FAN AND PITCH ANGLE SELECTION FOR EFFICIENT MINE VENTILATION USING ANALYTICAL HIERACHY PROCESS AND NEURO FUZZY APPROACH

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ABSTRACT

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Ventilation is a critical task in underground mining operation. Lack of a good ventilation system causes accumulation of harmful gases, explosions, and even fatalities. A proper ventilation system provides adequate fresh air to miners for a safe and comfortable working environment. Fans, which provide air flow to different faces of a mine, have great impact in ventilation systems. Thus, selection of appropriate fans for a mine is the acute task. Unsuitable selection of a fan decreases safety and production rate, which increases capital and operational costs. Moreover, pitch angle of fans' blades plays an important role in fan's efficiency. Therefore, selection of a fan and its pitch angle, which yields the maximum efficiency, is an emerging issue for an efficient mine ventilation.

The main objective of this research study is to provide a decision making methodology for the selection of a main fan and its appropriate pitch angle for efficient mine ventilation. Nowadays, analytical hierarchy process as multi criteria decision making is used, and it yields outputs based on pairwise comparison. On the other hand, Fuzzy Logic as a soft computing method was combined with analytical hierarchy process and combined model did not yield appropriate results; because Fuzzy AHP increased uncertainty ratio in this study. However, fuzzy analytical hierarchy process might be inapplicable when it faces with vague and complex data set. Soft computing methods can be utilized for complicated situations. One of the soft computing methods is a Neuro-Fuzzy algorithm which is used in classification and DM issues.

This study has two phases: i) selection of an appropriate fan using Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and ii) selection of an appropriate pitch angle using Neuro-Fuzzy algorithm and Fuzzy AHP method.

This study showed that AHP can be effectively utilized for main fan selection. It performs better than Fuzzy AHP because FAHP contains more expertise and makes problems more complex for evaluating. When FAHP and Neuro-Fuzzy is compared for pitch angle selection, both methodologies yielded the same results. Therefore, utilization of Neuro-Fuzzy in situation with complicated and vague data will be applicable.

Keywords: Mine Ventilation, Fan Selection, Pitch Angle Selection, Multi Criteria Decision Making (MCDM), Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (FAHP), Neuro-Fuzzy.

ÖZ

ANALİTIK HIYERARŞI SÜRECİ VE NÖRO-BULANIK ALGORİTMASI KULLANILARAK ETKİLİ MADEN HAVALANDIRMA İÇİN FAN VE EĞİM AÇISI SEÇİMİ

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Havalandırma, yeraltı madenciliği için kritik bir işlemdir. İyi bir havalandırma sisteminin olmamasından kaynaklanan zararlı gazlar, patlamalar ve zehirlenmeler yaratarak ölümlere neden olabilir. Uygun bir havalandırma sistemi, solunum için madencilere yeterli temiz hava sağlar. Fanlar, maden içerisindeki hava miktarını ve dağılımını belirledikleri için havalandırma içinde büyük bir etkiye sahiptirler. Bu nedenle, fanın maden için uygunluğuna dikkat edilmesi gerekmektedir. Uygun olmayan bir fanın seçimi, güvenlik ve üretim hızını azaltarak, yatırım ve işletme maliyetlerinin artmasına sebep olmaktadır. Ayrıca, bir fanın etkinliğinde, fanların kanatlarının eğim açısı önemli bir role sahiptir. Sonuç olarak, azami verimle çalışan bir fan ve ona

uygun eğim açısının seçimiyle, daha verimli bir maden havalandırması sağlanabilir.
Bu araştırma çalışmasında temel amaç, ana fan ve ona uygun eğim açı seçiminde verimliliği en üst seviyeye çıkaracak bir karar verme metodolojisini oluşturmaktır. Çok kriterli bir karar verme sürecinde, ikili karşılaştırmayı baz alan Analitik Hiyerarşi Süreci sıklıkla kullanılmaktadır. Bunun yanısıra, Bulanık Mantık, analitik hiyerarşi süreci ve kombine edilmiş model ile birlikte bir uzman sistem olarak daha iyi sonuçlar sunmamaktadır. Çünkü bulanık AHS çalışmadaki belirsizlik oranını arttırmıştır. Ancak, bulanık analitik hiyerarşi süreci, belirsiz ve karmaşık veri seti ile çalışıldığında uygulanamaz olabilir. Bu nedenle, yumuşak hesaplama yöntemleri karmaşık durumlar için kullanılabilir. Yumuşak hesaplama yöntemlerinden biri Nöro-Bulanık algoritmasıdır. Nöro-Bulanık karmaşık karar verme konularında kullanılan veri seti benzetmesi geniş kapsamlı sonuçlar sağlamaktadır.

Bu çalışma iki aşamadan oluşmaktadır. Bunlar: i) Analitik Hiyerarşi Süreci (AHS) ve Bulanık Analitik Hiyerarşi Süreci (Bulanlık AHS) kullanılarak fan seçimi ve ii) Nöro-Bulanık algoritma and Bulanık AHS yöntemi kullanılarak en uygun eğim açısının belirlenmesidir.

Bu çalışma Bulanık AHS yönteminin, ana fan seçimi için etkin bir şekilde kullanılabilir olduğunu göstermiştir. Bulanık AHS uygulamada AHSden daha kullanışlıdır, zira daha fazla uzmanlık ve tasarımcı bilgilerini içermektedir ve sorunun değerlendirmesini zorlaştırmaktadır. Bulanık AHS ve Nöro-Bulanık eğim açısı seçimi için karşılaştırıldığında, her iki metodoloji de aynı sonucu vermiştir. Bu nedenle, karmaşık ve belirsiz veriler olduğu durumda Nöro-Bulanık kullanımı geçerli olacaktır.

Anahtar kelimeler: Maden Havalandırma, Fan Seçimi, Eğim Açısı Seçimi, Çok Kriterli Karar Verme, Analitik Hiyerarşi Süreci (AHS), Bulanık Analitik Hiyerarşi Süreci (Bulanlık AHS), Nöro-Bulanık.

To My Parents and Wife

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CHAPTER 1

INTRODUCTION

1.1 General Remarks

According to Sylvestre (1999), surface deposits have finished, so mining of minerals at increased depths is inevitable to provide the future world demand. However, increasing depth of mines may result in difficulties, such as temperature increasing in mine atmosphere and making the workplace unsafe for miners (Güyagüler, 2005). Mine temperature increases have detrimental effects on miners' productivity rate and efficiency. Ventilation system, which provides fresh air to a mine, has a vital role in underground mine. Since, utilization of natural ventilation is an inefficient method in deep underground mines; usage of appropriate ventilation equipment, is an undeniable issue. Fans are especially utilized for providing air flow in splits and faces. Inefficient fans in mines increase capital and operational costs. Moreover, inappropriate fans provide lower or higher range of air flow; higher range of air flow increases operating costs and lower range of air flow decreases safety. In conventional method of providing air, designers of ventilation system have been supplying maximum air quantity based on the capacity of the mines' system (Karacan, 2007). On the other hand, providing maximum amount of air quantity is neither economic nor safe, moreover, capacity of ventilation system may decrease (Hu, 2003). Hence, selection of a proper fan for mine ventilation has an essential role. Appropriate fans have to work efficiently, and various types of factors have a role in the efficiency of a fan such as: i) motor speed,

ii) blade angle, and iii) variable inlet vane control. Thus, blade angle has a great impact on efficiency of fan. Selection of an appropriate fan and pitch angle is a necessary task. Conventional method is used for fan selection which is based on pressure and air quantity of fans. However, there are more criteria that should be considered in the selection process. In this study Analytical Hierarchy Process (AHP) as Multi Criteria Decision Making (MCDM) method is utilized for the selection in order to develop more efficient fan selection methodology. Moreover, Fuzzy Analytical Hierarchy Process (FAHP) as Decision Making (DM) method was used for fan selection. In addition, FAHP was used for selection of an appropriate pitch angle. However, application of FAHP is inefficient in complex data set. Thus, soft computing method as an alternative of FAHP can be used in complicated situations. Neuro-Fuzzy as soft computing method is also used for pitch angle selection.

1.2 Statement of the Problem

Fans provide air flow in underground mines. Hence, fans have a critical role in ventilation systems. An inappropriate fan in a mine ventilation system causes problems in financial and technical aspects. Thus, DM about a proper fan is a vital task. Conventional method for a fan selection uses intersection of operation curves of a mine and operation curve of a fan. Moreover, pressure and air quantity as major factors are utilized for DM procedure, in conventional method of fan selection. However, utilization of two factors is not adequate for DM, so more criteria must be used to achieve appropriate selection. Thus, selection of an appropriate fan demands more criteria. Hence, MCDM can be utilized in this issue. Therefore, expertise and judgments of designers should be included in MCDM methods. Expert systems can be applied in DM method and combination of expert systems and MCDM methods might be yielded better results.

Pitch angle of fan’s blade has great impact on fan efficiency. Inappropriate degree of pitch angle blades increases depreciation rate of fan’s blades, which has a great effect on capital and operational costs. On the other hand, inappropriate degree of pitch angle decreases the provided air quantity, so it has impacts on technical aspects. Thus, an appropriate pitch angle can prove the efficiency of a fan. Selection of an appropriate pitch angle for fans' blades is an essential operation. Trial and error is a conventional method for pitch angle selection. However, trial and error method requires expertise, which may not be an available condition all the time. Hence, MCDM method is necessary for selection of a proper pitch angle. Data relationship in a pitch angle selection is so complicated, so utilization of MCDM as hard computing method is an inappropriate operation. Hence, soft computing methods are used in MCDM subject.

1.3 Objectives and Scope of the Study

The main objective of this study is to provide a methodology for the selection of an appropriate fan and its pitch angle for efficient mine ventilation system. Appropriate fans have impressions on safety, financial, and technical sides. Moreover, application of an adequate method in selection of fan has a climacteric rule in ventilation operations. As an extension, selection of an appropriate pitch angle will increase efficiency of a main fan, so suitable selections have great impact on output of ventilation system efficiency. In this study, variance types of DM methods were utilized, but the appropriate method was selected between them. In this study, progressive procedure of DM is shown, which represents transition of DM method from hard computing to soft computing methods.

1.4 Research Methodology

In this study; Analytic Hierarchy Process (AHP) was utilized for fan selection as MCDM method. Since AHP has some difficulties such as higher degree of uncertainty and lower degree of expertise, integration of AHP with a new expert system was achieved to cover AHP's defects. Fuzzy Logic (FL) as an expert system was combined with AHP. Amelia *et al*. (2009) argued that Fuzzy Logic has a simple mechanism to provide the model in DM process which contains vague data. In the classical main fan selection, AHP and Fuzzy AHP were utilized. Fuzzy AHP method and Neuro-Fuzzy algorithm were used in selection of proper pitch angle.

Major sections of this research methodology are listed as follows:

i. Data gathering was done for selection of a fan among four types of fans. Moreover, data gathering is provided for a pitch angle selection. This phase of data gathering was done using available literature and curves of a Howden fans. All curves were digitized to quantities.

ii. Classical AHP and Fuzzy AHP methods were evaluated for the main fan selection based on data. Outputs from classical AHP and Fuzzy AHP did not represent better quality in contrast to conventional method of fan selection. Finally, results of AHP and Fuzzy AHP were compared with each other, so an appropriate output was revealed.

iii. Fuzzy AHP method and Neuro-Fuzzy algorithm were utilized for selection of an appropriate pitch angle. Data from Howden fan were utilized in FAHP and Neuro-Fuzzy. Finally, results of Fuzzy AHP and Neuro-Fuzzy have compared to each other, so these methods yielded the same results for this selection.

