Selection of the Best Module Design for Ultrafiltration (UF) Membrane in Dairy Industry: An Application of AHP and PROMETHEE

Mohsen Pirdashti pirdashti@shomal.ac.ir
Faculty of Engineering/Chemical
Engineering Department/
Shomal University
Amol, 46134, Iran

Majid Behzadian behzadian_ie@yahoo.com
Faculty of Engineering/Industrial
Engineering Department/
Shomal University
Amol, 46134, Iran

Abstract

Membrane with a type module has been expressed one of the key area of interest in dairy industry. Although recent publications have given a chance academics and practitioners to prove successful applications of membrane processes to the vast areas; a small number of publications have been devoted attention to the problem of capital equipment decision-making. To facilitate decision-making process in the membrane separation, this report focuses on the application of analytical hierarchy process (AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), from a group decision-making viewpoint; it uses the Delphi technique to evaluate available alternatives according the criteria elicited from expert's opinions. A real case study on the ultrafiltration membrane area is put forward to determine the best module design based on the five criteria expressed by decision-makers: sanitation design, clean–in-place, packing density, resistance to fouling and shear stress, and relative cost. Finally, the paper utilizes Expert Choice and DECISION LAB software's to facilitate calculations.

Keywords: Analytic Hierarchy Process (AHP), PROMETHEE, Delphi, multi-criteria decision making, group decision support systems, membrane separation, ultrafiltration.

1. INTRODUCTION

Dairy has been recognized as an important food industry which applies membranes in several sections (1). Since the discovery of asymmetric membrane by Loeb and Souriragin in the early 1960's, membrane processes as microfiltration (MF), ultrafiltration (UF) and reverse osmosis (RO) have widely been applied to the dairy, food and beverage industry (2). Compared to phase-inversion processes, membrane processes are inherently less energy intensive; they are able to save energy up to 30-50% of the current values. In addition, membrane processes are compact, modular and easily amenable automation and scale-up; they are fast (due to fast mass transfer through the thin membrane layer), more efficient, unique in some applications (such as hemodialysis), consume no or less additives and chemical sand applicable to very dilute solutions (such as biotechnology products) with lower capital investments. Membrane processes are carried out in low temperature; hence they can be used for heat-sensitive materials such as food, medical and biotechnological products. Successful applications of membrane processes have been reported by a variety of industries around the world (3). Some of recent membrane applications in dairy industry are shown in table 1 (4).

Applications	Membrane types
Cheese whey concentration	UF-RO
Milk concentration	UF-RO
Desalting of whey	ED
Waste treatment	UF

TABLE 1: Some of membrane application in dairy industry.

UF is a pressure-driven membrane process widely considered as economical alternatives to conventional separation processes valuable products in the dairy industry; it has performed at the standard unit operations (5, 6). In addition to selection of the proper membrane martial and optimization of operating conditions (feed velocities, temperature, staging, etc.), bulk stream pretreatment (removal or stabilization of foulants), the selection of proper module configuration is one of the key stages in the industrial membrane system design (4). Module design for UF membrane in dairy application cases includes a considerable number of alternatives and criteria which should be analyzed and optimized (7). There has been a considerable demand for an appropriate management in determination of the best module as well as resolving the priority of other alternatives in comparison to the selected module. To cope with this demand, the AHP method and PROMETHEE from a group decision-making view of point has been put forward for a satisfactory solution. Flexibility of the results achieved in this study for AHP method, particularly in the sensitivity analysis stage, as well as taking into account the latest statistical information, and good agreement between the AHP result with PROMETHEE output has made this study a valuable contribution to selection of the best module in dairy application cases.

2. AVAILABLE MODULES

The term “module” is universally used; but the definition varies. Here, a module is the simplest membrane element that can be put into practice. Module design should deal with five major issues, plus a host of minor ones. First is economy of manufacture; Secondly, a module should mobilize a strong support and be able to properly maintain membrane integrity against damage and leaks; thirdly, it should deploy the feed stream so as to make intimate contact with the membrane, provide sufficient mass transfer to keep polarization in control, and do so with a minimum waste of energy; fourthly, the module should permit easy aggress of permeate; and fifthly it should permit the membrane to be cleaned when necessary. Despite the invention of various types of modules, a fair number of modules have commercially been operated; but the winning designs have varied depending on a few simple themes since 1996 (8). In order to membrane module is a unit assembly containing a combination of membranes and the membrane containment vessel (4). Commercially available modules include spiral wound, hollow fiber, tubular and plate-and-frame modules (5). These modules for membrane design were assessed in this study; a general description of the different module types is presented in the following sections.

