338	0.347	0.338	0.335	0.266
E_{11}	3.222	0.177	0.177	0.180	0.179	0.179	0.217
E_{12}	5.311	0.352	0.352	0.336	0.333	0.333	0.318
E_{13}	0.714	0.049	0.049	0.040	0.040	0.040	0.041
E_{14}	1.000	0.069	0.069	0.035	0.043	0.050	0.063

Table 8.continue

	Eigenvector	Iteration 1.	Iteration 2.	Iteration 3.	Iteration 4.	Iteration 5.	Iteration 8.
λ_{max}	8.934	8.934	8.465	8.326	8.158	7.999	7.649
$C.R.$	0.244	0.244	0.184	0.167	0.146	0.126	0.081
$\sum s_i^{-1}$	0.782	0.782	0.797	0.829	0.834	0.837	0.914
The most inconsistent element	-------	**(1,2)**	**(2,5)**	**(2,7)**	**(1,7)**	**(3,4)**	**(1,2)**

Table 9. Improvement in pairwise comparison matrix for governmental managers

	Eigenvector	Iteration 1.	Iteration 2.	Iteration 3.	Iteration 4.	Iteration 5.	Iteration 8.
E_{15}	5.702	0.340	0.331	0.279	0.234	0.240	0.209
E_{16}	2.263	0.107	0.109	0.117	0.122	0.127	0.130
E_{17}	3.767	0.216	0.215	0.213	0.242	0.249	0.262
E_{18}	1.031	0.047	0.045	0.045	0.047	0.045	0.046
E_{19}	0.578	0.034	0.034	0.033	0.034	0.034	0.034
E_{20}	4.423	0.267	0.267	0.266	0.267	0.267	0.266
E_{21}	1.000	0.058	0.061	0.060	0.061	0.065	0.067
λ_{max}	7.892	7.805	7.638	7.504	7.345	7.275	7.193
$C.R.$	0.112	0.101	0.080	0.063	0.043	0.034	0.024
$\sum s_i^{-1}$	0.871	0.896	0.900	0.915	0.961	0.962	0.977
The most inconsistent element	-------	**(2,6)**	**(1,2)**	**(1,3)**	**(4,7)**	**(1,2)**	**(2,7)**

The final weights of experts are calculated based on the final consistent comparison matrix are shown in table 10. It should be noted that the modified comparison matrices for both academic and governmental are approved by experts.

Table 10.The final weights of experts

Industrial experts	Weights	academic experts	Weights	governmental managers	Weights
E_1	0.027	E_8	0.056	E_{15}	0.209
E_2	0.030	E_9	0.081	E_{16}	0.130
E_3	0.061	E_{10}	0.266	E_{17}	0.262
E_4	0.168	E_{11}	0.217	E_{18}	0.046
E_5	0.107	E_{12}	0.318	E_{19}	0.034
E_6	0.171	E_{13}	0.041	E_{20}	0.266
E_7	0.449	E_{14}	0.063	E_{21}	0.067

The expert weights in table 10 are aggregated with consistent comparison matrices (obtained from individual judgment and applying the modifying technique) using the weighted geometric mean to obtain the final weights of criteria. In table 11 the final weights of main criteria are given. Indeed, experts with high weights have more impact on final criteria weights.Due to the extensiveness of the results only the main results are presented. Although the detailed result to obtain the weights of experts and the steps of modifying technique are presented.

Table 11.the final weights of main criteria

Criteria	Weights
Logistic	0.232
Economic	0.285
Strategic	0.157
Technical	0.326

5.3. Evaluation of alternatives and determination of the final rank

At this stage of the decision procedure, the team members wereasked to establish the decision matrix, by pairwise comparison ofthe alternatives with respect to each of the criteria separately. After establishing the decision matrix (according to the fourth stage of proposed method), the weights of criteria are used to establish the weighted normalized decision matrix in TOPSIS method (according to the explained steps in section 3.3).Finally, by following the TOPSIS steps and calculations as described in Section 3.3, the ranking of the membrane applications was determined. Due to the extensiveness of the results, the values of D_j^* and D_j^- with final ranking resultsare summarized in Table 12.

Based on the CC_i (closeness coefficient) values, the ranking of the membraneapplications, in descending order (from the most preferable application to the least one), isWater Desalination, Wastewater Reusing, Medical Applications, Food Application, Ultrapure Water andGas

Separation. Asa result, Water Desalination with a CC_i value of 0.595is selected as the most suitable membrane application for Iran marketplace.

Table 12.Final evaluation and ranking of the alternative membrane applications

Membrane applications	D_i^-	D_i^*	CC_i	Rank
Water Desalination	3.68	2.50	0.595	1
Wastewater Reusing	3.48	3.41	0.505	2
Food Application	3.36	4.04	0.454	4
Ultrapure Water	3.31	4.69	0.414	5
Gas Separation	3.25	4.70	0.409	6
Medical Applications	3.42	3.83	0.472	3

6.Conclusions and suggestions

The selection of Membrane applications has been challenging for most developing countries. In this study, for the first time a multi-criteria decision making (MCDM) approachis establishedfor evaluating and ranking different membrane applications. Hence, the complex problem is broken down into more manageable problem and is modeled as a MCDM problem with a four-level hierarchy. The AHP is used to analyzethe structure of the membrane application selection problem and to determineweights of the criteria, sub-criteria and experts. We improved consistency of judgmentmatrices through the use of a modified technique.This technique derives a judgment matrix with acceptable consistency (C.R. < 0.1) from the original one.Finally, the TOPSIS method is used to obtain thefinal rank of membrane applications.

The model was then applied to a real world case study (membrane applications selection in IRAN), and its applicability and reliabilitywere well demonstrated.A committee of experts from different decision-making groups including industrial, academic and governmental experts has been formed to perform the multiple attribute evaluation of membrane applications. Based on the model evaluation, water desalination with theCC_i value of 0.595was the most appropriate membrane application for Iran marketplace to be executed.

Although the model was developed and tested for use in membrane applications selection problem, it can also be used with slight modificationsin other decision-making problems in membraneindustries of differentcountries. Also, mathematical models can be combined withthe proposed model or other MCDM methods can be developed for membrane applicationsselection problem. This will improve the proposed method andis one of the directions in our future research.

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