1.5 Outline of the Thesis

The first chapter of this dissertation represents general information about application of AHP, FAHP, and Neuro-Fuzzy for the selection of a main fan and a pitch angle. The second chapter presents literature survey about the decision making issues which are related to the application of MADM methods and Neuro-Fuzzy algorithms. In third section, Çayırhan lignite coal mine was described. In the fourth section, utilization of classical AHP and Fuzzy AHP for a fan selection was discussed. In addition, the fifth chapter consists of application of Fuzzy AHP and Neuro-Fuzzy algorithm for a pitch angle selection. Finally, the sixth chapter presents the main conclusions and recommendations derived from this research study.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

This chapter presents brief information about mine ventilation and its fundamental character in underground mines. Essential role of ventilation fans and major factors in selection of a fan were stated. Moreover, conventional selection of fan and related factors in its efficiency were discussed. New decision making methods for fan selection were explained. Utilization of multi criteria decision making method and its use in variety types of DM subjects was presented in this chapter. As an extension, modification of qualitative data to quantitative one based on questionnaire form was presented. Vast type of data normalizing was introduced and multi attribute decision making method was discussed. Literature survey and defining of AHP was done in sequence. Due to deficiencies of AHP, Fuzzy Logic (FL) was combined, so recognition and utility of FL in a wide range of fields was presented. Chang's method as FAHP and utilization of FAHP was stated. In addition, artificial neural network was nominated and related literature survey about it was done. In literature survey of decision making progress, Neuro-Fuzzy algorithm as soft computing method was described and its utilization in the mining and related industries was represented in this chapter.

2.2 General Review about Mine Ventilation

Ventilation systems play worthwhile role in mines, especially in coal mines. Fei-min *et al.* (2009) stated ventilation networks have a core characteristic in safe production of coal mines. In modern coal mine elaborate facility of ventilation is used to regulate the methane concentration (Hu, 2003). A ventilation network has branches, junctions, and meshes. Collection of branches, junction, and meshes is called topology of mine ventilation. Lian-Jiang (2009) noted that ventilation topological theory for ventilation simulation system is a necessary subject. Fans, regulators, and air locks are applied in underground mines. In ventilation systems, fans have major role. Fans have two categories as main fans and auxiliary fans. Fans also are classified as axial (Figure 2.1) and centrifugal (Figure 2.2) fans (El-nagdy, 2002). Fans (ventilators) are major devices in ventilation networks and they provide airflow to different parts of a mine. Fans are made of a wheel confidant (i.e., a wheel which covers by blades). Moreover, main fans settle in outside of a mine. Fans work in two modes as exhaust mode and blower mode. Exhaust fans settle in raise and blower type of fans place in winze. Logically, application of an appropriate fan to a mine's ventilation network is undeniable duty, and thus selection of an appropriate fan is critical action.

2.3 Conventional Methods for Fan Selection

Every fan has its own operational curve. Operational curve of a fan represents relationship of air flow quantity and pressure in a fix velocity of blades rotation. Operational curve of a fan depends on shape of blades and pitch angle (Figure 2.3). Proportion of N to Q provides ascendant curve in radial flow fans, on the other hand, this curve is pendulous for axial flow fans.

Figure 2.1 Axial flow fan (Beyk, 2011)

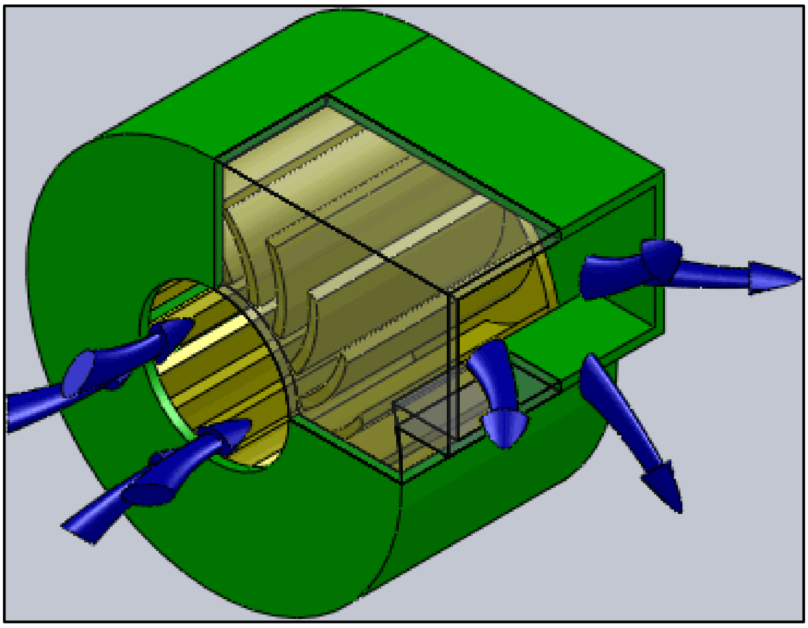

Figure 2.2 Centrifugal flow fan (Lahijany, 2012)

.

Operational curve of axial fans is slick and without any waves when it has small pitch angle for blades. On the other hand, curve has saddle shape when it has bigger pitch angle for blades.

Pressure and airflow quantity changes if diameters of fans, pitch angles, rotation speed, and specific weight changed, therefore their operational curve are modified. Relation between primary pressure (P_1), airflow (Q_1), power on blades (N_1,) diameters (D_1), rotation speed n_1, and specific weight (γ_1)with secondary pressure (P_2), airflow (Q_2), power on blades (N_2), diameters (D_2), rotation speed (n_2), and specific weight (γ_2) are shown in Table 2.1.

Table 2.1 Fan laws (Madani, 2003)

If γ changes	If n changes	If D changes	If n, γ and D changes
$Q_2=Q_1$	$Q_2=Q_1*(n_2/n_1)^2$	$Q_2=Q_1*(D_2/D_1)^3$	$Q_2=Q_1*(D_2/D_1)^3*(n_2/n_1)$
$P_2=P_1*(\gamma_2/\gamma_1)$	$P_2=P_1*(n_2/n_1)^2$	$P_2=P_1*(D_2/D_1)^2$	$P_2=P_1*(D_2/D_1)^2*(n_2/n_1)^2*(\gamma_2/\gamma_1)$
$N_2=N_1*(\gamma_2/\gamma_1)$	$N_2=N_1*(n_2/n_1)^3$	$N_2=N_1*(D_2/D_1)^5$	$N_2=N_1*(D_2/D_1)^5*(n_2/n_1)^3*(\gamma_2/\gamma_1)$
$n_1=n_2$		$n_1=n_2$	$n_1=n_2$ $n_1=n_2$

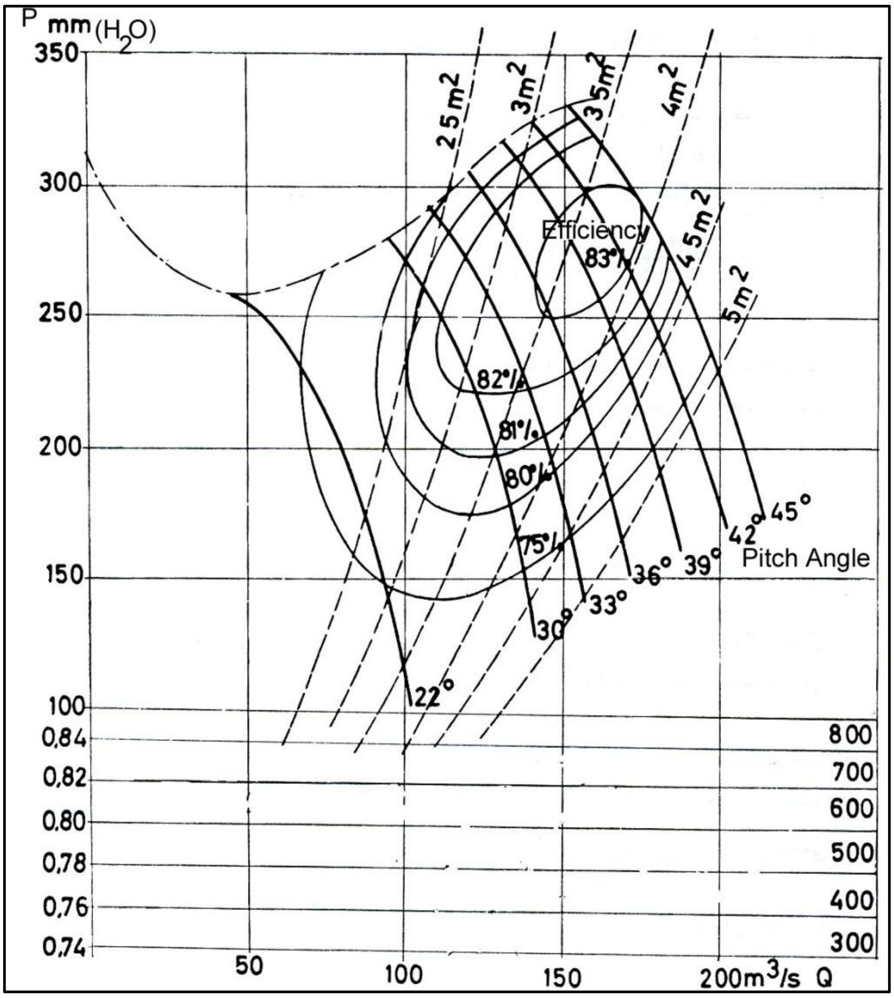

Figure 2.3 Pitch angle curve related to pressure and air quantity (Madani, 2003)

For use of Table 2.1, all fans are assumed to have the same model and uniform geometrical symmetry, Table 2.1 can be written as Equations (2.1)-(2.5):

$$Q \propto nD^3 \quad \text{or} \quad \frac{Q}{nD^3} = cte \tag{2.1}$$

$$P \propto \gamma n^2 D^2 \quad \text{or} \quad \frac{P}{\gamma n^2 D^2} = cte \tag{2.2}$$

$$N \propto \gamma n^3 D^5 \quad \text{or} \quad \frac{N}{\gamma n^2 D^5} = cte \tag{2.3}$$

In Equations (2.1)-(2.3):

Q = airflow,

P = pressure,

N = power on blades,

D = diameter,

n = rotation speed, and

γ = specific weight.

Moreover, some terms, such as specific speed and specific volume presented in Equations (2.4) and (2.5), respectively.

$$n_s = \frac{nD}{\sqrt{P}} \tag{2.4}$$

$$Q_s = \frac{Q}{D^2\sqrt{P}} \tag{2.5}$$

Specific speed (n_s) and specific volume (Q_s) are utilized in the selection of an appropriate fan. However, features of a fan are calculated in fix speed and handling of operational curve of fan represented on Table 2.1. Furthermore, different types of parameters have impression on selection of a fan, so making a decision in selection of an optimized preference is an essential task. Hence, application of decision making method is helpful in making decision about selection issue.

2.4 Overview on Decision Making (DM) Methods

Decision Making (DM) is an essential operation for every manager. An appropriate DM is one of the instruments which have a great role in success of every organization. Therefore, application of scientific methods is undeniable subject which is helpful in the beneficial DM. Decision maker handles varieties of parameters and most of DMs are Multi Criteria Decision Making (MCDM). Moreover, Multi Criteria Decision Making (MCDM) is categorized into two groups as: i) Multi Objective Decision Making (MODM) and ii) Multi Attribute Decision Making (MADM). Decision making has a vital character; which, Momeni (2008) stated that management and DM have the same utilizations. In addition, decision making is basic focus of management. DM covers planning, organization, and control subjects. In addition, Momeni (2008) expressed that management is a function of DM which is a method or a departure in a special direction and it is a proper goal between wide ranges of goals based on an adequate concept. Basic level for DM is data gathering. Moreover, data's quantities and qualities are very important. Quantity of data should be optimized but sometimes, experts must make decision based on limited quantity of data and short time for DM issues.