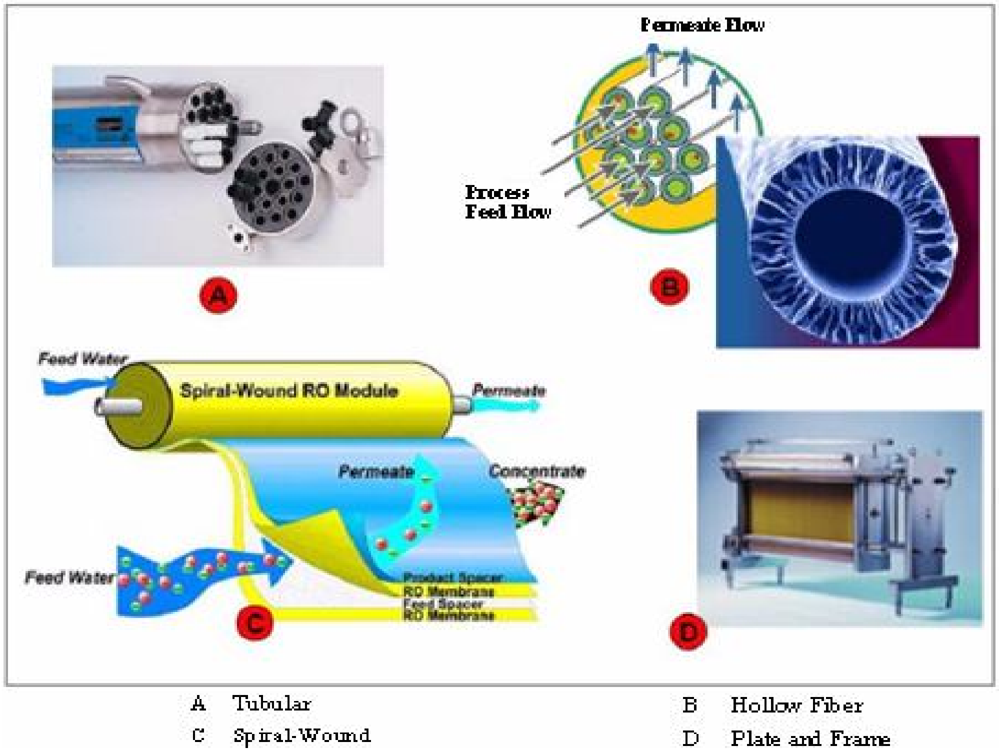


FIGURE 1: Membrane configurations for UF membrane.

Tubular Module (TM)

Tubular modules, which are among the earliest industrial designs, are often preferred for solutions containing suspended solids. The membranes are formed as tubes and are normally cast onto a supporting porous substrate. The tubes are not self-supporting and are normally inserted in a perforated tube. The tubes are typically housed in a shell and tube configuration. The membranes are normally sealed by means of elastomeric inserts at either end of the tube. The end caps determine if the flow is in series or parallel through the module. Permeate is collected in the shell side of the module (9).

Hollow-Fiber Module (HFM)

Hollow fiber modules were developed in the late 1960’s for use in desalination and has subsequently been adopt for UF and MF applications. A hollow fiber module consists of a bundle of self-supporting hollow fibers set inside a cylindrical shell and potted at both ends to create a shell and tube arrangement. The fibers range in size from 100 µm to 2500 µm. (9).

Spiral-Wound Module (SWM)

The spiral wound membrane module consists of two flat sheet membranes wound around a central core. The membranes are oriented with the permeate site of the membranes facing. The membranes are separated by a spacer and then glued together to form an envelope. Two enveloped separated by a feed spacer are attached to the central core and wound Swiss role style around the core. The spacer on the feed side acts as a turbulence promoter and support. Once wound the ends by fixed by and anti-telescoping device. Modules are either tape bound and held in a steel housing or made as glass-reinforced modules. The feed runs axially through the unit. The permeate flows around the spiral and is removed via the central tube. This module is wrapped into a spiral and placed in a cylinder shell (9).

Plate and Frame Module (PFM)

The plate and frame configuration consists of membranes cut from flat sheets and bounded or clamped to a flat supporting frame is normally grooved or milled to permit flow of the permeate. The basic layout can be compared with that of a standard filter press (8). In Figure 1, the arrows show the upstream and Permeate paths. The upstream leaves as the retentive and is enriched in Non-permeate. Permeates is collected from channels in support plates and Leaves enriched in the most permeable component (10).

3. ANALYTICAL HIERARCHY PROCESS(AHP) APPLICATION

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making (MCDM) approach that simplifies complex, ill-structured problems by arranging the decision factors in a hierarchical structure. The AHP is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution (11). One of the main characteristics of the AHP method is the possibility that AHP offers in group decision-making (12, 13,14). Since the evaluation of projects usually demands a remarkable team effort, AHP is an available method which provides decision-makers (DMs) with a systematic framework for group interaction and decision-making (15). The AHP method is selected for its specificity, which offers a certain freedom to a DM to express his preferences for particular criteria by using the original AHP measurement scale. The AHP method does not require such explicit quantification of criteria; but it needs specific hierarchical structuring of the MCDM problem. The method itself then generates the weights of the criteria by using the AHP measurement scale according to a specified procedure. Under such circumstances, a comparison of the results from such different methods applied to the same problem appears to be very interesting and challenging from both academic and practical perspectives (16). According to Saaty [17,18, 19], the following steps are intended to proceed the AHP method:

1. Define the problem and determine its goal,
2. Structure the hierarchy with the decision-maker’s objective at the top with the intermediate levels capturing criteria on which subsequent levels depend and the bottom level containing the alternatives, and
3. Construct a set of $n \times n$ pair-wise comparison matrices for each of the lower levels with one matrix for each element in the level immediately above. The pairwise comparisons are made using the relative measurement scale in Table 2 (20, 21, 22). The pair-wise comparisons capture a decision maker’s perception of which element dominates the other.
4. There are n (n-1)/2 judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5. The hierarchy synthesis function is used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. After all the pair-wise comparisons are completed, the consistency of the comparisons is assessed by using the eigenvalue, λ, to calculate a consistency index, CI:

$$CI = (\lambda - n)/(n-1) \tag{1}$$

Where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 3. Saaty [1980](21) suggests that the CR is acceptable if it does not exceed 0.10. If the CR is greater than 0.10, the judgment matrix should be considered inconsistent. To obtain a consistent matrix, the judgments should be reviewed and repeated.

7. Steps 3-6 are performed for all levels in the hierarchy (23).

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred

4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

TABLE 2: Pair-wise comparison scale for AHP preference.

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

TABLE 3: Average random consistency.

Group AHP Method

While AHP can be used to capture the priorities of individual decision participants, it is necessary to combine these individual assessments into a consensus. To aggregate individual AHP judgments into a group decision, there are two perspectives as follows:

Aggregation of Individual Judgment

In this view, a group decision matrix is constructed from the unique matrix of each decision participant. An element of this matrix (a_{ij}^{G}) is calculated using a geometric average of the elements from each unique matrix,

$$a_{ij}^{G} = \left\{ \prod_{K=1}^{n} (a_{ijk})^{\beta_K} \right\}^{\frac{1}{\sum \beta_K}} = \left\{ \prod_{K=1}^{n} (a_{ijk})^{\beta_K} \right\} \qquad , i, j = 1, \ldots, m \quad , K = 1, \ldots, n \tag{2}$$

Where β_k and a_{ijk} are the importance and efficiency of the K decision and the elements of the K matrix, respectively (24).

Aggregation of Individual Priorities (AIP)

In this approach, the order of the decision weights for each decision alternative for the *K* decision (W_i^{k}), *K*=1….*n*, where n is the number of decision-makers, is calculated and a group decision weight (W_i^{G}) for the alternative is constructed:

$$W^{G} = (W_i^{G}) \qquad ; W_i^{G} = \prod_{K=1}^{n} (w_i^{K})^{\beta_K} \qquad i = 1, \ldots, m \tag{3}$$

Where β_k indicates amount and importance of effectiveness of *K* decision and W^{G} matrix indicate aggregation weight of a single judgment in respect to each alternative.

In both approaches, each individual judgment affects the final judgment β_k . So that:

$$\sum_{K=1}^{n} \beta_k = 1 \tag{4}$$

After aggregating the individual judgments, matrices with the same dimensions as the unique individual matrices are constructed in which the local and final weights as well as the inconsistency of each matrix and total inconsistency are calculated with the same basic AHP method (24).

4. PROMETHEE II

The PROMETHEE II is used to provide a complete ranking on a finite set of feasible alternatives from the best to the worst. The central principle of PROMETHEE II is based on a pair-wise comparison of alternatives along each recognized criterion. Alternatives are evaluated according to different criteria, which have to be maximized or minimized. The implementation of PROMETHEE II requires relevant information on the weights and preference function of the criteria. PROMETHEE II assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large (25). There are a number of papers in this regard combined PROMETHEE with AHP (26,27, 28). The final ranking of alternatives in this integration was done by PROMETHEE and the importance of criteria was determined by AHP. For each criterion, the preference function translates the difference between the evaluations obtained by two alternatives into a preference degree ranging from zero to one. In order to facilitate the selection of a specific preference function, Brans and Vincke (1985) (29)proposed six basic types, namely: Usual criterion, *U*-shape criterion, *V*-shape criterion, Level criterion, *V*-shape with indifference criterion, and Gaussian criterion. These six types are particularly easy to define. For each criterion, the value of an indifference threshold *q*, the value of a strict preference threshold *p*, or the value of *s* an intermediate value between *p* and *q* has to be fixed (30). The following paragraphs present stepwise procedure for the implementation of PROMETHEE II:

Step 1: Determination of deviations based on pair-wise comparisons

$$d_j(a,b)=g_j(a)-g_j(b) \tag{5}$$

Where $d_j(a,b)$ denotes the difference between the evaluations of *a* and *b* on each criterion.

Step 2: Application of the preference function

$$P_j(a,b)=F_j[d_j(a,b)] \qquad j=1,\ldots,k \tag{6}$$

Where $P_j(a,b)$ denotes the preference of alternative *a* with regard to alternative *b* on each criterion, as a function of $d_j(a,b)$.

Step 3: Calculation of an overall or global preference index

$$\forall\, a,b\in A\,, \qquad \pi(a,b)=\sum_{j=1}^{k}P_j(a,b)w_j \tag{7}$$

Where $\pi(a,b)$ of *a* over *b* (from zero to one) is defined as the weighted sum $p(a,b)$ of for each criterion, and w_j is the weight associated with *j*th criterion.