Momeni (2008) stated that decision making process has five steps as illustrated in Figure 2.4:

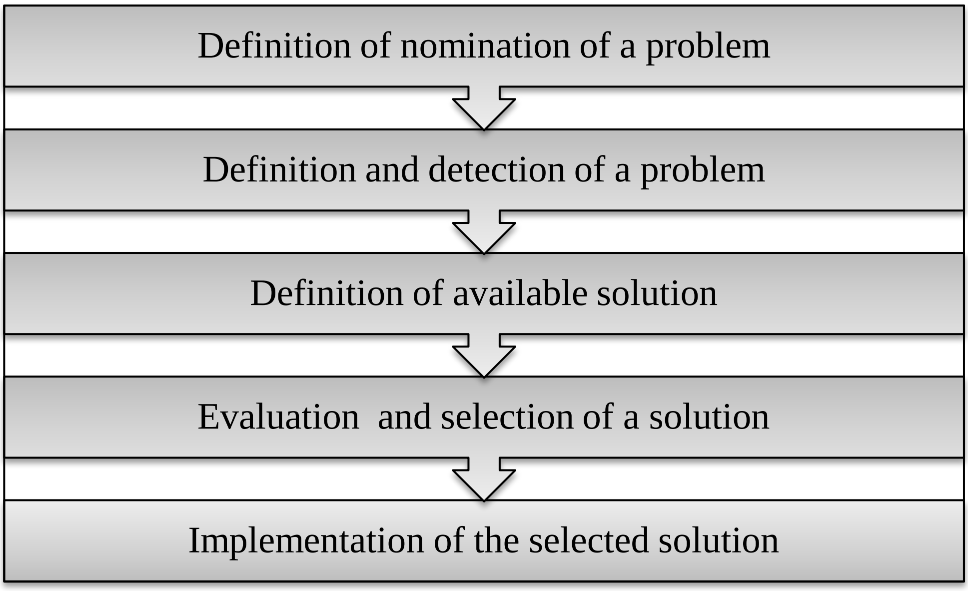

Figure 2.4 Decision making process (Momeni, 2008)

DM is a general term and it should be explained in specific method. Thus, as an extension, Multi Criteria Decision Making might be applied as a DM method. MCDM is expanded a type of DM and it is utilized frequently.

2.5 Multi Criteria Decision Making (MCDM)

Optimization of a problem based on a goal has been an essential subject since Second World War. Hence, multi criteria have a key subject in optimizing problems. As an example, in buying a car variety types of factors, such as, cost, safety, elegance, and consumption of fuel, have effects. However, some of these factors are in contrast with each other. MCDM has two popular methods MADM and MODM. Therefore, MADM is an applicable method which is based on type of problem.

The criteria analyze is done in MADM subjects. Decision makers define criteria very carefully and every criterion is studied for each switch. MCDM is represented by decision matrix. The format of decision matrix is shown in Table 2.2.

Table 2.2 Decision Matrix (Momeni, 2008)

Switch \ Criteria	C_1	C_2	...	C_j	...	C_n
A_1	a_{11}	a_{12}	...	a_{1j}	...	a_{1n}
A_2	a_{21}	a_{22}	...	a_{2j}	...	a_{2n}
...	...	...	...	...	...	...
A_m	a_{m1}	a_{m2}	...	a_{mj}	...	a_{mn}

Criteria in MADM have different scale and most of them are in opposite situation with each other. Moreover, an ideal criterion does not exist. However, criteria have positive and negative aspects. Thus, access to the optimum criteria is impossible, but the selection of an optimized criterion is possible. In data gathering step, the best method is to make questionnaire forms (e.g. Appendices A and B), and questionnaire forms gather data in qualitative format. Hence, the qualitative data must be converted to the quantitative format.

2.5.1 Modifying Qualitative Criteria to Quantitative Ones

In DM subjects, quantitative criteria and qualitative criteria exist. Qualitative data which is gathered from the questioner forms should be changed to the quantitative format. Variety types of methods are utilized to convert the qualitative criteria to the quantitative ones. The most commonly utilized method for this purpose is utilization of distance and degree scales. One of the popular methods for conversion based on the distance scale is bipolar distance scale which is shown in Figure 2.5 (Momeni, 2008).

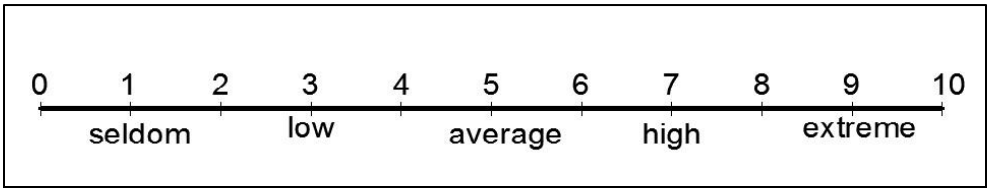

Figure 2.5 Positive aspect of bipolar distance scale (Momeni, 2008)

This measurement has eleven points which has infimum zero and suprimum 10. This scale applies in criteria with positive aspect. The scale in Figure 2.6 is utilized in negative aspect.

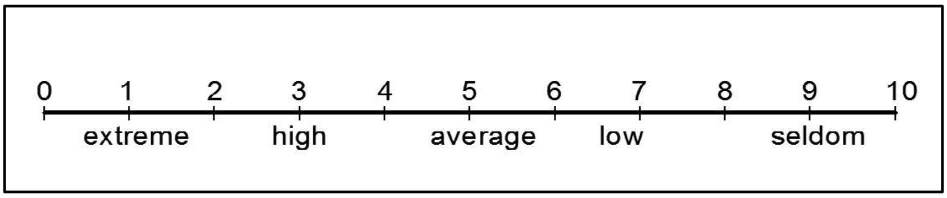

Figure 2.6 Negative aspect of bipolar distance scale (Momeni, 2008)

In application of this type of scaling, two assumptions are necessary:
1. Distance between low and seldom must be equal to the distance of high and extreme.
2. Point nine has triple power of three points.

After converting qualitative data to quantitative ones, application of normalizing for data is necessary task. Normalization makes criteria without aspect for doing more evaluations on data.

2.5.2 Normalization of Variety Types of Data

Criteria with positive and negative aspects exist in decision making matrix. Moreover, quantitative criteria have variety types. Therefore, comparison between criteria will be done when normalization applied for criteria. Three types of techniques are applied for normalizing:

i) Application of norm,

ii) Application of linear normalizing, and

iii) Application of fuzzy normalizing.

Norm method is shown in Equation (2.6).

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \tag{2.6}$$

In Equation (2.6), n_{ij} is an element without scalar. This element refers to switch i and criteria j. Thus, all columns of a decision making matrix has the same scale, so comparison is done very easily for elements.

In the linear normalizing, all elements have positive aspect, so every element in a column divided by a maximum element in that column, which is presented in Equation (2.7).

$$n_{ji} = \frac{a_{ij}}{Max(a_{ij})} \tag{2.7}$$

Moreover, Equation (2.8) is applied for criteria with negative aspect.

$$n_{ij} = 1 - \frac{a_{ij}}{Max(a_{ij})} \tag{2.8}$$

Positive and negative aspects exist in a DM matrix, so negative aspect must be converted to positive side by inversing, which is shown in Equation (2.9).

$$n_{ij} = \frac{\frac{1}{a_{ij}}}{Max(\frac{1}{a_{ij}})} = \frac{Min(a_{ij})}{a_{ij}} \tag{2.9}$$

Results of Equations (2.7)-(2.9) are quantities between zero and one.

Fuzzy normalization formula in Equation (2.10), is used, when criteria has a positive aspect. On the other hand, formula in Equation (2.11) is utilized for a negative aspect.

$$n_{ij} = \frac{a_{ij} - a_i^{Min}}{a_{ij}^{Max} - a_i^{Min}} \tag{2.10}$$

$$n_{ij} = \frac{a_i^{Min} - a_{ij}}{a_{ij}^{Max} - a_i^{Min}} \tag{2.11}$$

After normalizing data, the next essential process is making weights for criteria. Weights for criteria present priority in DM procedure.

2.5.3 Evaluation of Criteria Weights

In decision making problems lots of criteria have roles, so recognizing comparative importance of criteria is very essential. Therefore, every criterion takes a weight, so that summation of weights could be equal to one. These weights represent importance of every criterion in comparison with other criteria. Variety types of methods are applied for evaluation of comparative weights. They are:

i) Entropy method,
ii) Linmap method,
iii) Least squares method, and
iv) Special vector method.

Based on these methods, new soft computing methods are utilized for criteria weights. In addition, operations of criteria weighting is done in core of MADM procedure. On the other hand, combination of soft computing method (i.e. is applied for making weight for criteria) with MADM for weighting of criteria has become popular.

MADM has different methods, such as, SAW, TOPSIS, ELECTRE, and AHP. One of the popular models for MADM is AHP. In a study about selection of Tunnel Boring Machines (TBM), Edalat *et al.* (2011) applied MADM method. TBM selection study represents variety types of parameters which have role in TBM efficiency. The author divided the goal to three sub-goals: i) technical adequacy, ii) cost, and iii) environmental impact. Technical adequacy has six criteria, cost has two, and environmental impact has three criteria. Thus, Edalat *et al.* (2011) noted that major objectives are i) maximizing the technical adequacy, ii) minimizing the costs, and iii) minimizing the environmental impact. The authors studied to make a decision for two different types of TBM, which are Earth Pressure Balance (EPB) and Slurry Shield (SS). Multi Criteria Method (MCM) was utilized for selecting optimized TBM for a tunnel.

2.6 Analytical Hierarchy Process (AHP) as MCDM

Kahraman (2008) argued MCDM as a famous method in DM issues. Kahraman (2008) presented two categories of MCDM exist as Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). One of most popular MADM method is Analytical Hierarchy Process (AHP), which was developed primarily by Saaty (1977). This method analyzes problems like human brains and gives abilities to decision makers to identify reaction of complex and vague conditions. Thus, AHP process helps decision makers to arrange their preferences based on their experiences and goals. Moreover, emotions and judgments are included in arrangements. AHP is based on a ranking method due to weights of pairwise comparisons. Decision makers are formed complex structure to hierarchy manner by AHP (Cheng *et al.*, 1999). Moreover, Kahraman (2008) noted that pairwise comparisons matrix is summarized by AHP. Decision making problem in criterion (i.e. top of the hierarchy or goal) are divided into criteria, sub-criteria, and decision alternatives at the bottom of the hierarchy.

The application of the AHP to the complex problem usually involves four major steps (Cheng *et al.*, 1999):

1. Dividing a complex problem into small elements and structured elements in the form of hierarchy.
2. Providing elements in pair forms.
3. Applying eigenvalue method for providing relative weights of pairs, and
4. Aggregating these relative weights and synthesizing them for the final measurement of given decision alternatives.

Park *et al*. (2002) applied case-based reasoning for prediction of bankruptcy. In case-based reasoning, similar results of previous data for similar new problems are used. The author applied k-nearest neighbor as a derivative method of case-based reasoning for bankruptcy prediction issue. Park *et al*. (2002) noted that case-based reasoning uses retrieve relevant cases from case library (i.e. data set). The authors said that utilization of retrieve relevant cases was done in three steps such as: i) important attribute of a new case for retrieving candidate were selected, ii) accumulation of match score for comparable cases, and iii) retrieving those comparable cases with higher aggregation match scores. Park *et al*. (2002) showed in k-nearest neighbor similarity is calculated by Equation (2.12):

$$\text{Similarity (T,S)} = \sqrt{\sum_{i=1}^{F} w_i (T_i - S_i)^2} \tag{2.12}$$

In Equation (2.12), w_i is the weight of feature, T_i is target case, S_i is source case, F is number of attribute, and i is number of attribute. Park *et al*. (2002) argued that evaluating appropriate weights for k-nearest neighbor would increase performance of this method. Thus, expert judgments for making weights were used in Park *et al*.'s (2002) study. In case-based reasoning method, variety types of methods were combined for yielding better results. Therefore, Park *et al*. (2002) utilized combination of analytical hierarchy process with k-nearest neighbor for making decision about index of bankruptcy prediction. In that study, 21 experts' judgments were utilized and these expertises were used in AHP method for making weights for criteria. Park *et al*. (2002) made two criteria for bankruptcy problem. They are financial criteria and non-financial criteria. In this study, expertise represented that financial criteria has 63 percent weight in contrast to non-financial criteria, which has 37 percent of weight. In addition, Park *et al*. (2002) divided financial issues to five sub-criteria such as: i) stability, ii) profitability, iii) activity, iv) productivity, and v) growth. Final result of this study yielded that profitability has higher degree of weight. Park *et al*. (2002) utilized AHP approach to making classification based on weights of criteria in k-nearest neighbor method. The combined method were used and yielded better result in contrast to the pure k-nearest neighbor.

Berrittella *et al*. (2009) utilized AHP for decision making about two major factors of airlines management, which are low cast airline and full service airline. Moreover, the authors noted that in airline management two factors have role, direct costs and indirect costs. Berrittella *et al*. (2009) represented that direct costs has 50 percent of weight for DM in contrast to overburden costs (i.e. its weight is 42 percent) and other costs (i.e. its weight is 8 percent) for low cost airlines. On the other hand, this study yielded that direct costs has 41 percent of weight, overburden costs has 47 percent and other costs has 12 percent degree of costs in full service airlines. Berrittella *et al*. (2009) presented major proof of low cost airlines' success. The authors utilized Monte Carlo for sensitivity analysis and Monte Carlo represented robustness of the results.

Delgado-Galvan *et al*. (2010) applied AHP for water leakage management. The study was utilized four criteria and two sub-criteria. These criteria were: planning development and its implementation, damage to properties, supply disruption, and closed or restricted street. Moreover, sub-criteria were categorized as active leakage control and passive leakage control. The authors tried to improve the consistency application of pairwise comparison in the study. Delgado-Galvan *et al*. (2010) compared their consistency with conventional method of consistency index and the authors overcame the problem of conventional consistency.

Dey *et al.* (2008) utilized AHP for a site selection in limestone quarry operation. The authors noted that site selection was an essential task in quarry expansion to support cement production. Dey *et al*. (2008) faced with three alternatives as goal for a site selection and selection of a site is dependent on variety types of criteria. Thus, the authors applied AHP as a methodology for MCDM issue. Dey *et al*. (2008) presented seven steps as their methodology's steps, such as: i) identifying site alternatives, ii) identifying factors and sub-factors for selection issue, iii) comparative data base for selection, iv) improving the hierarchical method for site selection based on AHP, v) making importance for goals and factors, vi) taking weights as priority rank for alternatives and criteria, and vii) synthesizing results across the hierarchy for a site selection. Site selection issue has three alternatives and four criteria, which are: technical, environmental, social, and national planning network. Moreover, Dey *et al*. (2008) represented that every criteria has two sub-criteria at least. The study showed that utilization of AHP in site selection was an effective methodology which contains objective and subjective in core of the solution.

Sharma *et al*. (2008) stated that distribution has vital role in supplying chain and consumers' experiences. Companies select variety types of distribution systems for supply chain. The authors noted that chain should integrate the wide ranges of elements and designed chain, which should optimize for achieving an appropriate chain. This study deals with design and selection of an appropriate chain configuration to achieve optimal performance. Sharma *et al*. (2008) stated that distribution is done by two formats: i) product is delivered to customers directly and ii) product is delivered by intermediary level. Each network has weakness and strength and selection of suitable system which contains maximum amount of positive points is a necessary task. The authors argued that costumers need to satisfy at the lowest possible cost. Sharma *et al.* (2008) utilized two factors as criteria, cost factor and service factor. Moreover, author used five sub-criteria: i) inventory, ii) transportation, iii) facilities and handling, iv) response time, and v) product variety. Evaluation of this study represented that cost factor has 67 percent of weight and 33 percent of weight related to service factor. In addition, transportation was selected as major sub-criteria in distribution system.

Hariharan *et al.* (2005) developed a model for measuring of intensive care units and applied the model to compare the quality of services and its improvement. The authors noted that health care delivery is multifactorial. The authors utilized analytical hierarchy process to evolve the model. Hariharan *et al*. (2005) identified sub-factors which have influence on the critical factors. In the study, three intensive care units were used as switches. In the study, questionnaire forms filled by 15 anesthesiologists, 5 senior nurses, and 10 staff nurses. Hariharan *et al.* (2005) noted that consistency check was done and it was found to be less than 0.1.

Das *et al.* (2003) utilized AHP as a method of DM for selection of an appropriate tool wear. The authors applied three components of cutting forces for decision making about a tool wear, which can be in three situations i) sharp, ii) workable, and iii) worn out. Das *et al.* (2003) noted that sharp cutting tool wears out with the progress of machining time, so utilizing the tool causes reground of wear. Thus, DM about changing time of tool wear is very important. Three criteria were used, which are: feed force, transverse force, and tangential force. The authors evaluated eigen value and consistency index for criteria comparison, which are 3.029 and 0.0045, respectively. Das *et al.* (2003) stated that result of AHP utilization for the estimated state of tool wear match to the directly observe red state of tool wear.

However, application of classical AHP has some defects, such as disability of method on making degree of weight for experts' judgment. Thus, combination of AHP with expert system is essential to solve these deficits. One of these expert systems is Fuzzy Logic.

2.7 Fuzzy Logic (FL) as MCDM

Fuzzy logic (FL) concept was stated by Zadeh (1965). This method has being expanded during years and application of this method has become popular. This logic is applied in misgiving situation. Fuzzy can change formation of lots of imprecise and ambiguous to mathematical model. This deformation allows controlling and making decision about these subjects. Azadegan *et al.* (2011) stated that:

> "*Fuzzy Logic and tools based on fuzzy logic, allow for the inclusion of uncertainties and imperfect information in decision making models, making them well suited for manufacturing decisions*".

Fuzzy talks about subjects, which do not have exact limits, as an example: an apple exists on table, if it is cut to piece and ask: is remaining part an apple? Thus, answer is yes. If it is continued the cutting operation and cut it again and ask it again and again, remained part is an apple. Thus, main question is "when apple change to nothing?" Recognition of limits, which shows sets definition is an essential duty of FL.

Words like "good", "bad", "strong", "weak", "warm", and "hot" are utilized all the time, but where is exact boundary for these words. Moreover, these adjectives are utilized more in daily life.

Some cases like "all" or "not all", "women" or "man", "black" or "white", and "A" or "not A" in science are applied usually. In classical view of sciences every predicate has two aspects true or false. Moreover, every fact has two sides "white" or "black". In addition, Aristotle stated this binary idea. Aristotle's logic shaped classic mathematic. Binary concept also categories everything into two parts as "true" or "false".

Amelia *et al.* (2009) noted that FL has a mechanism in providing mapping between crude palm oil and palm kernel losses. Moreover, Amelia *et al.* (2009) argued utilization of FL in the production and optimization, which has become popular since 1975. Moreover, Mamdani and Assilian (1975) used FL controller for a steam engine for the first time. The authors modeled palm oil production by FL as expert system. Variety types of methods for modeling were used such as: genetic algorithm and visual basic editor. Amelia *et al.* (2009) represented that FL had a better result for modeling of crude palm in comparison to other heuristic optimization methods.

Thus, application of FL covers lack of full experts' ideas and judgments in AHP, and this method is called Fuzzy AHP. Modaress *et al.* (2010) applied Fuzzy AHP for training center of Industrial Management Institute as Iranian educational system for training managers. Study represented an optimized short course which is necessary for managers. Modaress *et al.* (2010) utilized linguistic parameters for pairwise comparison matrix. In addition, Modaress *et al.* (2010) fuzzified criteria and weights revealed for criteria. Many researchers were utilized Fuzzy AHP as a DM method for selection. Chiou (2005) applied

Fuzzy AHP for DM for small and medium enterprise in construction field. The author categorized criteria to five parts: i) Enterprise Strategy Planning, ii) Consortia Partner Selecting, iii) Alliance Interface Management, iv) Regulation Completeness, and v) Government Incentive Policy. Chiou (2005) applied Fuzzy AHP and SAW (Simple Additive Weight) method for DM. The study represented Fuzzy AHP was utilized to provide weights of considered criteria and make a priority for criteria and alternatives. Tolga *et al.* (2005) studied on application of Fuzzy AHP on operating system selection. In the study, the selection has two major criteria economic aspects and non-economic aspects. Energy sources selection was done by Fuzzy AHP in Mexiner (2009). The author applied FAHP for making priority for application sources. The study noted that five parameters have role in DM about sources, which are: i) cost, ii) availability, iii) climate, iv) degree of dependency, and iv) utilization. The results presented that climate has the largest weight in contrast to other parameters. In addition, many researchers have utilized Fuzzy AHP as a DM method for selection (Hom, 2002; Kahraman *et al.*, 2003; Kapooer *et al.*, 2005; Azadegan *et al.* 2011; Özdağoğlu *et al.*, 2007). On the other hand, application of Fuzzy AHP based on complex calculations is a hard task, so necessity of a method which works easier is undeniable. In addition, application of Fuzzy AHP in a wide range of data is hard. Hence, application of Artificial Neural Network (ANN) will be suitable.

2.8 Artificial Neural Network (ANN) as MCDM

Human apply intelligence for dealing with problems. If this intelligence combined with science and wisdom, the combined method is changed to artificial intelligent system. Artificial Intelligence (AI) was stated after the Second World War, when Alan Turing (1945) examined contest of AI and human brain process. First robots manufacturing and application of machine language in Europe and USA started in 1960 (Momeni, 2008). Thus, researches about artificial intelligence achieve closer points to humans' abilities. One of the artificial intelligent systems is Artificial Neural Network.

Artificial Neural Network (ANN) is a dynamic system, which do processing operations on tentative data. Classification, speech recognition, pattern recognition, control systems, and vision have been done by ANN, which is trained to run complex functions (Demuth, 2001). Thus, Demuth (2001) results indicated that rule detected by ANN and network learns the rule. These systems learn total rules by calculation on numerical data or examples. In nature, the connections between elements largely determine the network function. Figure 2.7 illustrates simple ways that artificial neural network applies to learn.