Step 4: Calculation of outranking flows and partial ranking

$$\phi^+(a)=\frac{1}{n-1}\sum_{x\in A}\pi(a,x) \tag{8}$$

and

$$\phi^{-}(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x, a) \tag{9}$$

Where $\phi^{+}(a)$ and $\phi^{-}(a)$ denote the positive outranking flow and the negative outranking flow for each alternative, respectively.

Step 5: Calculation of net outranking flow and complete ranking

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{10}$$

Where $\phi(a)$ denotes the net outranking flow for each alternative

5. THE PROCEDURE

Utilizing Delphi process

The Delphi method has been a popular tool in information systems research because the process increases the confidence with which researchers can use the results in subsequent studies and managers can make decisions based on the information gathered using this method. Researchers employ this technique primarily in cases where judgmental information is indispensable. The Delphi technique has been used in a number of real application cases: to predict technological developments (31), to identify issues affecting health care administration (32, 33), to assess interventions and policies in the mental health industry (34), to construct a model for project funding decisions at the National Cancer Institute (35), to evaluate the strategic importance of jobs in pay rate decisions (36), to evaluate emerging directions in information systems management (37), and to assess strategic responses to threats from global terrorism (38). A key advantage of Delphi is that it avoids direct confrontation between the participating experts (39). While real applications differ markedly according to the type of industry, the Delphi method consists of three essential processes that achieve information exchange among a group of DMs without introducing the potential biases of interpersonal interaction. The first process is to collect judgments, along with the underlying rationales, from individuals who are knowledgeable about an issue by questioning them individually. The second process is to collate and statistically summarize the individual judgments and rationales without revealing the identity of the individuals. The third process is to feed back the collated information to the DMs and ask them to reconsider their judgments. This sequence of collating, feedback and revision is repeated over several rounds until further repetitions produce practically no changes in individual judgments. Both Delphi and AHP assume knowledgeable DMs (40). Therefore, the careful selection of the participants for the DM group is important. This issue was discussed by Brockoff (1983) (40) and Preble (1984)(41). The experts who were selected to participate in this study include University Professors, Diary producers, Membrane inhibitors, who are familiar with the membrane process. While the experts in these groups are knowledgeable about the membrane process issues, they were provided with the most recent research results and statistical information from the UF separation. After identifying knowledgeable experts, the next step was sending questionnaires to elicit the experts' opinions about the factors affecting on selection module for UF membrane in dairy industry. The first questionnaire asked the participants to identify the factors they thought were most important in selecting a module. A comprehensive and mutually exclusive list was collated from the responses. A second questionnaire included the list generated from the initial responses and asked the experts to check those factors they considered to be important. A list of potential impacts was presented, and respondents indicated those impacts they considered most important. These were grouped under five objectives; these five factors were included as criteria:

Sanitation Design (SD)

Sanitation design plays an essential factor in the selection of a specific UF module. Sanitary operation is of paramount importance because the design allows for easy cleaning and sterilization.

Clean –in-Place (CIP)

Easy to clean or the ability to clean membranes when necessary and replace membranes is good. This is an important factor in comparing the different UF modules types.

Packing Density (PD)

Packing density is the ratio of Membrane surface to membrane module volume. That low packing density is a problem in high pressure where pressure vessel costs are significant.

Resistance to Fouling and Shear stress (RFS)

Fouling is a process resulting in loss of performance of a membrane due to the deposition of suspended or dissolved substances on its external surfaces, at its pore opening, or within its pores. It is one of the major considerations in the handling of milk products, particularly the UF of whey; however, resistance to fouling and self-cleaning is very important parameters for this application.

Relative Cost (RC)

The membrane module should satisfy a number of economic requirements. In order to optimization of initial module costs and operating life are very important in industrial membrane system design.

Application of expert choice software to facilitate the calculations

Expert Choice (43) provides strong support for DMs faced with solving complex problems, involving the evaluation of alternative courses of action on qualitative as well as quantitative criteria (44, 45). The software helps a DM to devise the structure of a complex problem as a hierarchy of criteria and alternatives; it guides the DM through a series of simple pairwise comparisons to solve the problem. While Expert Choice is powerful and intuitive, it is also easy to use; therefore, the solution is more likely to reflect the expertise of the DM while minimizing interference from the program and the computer. Figure 2 shows the hierarchical structure of the problem. The five criteria identified in the Delphi process and alternative modules are the second level and third level of structure, respectively.