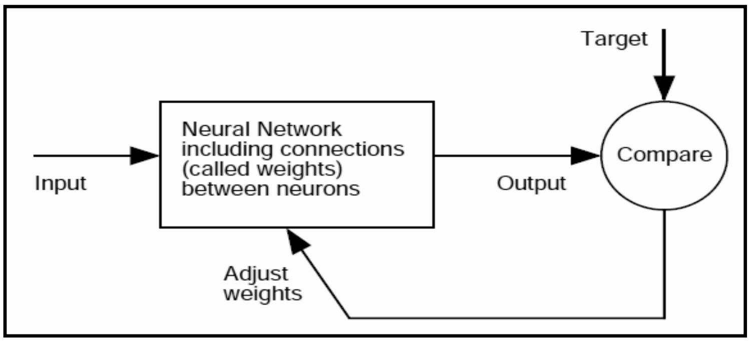

Figure 2.7 Schematic learning algorithm of ANN (Demuth, 2001)

Advantages of ANN are:

i) Simulation of nonlinear equations,
ii) Learning ability,
iii) Comparison ability,
iv) Learning ability during tests,
v) Tolerance damage ability,
vi) Relief ability,
vii) High speed processing operation, and
vii) Similarity to human neural network.

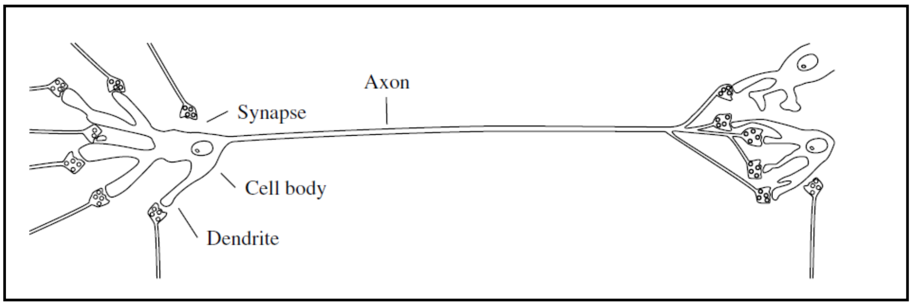

Figure 2.8 A Simple schematic of human neurons (Ross, 2004)

Neuron is the smallest part of the neural network, which processes data. In addition, neuron is an analyzer unit, which gets signals from variety of neurons by Dendrites. Ross (2004) argued that the neurons are stimulated by synapse. If accumulation of stimulates, which are received by a neuron is higher than a threshold value, the neuron will send an impulse to another neuron via axon (Figure 2.8) (Ross, 2004).

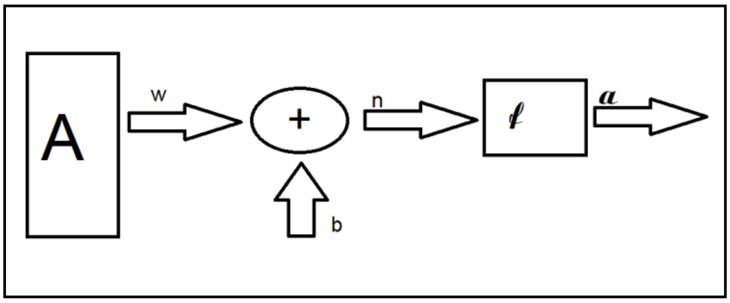

Figure 2.9 Single input model

In Figure 2.9 A and *a* are input and output, respectively. Moreover, effect of A on *a* defines by weight of W. Indeed, other inputs have constant value 1, which products by bias (b), and are added by WA. Thus, this summation will be absolute value n, which refers to function (*f*). Hence, output of neuron shows by Equation (2.13):

$$a = f(wA^T + b) \tag{2.13}$$

In multi-input model of artificial neural network (Figure 2.10), a neuron has more than one input. The threshold element sums the product of these inputs and their associated weights, compares it to a prescribed threshold value. Nonlinear function is applied when accumulation of stimulus is bigger that threshold value (Ross, 2004).

Ross (2004) argued

> "*The signal output y (Figure 2.9) is a nonlinear function (F) of the difference between the preceding computed summation and the threshold value which is expressed as Equation (2.14)*":

$$y = F(\sum w_i x_i - t) \tag{2.14}$$

In Equation (2.14):

x_i : signal input (i=1, 2,…n)

w_i : weight associated with the signal input x_i ,

t: threshold level prescribe by user,

F(s): is a nonlinear function, e.g., sigmoid function $F(s) = \frac{1}{1+e^{-s}}$.

The nonlinear function, F, is a modeling choice, which is a function in the type of output signal and it is desired in the neural network model. Popular choices for this function are a sigmoid function, a step function, and a ramp function on the unit interval (Ross, 2004). Duan *et al.* (2010) applied ANN for forecasting of blasting vibration. In this study, effects of vibrating parameters are predicted based on hole by hole detonation. Moreover, optimization method was utilized for forecasting about vibration effects, which represented ANN has better result in comparison to optimization method.

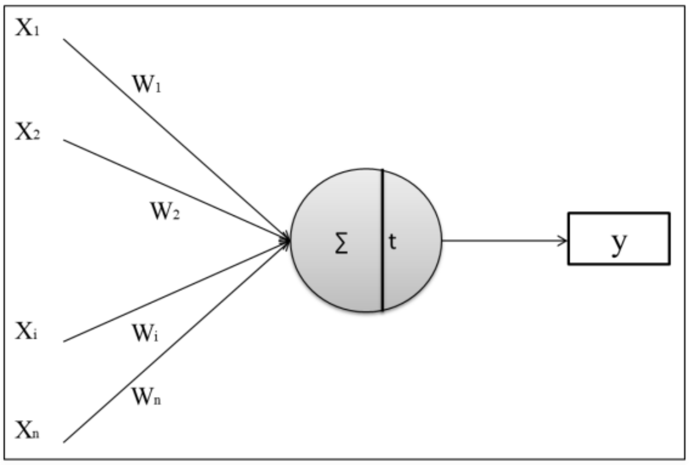

Figure 2.10 Multi-input neuron model (Ross, 2004)

Karacan *et al.* (2003) used ANN for optimizing methane emission in longwall mines. The author utilized ANN for modeling a system for controlling harmful gas emission from environment. Zeynelgil *et al*. (2002) applied ANN as a technique for automatic control of multi-area power system. The authors used ANN for controlling four interconnected power system. These areas contain steam turbines and hydro turbines. Zeynelgil *et al*. (2002) applied back propagation thought time algorithm for learning of ANN. Thus, results of study represented performance of ANN are higher than classical method of controlling. Güray (2003) developed a system for mining method selection based on ore body features. The author stated that previous studies methodologies were based on statistic data. Moreover, Güray (2003) noted that in previous related works engineers judgments were not included. In addition, the author said that there is not any specific formulation for mine method selection. Thus, Güray (2003) developed a system for selection of mine method based on 13 different expert systems and one inference agent. The author called this system Ore-Age system. Güray’s system were made in three variety parts, such as i) composition of thirteen virtual experts which was based Takagi-Sugeno-Kang (TSK) method, ii) mediator between uses and virtual experts, which is called Ore-Age system, and iii) user part. Güray (2003) noted that system has two contributions, data base of virtual evaluating which is provided by Neuro-Fuzzy method and tutoring ability of system. Güray (2003) stated variety type of methods were used for mine method selection, and said one of famous method is Nicholas method. The author represented Nicholas method has some deficits, such as: capital cost, operational cost, productivity factors, and spontaneous combustion factor, which are not included in Nicholas method. Güray (2003) applied all the Nicholas parameters and excluded defected parameters in Nicholas parameter in Ore-age system. The author argued previous studies utilized limited number of selection methods in decision making producers, but Güray (2003) used 12 selection methods as goal data base in Ore-Age system. Ore-Age system asks required data from user; aftermath, data send to virtual expert part. Then, the results of Ore-Age system are recommended to users.

2.9 Combination of Neural Network and Fuzzy Logic

Schmitz (1998) stated that nonlinear regression in time domain is done by a neural network model. The author claimed that application of ANN has a problem, which information is stored in ambiguous form, and it is impossible to interpret them by words. However, FL has an ability based on if-then rule (i.e. Fuzzy Logic is linguistic base method). In addition, FL utilizes natural language for its rule making producers, but it cannot learn rules by itself. Schmitz (1998) noted that combination of FL and ANN overcomes imperfections and this combination is called Neuro-Fuzzy method. Neuro-Fuzzy covers learning and readability at the same time. Application of Neuro-Fuzzy is so popular. Sahu *et al*. (2010) applied Neuro-Fuzzy algorithm for predication of spontaneous heating susceptibility in coal mines. The author represented that a main factor for fire in mine is spontaneous heating. Sahu *et al*. (2010) utilized MATLAB program toolbox which contains Adaptive Neuro-Fuzzy Inference System (ANFIS). In this study, the author applied three variables as inputs i) moisture, ii) volatile matter, and iii) ash content. Sahu *et al*. (2010) noted that Takagi–Sugeno– Kang (TSK) model was used in the study, but the studies' problem was based on linearity of data. However, Sahu *et al.* (2010) could not apply Neuro-Fuzzy appropriately and the studies' defects related to trend of data and method of Neuro-Fuzzy which is utilized for predication or classification. Moreover, Nauck *et al*. (1997) used Neuro-Fuzzy for FL classification rules from data. The study noted that Neuro-Fuzzy algorithm has been extended for covering FL controller and FL classifications. The author stated that Neuro-Fuzzy was applied for recognizing Fuzzy learning system, which was learned fuzzy sets and Fuzzy rules. Nauck *et al*. (1997) argued that Neuro-Fuzzy learn Fuzzy rule very easily and make a membership function appropriately.

CHAPTER 3

DESCRIPTION OFÇAYIRHAN COAL MINE

3.1 Introduction

In today's world, in order to continue daily life, electricity is undeniable energy, which is utilized in variety types of activities. There are different kinds of methods to production of electricity, and one of them is coal production. Thus, underground coal mines gain more importance. The Çayırhan lignite mine is one of the good examples for underground coal mines. The method which is utilized in Çayırhan mine is retreat long wall mining method and the coal production does not stop due to fully mechanized system. The mine area is about 80 km^2 and there are some sectors which are divided into sub-sections based on geological condition.

3.2 Description of Company

In Turkey, the first underground fully mechanized lignite production was executed in Çayırhan coal mine based on the central Aanatolia lignite project. Financial resources of this project have been provided by European Economical Community's credit and equity sources. For utilization of these sources, necessary machines and equipment for the mine were imported abroad. Equipment must work in harmony for maximizing the production rate. Per year 5.5-5.8 million tons pit-run coal is produced by fully mechanized method of production from Çayırhan underground mine.

Çayırhan coal mine was taken over by the Turkey Coal Institute in 1966, and the institute of business manager of Central Anatolia was established in 1977. In addition, business manager transformed into a regional manager in 1985, and fully mechanized production has started. In 1987, power of 2*150 MW consisting of two units of thermal power was operated. Bidding opened in 1966; in addition, operating rights of thermal power of 620 MW consisting of four units plant in 2000, and the mine site which feeds those power plants has transferred to "Park Teknik Electrical Mining Industry Joint Stock Company" according to law of No.3096 Build-operate-transfer. In 1996, the company received the B and C fields' production projects, investments, and operations; then, the company provided the operation of A and F fields by rehabilitating. In 2004, the company has undertaken projects by following phases of the project and investment in the G field.

3.3 Area Information of Çayırhan Lignite Mine

Çayırhan Lignite pit has been operating in the Çayırhan where is located in the town of Nallıhan and the province of Ankara. Business takes places in 122 km of Ankara, which is located on Ankara-Nallıhan way. The mining area is spread about 80 km^2. Although there are some little up hills in the area. In addition, some dried up riverbeds can be observed.

Continental climate's characteristics are observed clearly which causes annual variation due to lack of water bodies. Moreover, summers of Çayırhan are hot and dry; winters are cold, rainy, and snowy. The weather conditions do not have a major influence on the mining operations since Çayırhan is an underground mine.

Required employee for the power plant and lignite mine is provided from the population who are living around Çayırhan coal mine, and this situation is the major income for the most of the native miners. However, some of the workers come from other cities, because of the good working opportunities in Çayırhan lignite mine.

The transportation of workers, who is living out of mine, is provided by buses. In addition, at the beginning of working hours, buses leave the workers to their working area and at the end of working hours; buses bring workers again to their offspring places. Moreover, there are private companies that provide transportation with buses between Ankara, Beypazarı, and Nallıhan.

3.4 Geology of the Çayırhan's Deposit

In Çayırhan lignite mine, coal deposits located on rough surface conditions which are composed of three veins. Coal seams have a slope which is changing between 6 degree to 30 degree, and it is located between layers of marl. The thickness of the overburden on two separate vein of coal is 150-300 meter. The average thicknesses of these veins are 1.5 m for roof vein and 1.7 m for vase vein. The marl layer, which has thickness 0.7-1.5 m, separates these roof vein and base vein from each other. Moreover, about 150 m below these two veins, there is a third coal seam ranging 2-11 m in thickness.

The coal is mostly homogenous in Çayırhan lignite mine. The density of the roof vein is 1.5 tones/m^3 and the density of the base vein is 1.4 tones/m^3. The Çayırhan coal mine stratigraphy is divided into four series and this series formed during Miocene era. All the coal formations are observed in this series.

M1 series: Coal formation is located in this series. A layer of siliceous limestone which is approximately 5-6 meters in thickness, and it is located the upper parts. Moreover, two coal seams are separated by sub-layer. The sub-layer consists of brown silica stone. A green colored argillite layer can be observed below these layers.

M2 series: the thickness of the layer which is composed of clay and marl is 80-120m. The lower and upper level of the M2 covered with oil shale and its thickness is around 20m. Although it has a high energy potential, so the production of this oil shale will be profitable.

M3 series: M3 has the hardest formation which is composed of silica lime stone. The thickness varies between 30-35 meters. Water is stored in large numbers of cracks at the lower levels of these layers.

M4 series: the major part of the area is covered by this formation, which was formed from gray, green, red, and beige color tuffs. Table 3.1 describes properties of top, intermediate, and bottom seams.

Table 3.1 Thickness of the coal veins and the sub layer (i.e. Table was gotten from Parkteknik archive)

	Average thickness (m)	Maximum thickness(m)	Minimum thickness (m)
Top seam	1.52	1.95	1.06
Intermediate seam	1.72	2.25	1.00
Bottom seam	0.85	1.70	0.45

The age of coal in the region has been identified as the lower Miocene. This region is tectonically quiet generally. There are faults in the direction of northwest-southwest, which are named as Davutoğlu and North faults. Moreover, there are minor faults perpendicular to these faults. Coal seam has a uniform thickness and faults affect the formation of mechanized panels which are not available except some areas in sector G.

420 million tons of coal reserves are determined in 80 kilometer square area in the coal basin, which was observed after the geological surveys and drilling operations. According to exploration analyses; coal seam consists; 22.06 percent water, 30.17 percent ash, 23.25 percent volatile substance, 23.94 percent carbon (c), 4.2 percent sulphur (S), and its calorie is 2500 kcal/kg.

3.5 Utilized methods in Mining Operation of Çayırhan

In Çayırhan Lignite coal mine, the methods which are utilized to excavated coal is fully mechanized and its method for excavation is long wall mining. In Çayırhan basin, taking into account main faults and synclinal structure, the basin is divided into sectors (i.e. sector B, C, and G). Excavation, transportation, supporting, and ventilation are done by the same method for all the sectors.

In underground mining, preparatory activities can be defined as the opening of necessary roads in order to reach ore. In the preparation, production panels are created in every sector with the help of a major transportation gallery. The major transport galleries have been proposed on stone and coal. Separating the galleries of production panels is called bottom foot-wall. Bottom foot-walls are the preparation work in the coal and equal to the height of coal vein. Bottom stone is composed of green clay stone. A structure known as sub-layer is composed of sandstones and upper stone is composed of fine sand stones, shale, and limestone bands.

The excavation operation of the bottom foot-walls are done by a machine which is called drum cutter-loader machine and it can open partial cross-sections. Coal faces are excavated by a drum cutter-loader machine and as well as with the drilling-blasting operations. In order to reduce the formation of dust and prevent the wearing out and burning of the cutting bits, water is sprayed during the excavation.

Two or three steps are performed in the excavation of coal faces. Bottom and upper cuts are excavated by a drum cutter-loader machine and then with the drilling-blasting operations, the necessary space is opened in order to provide faces for drum cutter-loader machine for working efficiently. In the drilling-blasting operations, antigrizu explosive are utilized. Blasting operations are performed by utilizing the electric capsules and assistant of magneto. Water-filled cartridges are used to in tightening and the suppression of dust.During preparatory works in operation, three different types of drum cutter-loader machines are utilized. These machines are designed to work efficiently and with low compression strength of rocks.

Fully mechanized long wall mining method consists of shearer-loader machine, walking supporting units, chain conveyors, transfer chain conveyors, band conveyors, power units, and transportation units. Transport of coal in the production process starting with the excavation of shearer-loader machine continues with chain conveyors in wall, transfer conveyors, and band conveyors. During excavation of shearer machine, a method is applied in order to pass a new excavation area. In this method, at each side of the wall with length of approximately 220 m and along approximately 20 units of walking supporting system, shearer-loader machine is made a special maneuver in order to become ready for new excavation face.

Each cut of shearer-loader machine takes 220-240 minutes for each wall face, except the preparatory operations at the beginning, which takes approximately 60-90 minutes. Under normal circumstances, each shift can make 2-4 cuts. However, in special circumstances related to the amount of production, more quick production can be carried out. Depending on the immersion depth of shear, 60-90cm progress is provided. Before starting the excavation work, maintenance work is done in machine.

3. 6 Transportation in Çayırhan

In all the sectors, the main transportation of the human and equipment are done by coolie cars and mono-rails. In the first 100m, transportation of excavated items is carried out with the chain conveyors. After proceeding of 100m, transportation of excavated items is carried out with the band conveyors. Coal installation to the transportation equipment is done by the drum cutter-loader machine. After blasting operation, the transportation of excavated items is done by electricity power side discharge loader.

The human and material transport to the foot-wall is done by electric monorail. The transportation of equipment between the end point of electric monorail and excavation area is made by compressed air monorails. Electric monorails can transport up to 12 tons. The rope speed is 2 m/s and the rope diameter is 16-19 mm. The utilized rails in mine are I 140 E and 3 m in length.

Human and material transport to the walls is provided with the endless rope system which is operated in railway systems. Especially in the transportation of heavy loads up to 30 tons can be done by rail furnished in the ground. Pull force of 140 N obtained from hydraulic system which works with the 250 kW electric motor, and it utilizes steel rope (28 mm). The coolies-car system is used in panel and walking supports transportation and it is essential while production continues in way of the upper floor. Material and human transportation in ways of the bottom floor is done by monorail system which can have a capacity up to 12 tons with special beams. Monorail system, similar to the coolie-car system, works with endless rope system. The utilized rope in monorail system is 18 mm steel rope. Pneumatic monorails that support both transportation system and generally utilized from the termination point of these systems to the excavation face are the other components of transportation system. Pneumatic monorails works with 6 bar compressed air and they are donated with air motors which have 6 kW or 9 kW working power.

3. 7 Ventilation System of Çayırhan

There is a control center out of the mine. In this control center, by benefiting from the measurement detector, rate of gases such as: CO, CO_2, O_2, and CH_4 are measured for every sector. In every shift, there is an engineer who is responsible for gases measurements especially for CO_2 and O2 ratio.

The fresh air comes from the south side and leaves from the north side in all sectors which is called natural ventilation. By natural ventilation, ventilation is possible for main gallery, but mine schemes are not included. However, foot-walls and mining faces which are important as much as main gallery, so the ventilation of these parts is carried out with the absorbent type forced ventilation which is the main ventilation system of mining in Çayırhan. The aspirator takes the fresh air from haulage way and accelerate it. The air is transported to the end of the gallery by the tube called "van tube". This tube has a diameter of 60 cm. The dirty air is pushed to the free face automatically and the fresh air is pushed into the gallery.

The dust that is caused by the cutting operation is collected by a special aspirator. The aspirator takes the dust throughout the van tube. Then the dust is mixed with water to produce mud.

3. 8 Supporting System of Çayırhan

Since the all operations are located underground, supporting is an important issue that should be focused on it. The main support system is walking support system that utilizes hydraulic power. The other support systems are steel support and steel straw systems.

In excavation works, after proceeding approximately 1.2 m, supporting operations are done up with intervals of 1 m. The supporting of main roads is carried out with V shape rigid supports. Opening sections of bottom foot-walls are opened in accordance with the inclination of the vein and layer and backed by trapezoid steel supports. The support of ceiling is made by yoke and the support of sides are made by plug connects. As an assist supporting, in order to prevent spills from the ceiling and side walls, steel wire meshes which are placed to ceiling and side walls in size of 0.5x1 m^2. In fact, steel brush and tightening wedges are utilized as an assisting supports.

In mining faces, walking support systems are used which are called hydraulic chocks. This system is attached to conveyor and as the shearer cutter-loader machine makes progress in face, both conveyor and hydraulic chucks are pushed by hydraulic power. This system differs in length since the coal seam has different thickness in different areas. There are also hydraulic props on the face and they are utilized to handle situations where involves extreme stress.

3. 9 Production Sectors of Çayırhan

Çayırhan contains three sectors such as: i) sector B, ii) sector C, and iii) sector G. Description of every sector is explained as below:

3. 9.1 Production Sector “B” of Çayırhan

In the area of sector B, the thickness of the sub-layer is 1.3-2 m and production starts from bottom face. As production continuous, ceiling mining face passes in front of the bottom mining face. The height of the ceiling wall is 1.60m and the bottom wall is 1.90 m. For balancing pressures on bottom and ceiling wall and for minimizing the risk of fire, 25-35m distance is left between bottom and ceiling mining faces.

In sector B, Eickhoff SL-300 double cutter –loader machine is utilized, for supporting on each bottom and ceiling walls, walking supporting systems is designed according to vein thickness. Transfer conveyors and double-chain conveyors are utilized. Chain tensioning units are mounted on the wall and transfer conveyors. With tension unit, the chain tension can be adjusted automatically and also chain jams can be removed by high torque which is produced by a unit with a low speed. The second important factor that reduces the chain jams is the region under the conveyors which should be closed. In order to keep chain abrasions as minimum levels, daily chain tension measurements are done.

The main ventilation system for section B is carried out in the form of suction tube forced ventilation. In preparatory galleries and walls, secondary ventilation blower system is utilized. In sector B, pneumatic air doors are used in order to direct the air. The amount of air per employee, who is working in the mine, is 15 m^3/min.