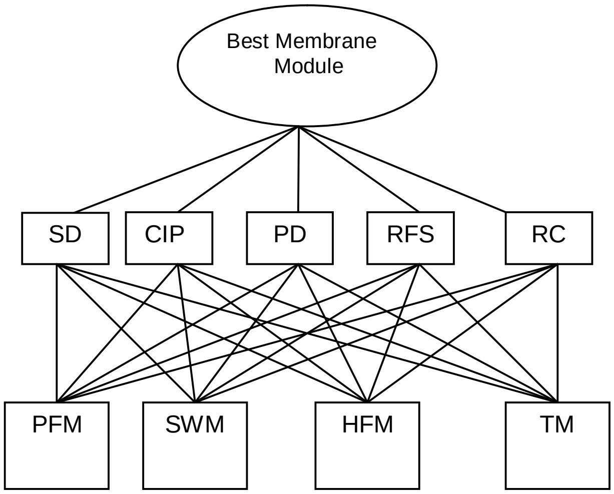
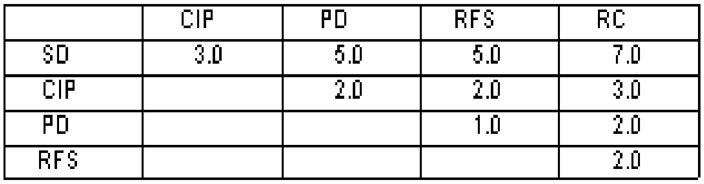


FIGURE 2: A hierarchal representation of problem with five criteria and four alternatives.

5. RESULTS

In the next step, each of the participants in the project used Expert Choice to assess the relative importance of the criteria and to evaluate the priority of alternative site locations. Pairwise comparisons form the core of the AHP technique. At each level of the hierarchy below the goal, a DM is asked to compare each possible pair of factors (*ci* and *cj*) and to provide judgments on the relative importance of each. As illustrated in Figure 3(a), each expert was asked to make pairwise comparisons between each possible pair of criteria.



	CIP	PD	RFS	RC
SD	3.0	5.0	5.0	7.0
CIP		2.0	2.0	3.0
PD			1.0	2.0
RFS				2.0

FIGURE 3(a): Compare the relative importance with respect to: GOAL.

These judgments provided inputs to Expert Choice. As described in the Appendix, once the pairwise comparison matrix at a given level of the hierarchy is complete, Expert Choice calculates the relative weights for the various factors at that level. Figure 3(b) shows the output for one of the experts. For this expert, SD considered the most important criterion while LE was assigned the least weight.

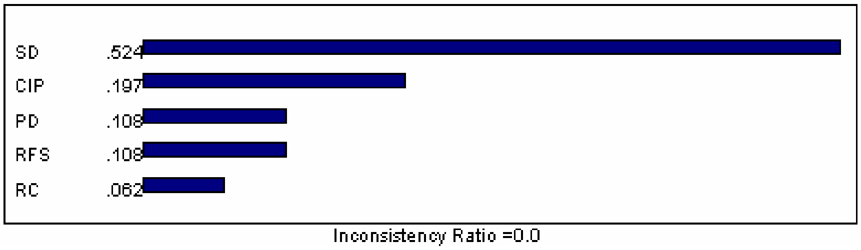


FIGURE 3(b): The relative weights with respect to: GOAL

In addition, Expert Choice computes an inconsistency ratio (IR) for each DM and encourages DMs whose IR exceeds 0.10 to reconsider their pairwise judgments. For example, if an expert rates CIP as two times more important than PD, and two times more important than RSF; then logically for that expert, PD and RSF should be equally important. Suppose, however, that in a pairwise comparison between these two criteria, the expert declares PD to be three times more important than RSF. In this case, a substantial inconsistency has occurred, and the calculated IR would be greater than 0.10. Expert Choice would encourage the DM to reconsider all of the underlying pairwise comparisons, and after a few trials, the DM should arrive at an acceptable level of consistency. Among the experts participating in this project, the largest IR for the initial comparison of the criteria was 0.02(<0.10). This level of inconsistency was very low, which indicated the meaningfulness of the criteria to the DMs. After assigning weights to the criteria, the next task for the experts was to evaluate the alternatives on these criteria. While there has been some criticism of AHP in the operations research literature, Harker and Vargas (1987) (46) and Saaty (1983) (47) have shown that AHP does have an axiomatic foundation. The cardinal measurement of preferences is fully represented by the eigenvector method, and the principles of hierarchical composition and rank reversal are valid. On the other hand, Dyer (1990a)(48) has questioned the theoretical basis underlying AHP, and argued that it can lead to preference reversals based on the alternative set being analyses. In response, Saaty (1990b) (49) explained how rank reversal is a positive feature when new reference points are introduced. In the module design decision, the geometric aggregation rule is used to avoid the controversies associated with rank reversal (49, 50, 51). When all the comparisons between criteria and alternatives were made by each expert, geometric averaging of the individual comparisons was used to synthesize the criterion weights and alternative priorities for the expert group. The EC outputs are from all the AHP processes. The results reveal that SWM and HFM were the modules preferred by the experts are shown figure 4(a) to 4(c).

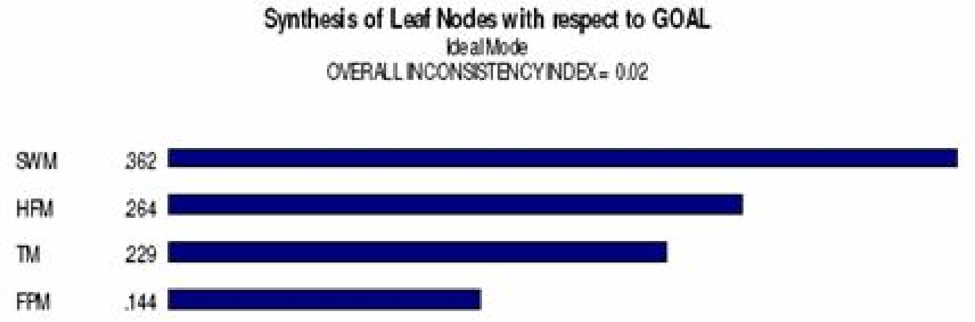


FIGURE 4(a): Synthesis of leaf nodes with respect to GOAL.

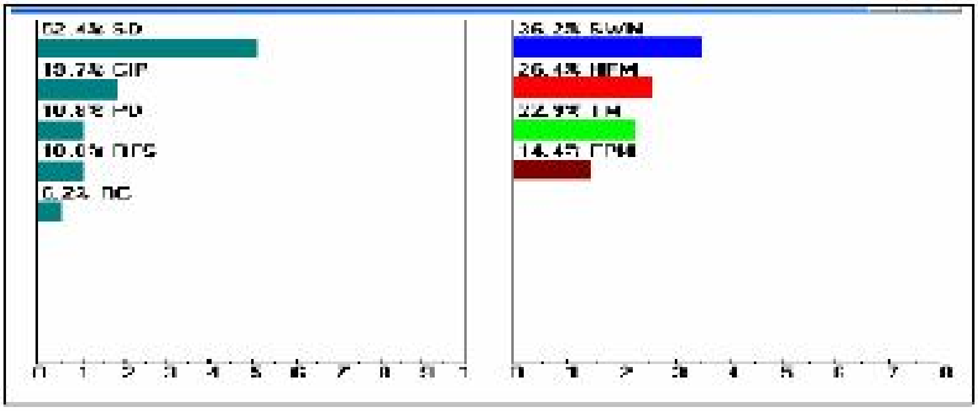


FIGURE 4(b): Dynamic sensitivity with respect to GOAL for nodes below GOAL.

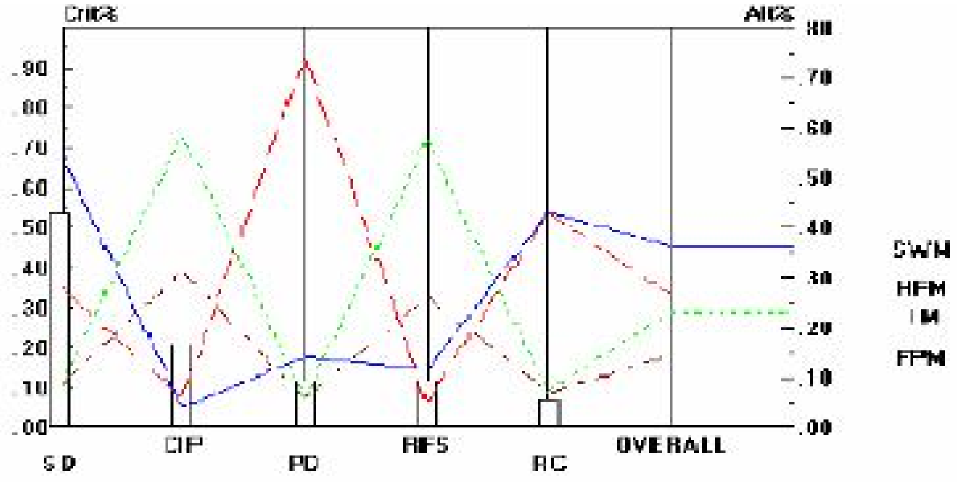


FIGURE 4(c): Performance sensitivity with respect to GOAL for nodes below GOAL.

The software is easy to use and understand; it provides visual representations of overall ranking on a computer screen.

In order to rank alternative technical requirements according to PROMETHEE II, the DECISION LAB software was run. The software, which was developed in collaboration with the Canadian company *Visual Decision*, is the current software implementation of the PROMETHEE & GAIA methods (52).

	RC	**CIP**	**RES**	**PD**	**SD**
Weight	0.062	0.107	0.108	0.108	0.524
Max/Min	Min	Max	Max	Max	Max
Type	5	5	5	5	5
q	1	1	1	1	1
p	3	3	3	3	3
PFM	3	5	5	4	3
SWM	7	3	4	5	7
HFM	6	3	2	8	5
TM	2	7	6	3	3

Table4: PROMETHEE II multi-criteria information.

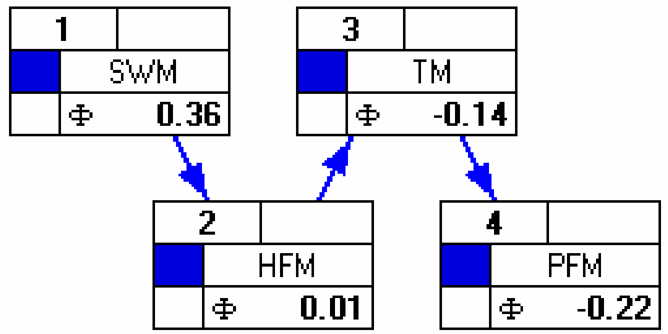


FIGURE 5: Ranking four alternatives by Decision lab software.