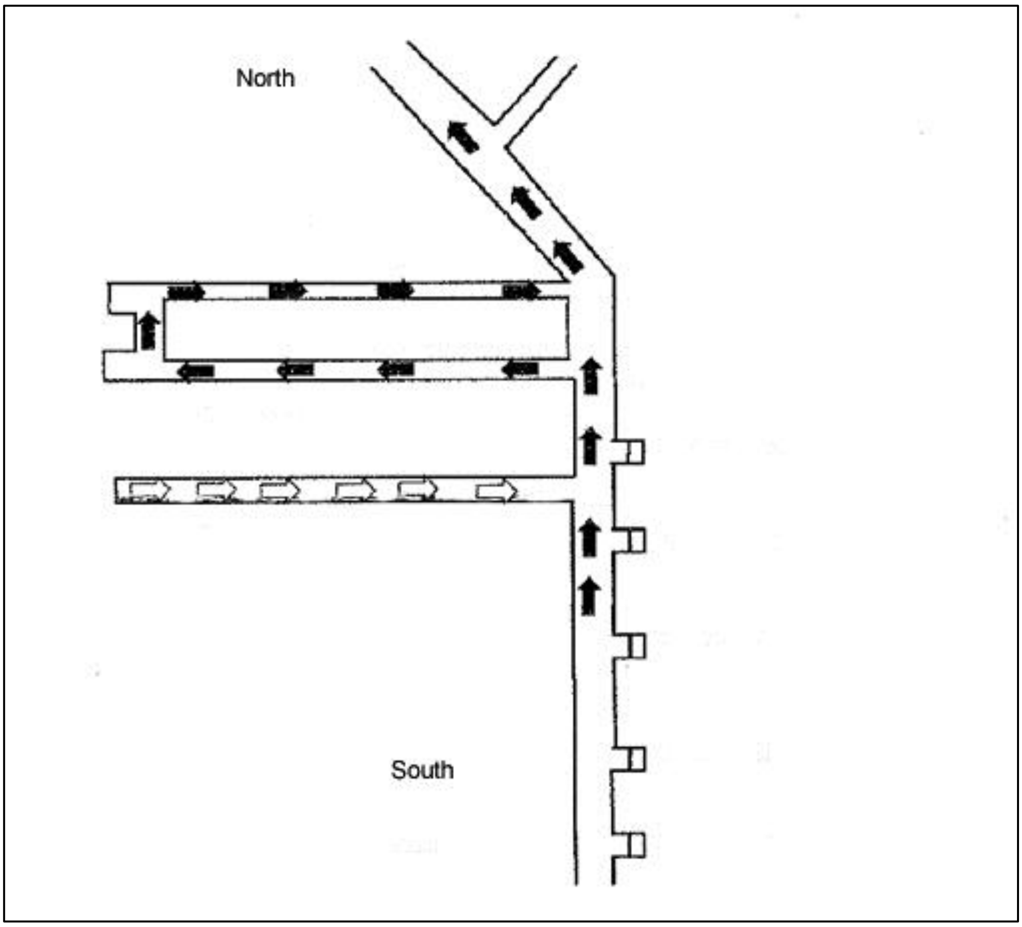

Figure 3.1 Example ventilation scheme for section B (İnan, 2005)

The transportation in section B is carried out by utilizing chain and belt conveyors. In sector B, produced coal is dumped by belt conveyors which have capacity around 200 tones. Aftermath, these coals are transported to coal delivery points with the trucks. In the mine, human and material transportation are made by monorails and coolie-cars.

3. 9.2 Production Sector "C" of Çayırhan

In the sector C, because of the thickness of the sub-layer between the veins which has 0.5-0.8 m thickness, bottom mining face and ceiling mining face are formed as one mining wall. Machines and equipment are chosen according to that formation of faces. The length of panel is 1750 m, the length of the mining face is 220 m, and the height of mining face is 4.5m. For creating production panels, drum cutter-loader machines are utilized in bottom foot wall and main gallery. In the production of sector C, Eickhoff SL-500 double shearer-loader machine is utilized. The coal produced by double shearer-loader machine is transported to bottom foot-wall by chain conveyors in mining face.

The major ventilation is carried out in the form of suction tube forced ventilation. In preparatory galleries and walls, secondary ventilation blower system is utilized. In sector C, pneumatic air doors are utilized in order to direct the air. The amount of air per employee working in the mine is 15 m^3/min.

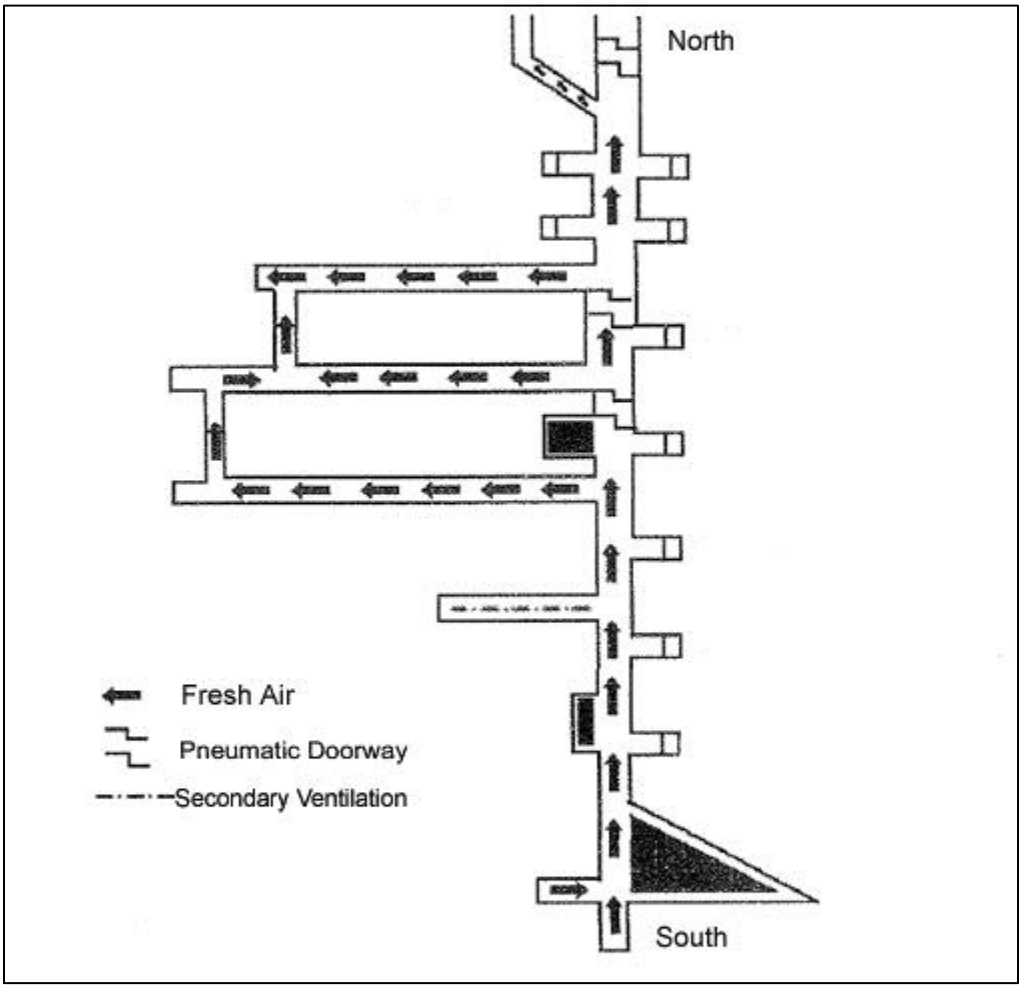

Figure 3.2 Example ventilation scheme for sector C (İnan, 2005)

The transportation of produced coal is carried out by utilizing chain and belt conveyors to out of the mine. The coal which is produced from preparatory works and mining face is transported out of the mine by belt conveyors in main gallery, so it reaches the delivery point. In the C sector of the mine, human and material transportation are made by monorails and coolie-cars.

3. 9.3 Production Sector “G” of Çayırhan

In section G of Çayırhan lignite mine, machines and equipment are chosen based on thickness of sub layers, which are between veins. The length of panel is 3200 m and the length of the mining face is 22 0m. Shearer-loader machine are utilized for creating of production panels in bottom-floor stages and main galleries. Due to faults that could not be determined at the planning stages, a special process, which is called “fault recovery”, is applied in excavation operation. The fault recovery operations affect the preparatory and production works negatively. In the production stage of G sector, Eickhoff SL-500 double shearer-loader machine is utilized. The coal produced by double shearer-loader machine is transported to bottom foot-wall by chain conveyors in mining face.

In G section of Çayırhan mine, form of suction tube forced ventilation is utilized. In preparatory galleries and walls, secondary ventilation blower system is utilized.

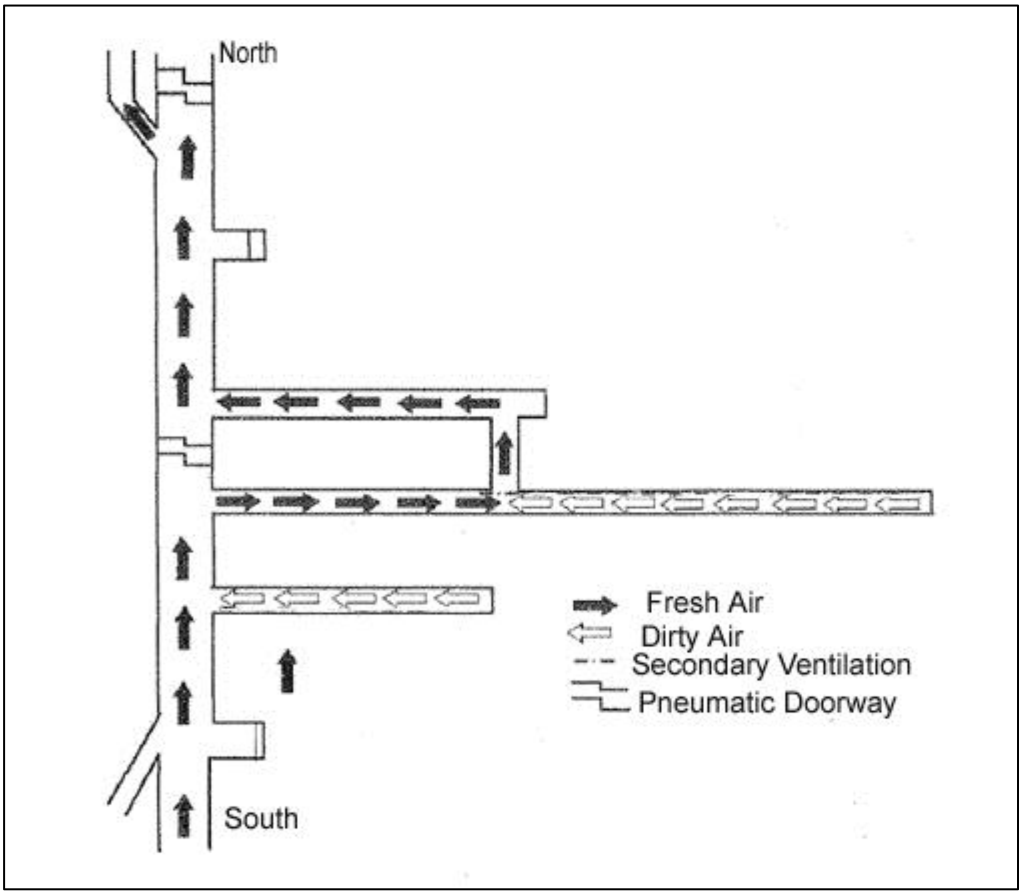

Figure 3.3 Example ventilation scheme for sector G (İnan, 2005)

The transport of produced coal is done by chain and belt conveyors in G section.

3. 10 Properties of Alternative Fans for Çayırhan Lignite mine

In this study, four types of fans were selected as alternative for ventilation system of Çayırhan lignite mine. Moreover, these fans are selected based on conventional method. Properties of these four types of fan are shown in Table 3.2.