In this specific problem, the alternative *SWM* is preferred from the multi-criteria viewpoint, whereas *PFM* is selected the worst alternative, as shown in Table 4. Figure 5 shows the result of the complete ranking with PROMETHEE II for four modules, as an output of DECISION LAB and this is a good agreement between the AHP result with PROMETHEE output.

6. SENSITIVITY ANALYSIS

Sensitivity analysis was used to investigate the stability of the alternatives' assigned priorities to changes in the relative importance of the criteria. For example, RC was not reliably predictable, and the facilities provided at various industrial modules were likely to be improved in the future. Consequently, it would desirable to examine the impact of changes in these weights on the priorities of the alternative facility modules. For dairy application, the experts considered RC to be the most volatile criterion. Figure 6(a) to 6(d) show the potential impact of the changes in RC on the priorities of the alternative modules. A 650% decrease to 852% increase in the relative weight assigned to RC, from 0% to 55.4%, produced no change in the ranking of the modules in comparison to Figure 6(a) and 6(d). Individually and as a group, the experts explored the impact of numerous scenarios on the weights and alternative priorities. They considered the solution presented in Figures 6(a) to 6(d) to be not only the most desirable, but also the most robust.

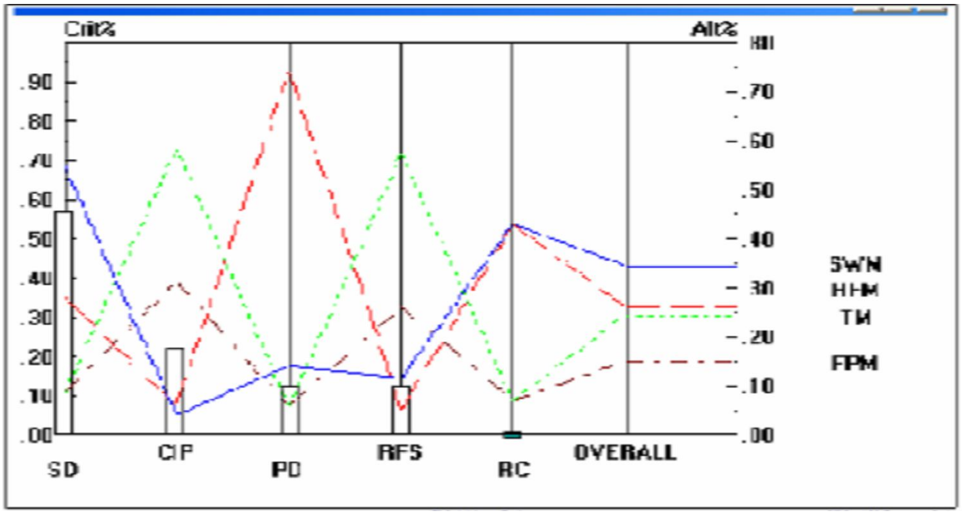


FIGURE 6(a): Performance sensitivity with respect to GOAL for nodes below GOAL.

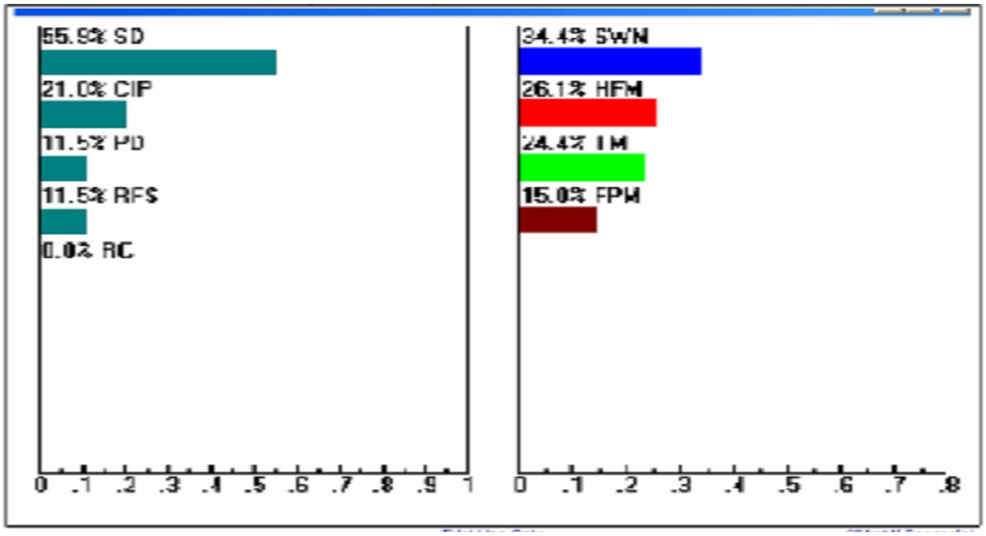


FIGURE 6(b): Dynamic sensitivity w.r.t GOAL for nodes below GOAL.

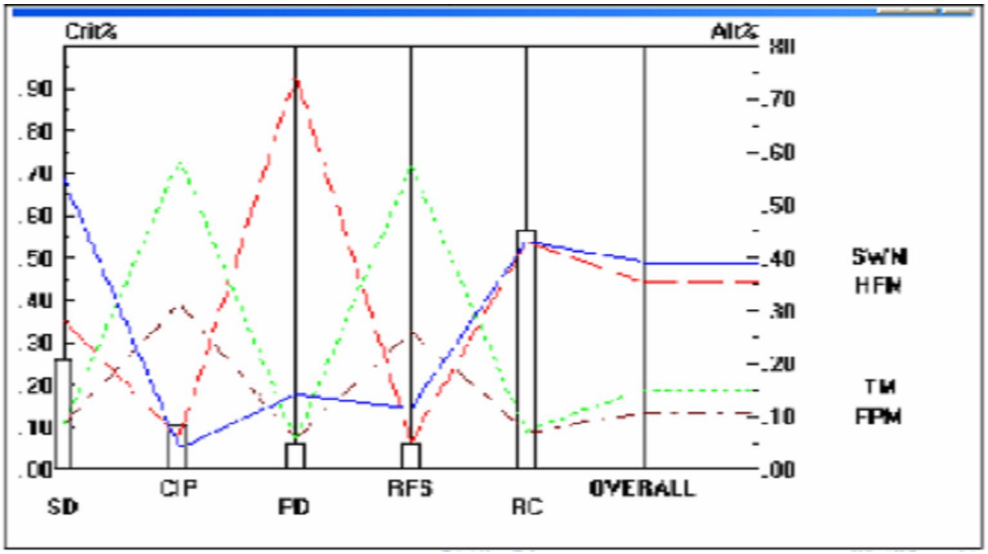


FIGURE 6(c): Performance sensitivity w.r.t GOAL for nodes below GOAL.

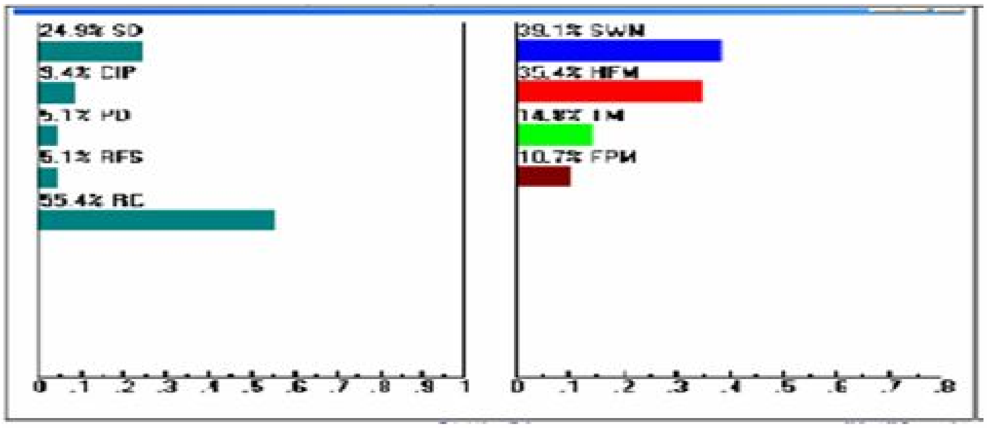


FIGURE 6(d): Dynamic sensitivity w.r.t GOAL for nodes below GOAL.

8. CONCLUTION

Despite the widespread interests for the application of membrane process to the dairy industry, arriving at a rational decision to select the best alternative from a group decision-making approach has been recognized as one of the main challenges among academics and practitioners. In this regard, the determination of the best Module design for UF membrane in dairy industry is a problem that involves both quantitative and qualitative criteria; however, the scale of a problem rises up due to complicated nature of the problem, presence of various alternatives and criteria, and a genuine difference of opinion between the experts. The major contribution of this paper is to use an AHP- Delphi multi-criteria model and a PROMETHEE-Delphi multi-criteria model to elicit, process, and synthesize these quantitative and qualitative expert opinions. For this purpose, the model applied Delphi technique to elicit expert opinions about criteria for the evaluation of four modules: SD and CIP, Sanitation design and Clean-in-place were considered important by the experts. The models also used AHP and Expert Choice and PROMETHEE and DECISION LAB to capture the priorities of individual decisions and to arrive at a common consensus among the DMs. As a result, the models developed in this paper provides a useful guideline as a structured and logical means of synthesizing judgments for evaluating appropriate modules for an organization; it devised an elaborate structure in a difficult and often emotion-burdened decision. The second implication is the functionalities of the modules listed in the models. Thus, DMs can examine the strengths and weaknesses of each module. The authors believe that this study would be especially useful for academics and practitioners who are working in dairy industry and are interest in decision science.

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