Table 3.2 Properties of alternative fans for Çayırhan mine (İnan, 2005)

Fan Number	Operation pressure (Pa)	Air Amount into the Mine (M^3/s)	Fan efficiency (%)	Total motor Power (kW)
Fan No.1	515.00	69.00	25.00	142.10
Fan No.2	400.00	60.50	34.80	69.50
Fan No.3	423.00	62.25	28.80	91.50
Fan No.3	460.00	64.80	33.90	88.00

CHAPTER 4

FAN SELECTION USING ANALYTICAL HIERACHY PROCESS AND FUZZY ANALYTICAL HIERACHY PROCESS

4.1 Introduction

Ventilation is a vital process in mining operations. A ventilation system provides fresh air to different parts of a mine. Composition of fans and set of connected branches make a ventilation network (El-nagdy *et al.*, 2002). An appropriate ventilation network affects variety of aspects in a mine, such as: i) rate of production (i.e. increasing profit in financial side and decreasing operational costs) and ii) increase of safety. In addition, mines require very effective and proper fans to deliver enough fresh air for miners to breathe; and to keep the levels of explosive, harmful gases, and dust to a safe level. A proper ventilation system requires appropriate main fans for providing optimized air flow and pressure in all faces and phases of a mine shafts and tunnels. Therefore, decision makers based on lots of parameters select proper fans. Technical and financial features of fans are two major parameters in fan selection procedure. Moreover, the technical parameter has five significant factors i) air quantity, ii) pressure, iii) beneficial use rate, iv) beneficial air amount at the face, and v) total motor power. Financial parameter has two main factors capital costs and operating costs (Table 4.1). Fan selection for a ventilation network is completely dependent on the uncertain technical and operational characteristics of fans. Conventional method for fan selection is based on fan characteristic curves and mines operational curves, which depend on exact and quantitative data. On the other hand, other parameters have impact on fan selection process and most of these parameters are vague and imprecise. As a method, Operational Research (OR) is applied in Decision Making (DM) issues.

Analytic Hierarchy Process (AHP) is one of the OR methods, which has vital ability in DM subjects. Özdağoğlu *et al.*, (2007) represented AHP is an effective way for DM in complex criteria structure. Moreover, AHP is applied for selection of appropriate alternative among decision alternatives when decision makers face with lots of criteria (Taylor, 2004).

Table 4.1 The proposed hierarchy model to select an optimum fan based on operational parameters

Goal	Criteria	S-Criteria
Operational and financial selection of most appropriated fan (A)	Operational parameters (B1)	Air quantity (C11)
		Pressure (C12)
		Beneficial use rate (C13)
		Beneficial air amount at the face (C14)
		Total motor power (C15)
	Financial parameters (B2)	Capital costs (C21)
		Operational costs(C22)

Furthermore, Özdağoğlu (2007) stated that decision data might be applicable if data has precise format. Therefore, application of Fuzzy Logic for imprecise data is a suitable method. Thus, combination of classical AHP method with FL, is called Fuzzy AHP (FAHP), is proved to be appropriate in Decision Making (DM) subjects.

4.2 Fan Selection Using Analytical Hierarchy Process (AHP)

Fan selection for a mine is a vital task for mine design engineers in mining operations. Major role of fans in ventilation network is undeniable. Moreover, every ventilation networks have two categories of fans main fan and auxiliary fan. Based on classical method, main fan selection is done using fan operational curves and mine operational curves. Intersection of the fan operational curves and the mine operational curve presents an appropriate main fan for a ventilation network of a mine. Moreover, new programs, such as VNETPC and VENTSIM, in recent decades help mine design engineers in DM subjects.

In this study, available fan selection data obtained from the literature were utilized. İnan (2005) introduced four types of fans, which could be suitable for applying in a coal mine. Table 4.2 presents the fans and their features. The author suggested that Fan 3 is the appropriate fan for the coal mine. Figure 4.1 illustrates the model of hierarchy of these four types of fans.

Table 4.2 Selected fans and their features (İnan, 2005)

Fan name	Air quantity (m^3/s)	Pressure (Pa)	Beneficial use rate (%)	Beneficial air amount (m^3/s)	Total power (kW)
Fan 1	515	69.00	95	38.92	142.13
Fan 2	400	60.50	95	35.84	69.5
Fan 3	423	62.25	95	35.02	91.5
Fan 4	460	64.80	95	36.52	88.0

Classical AHP was used to make a decision for fans data (Table 4.2). Comparisons are based on two main criteria and seven sub-criteria by utilization of AHP methodology. Firstly, the pairwise comparison matrices were shown in Table 4.3. Normalizing the pairwise comparison matrix was estimated according to the Fan 1 features; therefore output of the normalizing is called as rational matrix. The same procedures were followed for Fans 2-4. Figure 4.2 illustrates procedure of AHP application.

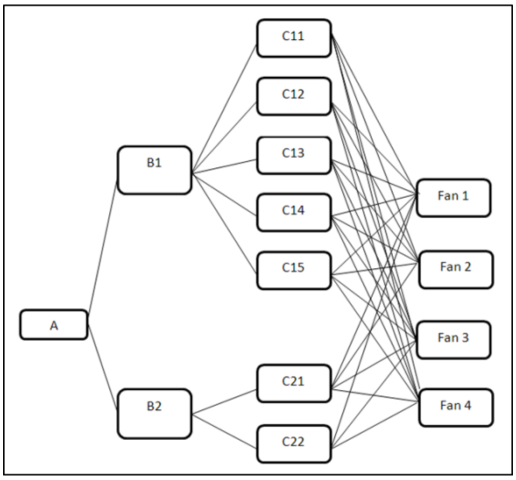

Figure 4.1. Visualized model of hierarchy analysis

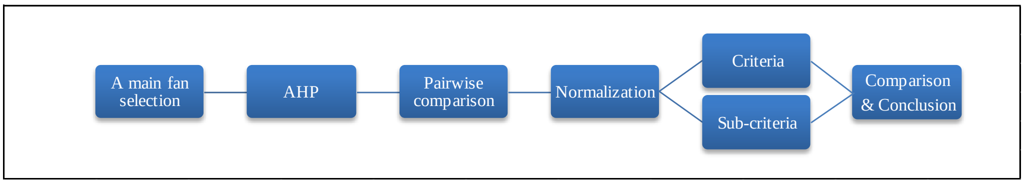

Figure 4.2 AHP methodology for fan selection

Table 4.3 The pairwise comparison matrix for Fan 1

Fan 1	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power
Pressure	1.000	0.134	0.184	0.075	0.276
Air quantity	7.464	1.000	1.377	0.564	2.06
Beneficial use rate	5.421	0.726	1.000	0.409	1.496
Beneficial air amount at the face	13.232	1.773	2.44	1.000	3.652
Total power	2.623	0.485	0.668	0.274	1.000
Total	30.74	4.118	5.669	2.322	8.484

Secondly, pairwise comparison matrices have been generated based on operational parameters. Tables 4.4-4.5 present pairwise comparisons of fans according to air quantity, pressure, beneficial use rate, and total motor power. Finally, results of operational parameters are shown in Table 4.6.

Table 4.4 Normalizing the pairwise comparison matrix according to Fan 1

Fan 1	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power	Ave.
Pressure	0.320	0.320	0.320	0.320	0.320	0.320
Air quantity	0.242	0.242	0.242	0.242	0.242	0.242
Beneficial use rate	0.176	0.176	0.176	0.176	0.176	0.176
Beneficial air amount at the face	0.430	0.430	0.430	0.430	0.430	0.430
Total power	0.118	0.118	0.118	0.118	0.118	0.118

Table 4.5 The pairwise comparison matrix for Fan 2

Fan 2	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power
Pressure	1.000	0.151	0.237	0.090	0.174
Air quantity	6.611	1.000	1.570	0.592	1.149
Beneficial use rate	4.210	0.636	1.000	0.377	0.732
Beneficial air amount at the face	11.160	1.688	2.650	1.000	1.939
Total power	5.755	0.870	1.367	0.516	1.000
Total	28.736	4.345	6.824	2.574	4.994

Table 4.6 Normalizing the pairwise comparison matrix according to Fan 2

Fan 2	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power	Ave.
Pressure	0.035	0.035	0.035	0.035	0.035	0.035
Air quantity	0.230	0.230	0.230	0.230	0.230	0.230
Beneficial use rate	0.146	0.146	0.146	0.146	0.146	0.146
Beneficial air amount at the face	0.388	0.388	0.388	0.388	0.388	0.388
Total power	0.200	0.200	0.200	0.200	0.200	0.200

Table 4.7 The pairwise comparison matrix for Fan 3

Fan 3	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power
Pressure	1.000	0.147	0.224	0.083	0.216
Air quantity	6.795	1.000	1.526	0.562	1.470
Beneficial use rate	4.453	0.655	1.000	0.369	0.963
Beneficial air amount at the face	12.079	1.777	2.713	1.000	2.613
Total power	4.622	0.680	1.038	0.383	1.000
Total	28.949	4.259	6.501	2.379	6.262

Table 4.8 Normalizing the pairwise comparison matrix according to Fan 3

Fan 3	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power	Ave.
Pressure	0.034	0.034	0.034	0.034	0.034	0.034
Air quantity	0.235	0.235	0.235	0.235	0.235	0.235
Beneficial use rate	0.154	0.154	0.154	0.154	0.154	0.154
Beneficial air amount at the face	0.417	0.417	0.417	0.417	0.417	0.417
Total power	0.160	0.160	0.160	0.160	0.160	0.160

Table 4.9 The pairwise comparison matrix for Fan 4

Fan 4	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power
Pressure	1.000	0.141	0.206	0.080	0.191
Air quantity	7.099	1.000	1.466	0.563	1.358
Beneficial use rate	4.842	0.682	1.000	0.384	0.926
Beneficial air amount at the face	12.596	1.774	2.601	1.000	2.410
Total power	5.227	0.736	1.080	0.415	1.000
Total	30.764	4.333	6.353	2.442	5.885

Table 4.10 Normalizing the pairwise comparison matrix according to Fan 4

Fan 4	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power	Ave.
Pressure	0.320	0.320	0.320	0.320	0.320	0.320
Air quantity	0.231	0.231	0.231	0.231	0.231	0.231
Beneficial use rate	0.57	0.157	0.157	0.157	0.157	0.157
Beneficial air amount at the face	0.409	0.409	0.409	0.409	0.409	0.409
Total power	0.170	0.170	0.170	0.170	0.170	0.170

Table 4.11 Pairwise comparison of fans based on parameters of Fan 1

Air Quantity	Fan 1	Fan 1 after normalizing	Fan 2	Fan 2 after normalizing	Fan 3	Fan 3 after normalizing	Fan 4	Fan 4 after normalizing
Fan 1	1.000	0.232	0.877	0.232	0.902	0.261	0.939	0.232
Fan 2	1.140	0.264	1.000	0.264	1.029	0.278	1.071	0.264
Fan 3	1.108	0.257	0.972	0.257	1.000	0.263	1.041	0.257
Fan 4	1.065	0.246	0.934	0.246	0.961	0.242	1.000	0.246
Total	4.313	1.000	3.783	1.000	3.892	1.000	4.051	1.000

Pressure	Fan 1	Fan 1 after normalizing	Fan 2	Fan 2 after normalizing	Fan 3	Fan 3 after normalizing	Fan 4	Fan 4 after normalizing
Fan 1	1.000	0.261	0.770	0.261	0.821	0.261	0.893	0.261
Fan 2	1.288	0.278	1.000	0.278	1.058	0.278	1.150	0.278
Fan 3	1.217	0.263	0.946	0.263	1.000	0.263	1.089	0.263
Fan 4	1.120	0.242	0.87	0.242	0.920	0.242	1.000	0.242
Total	4.625	1.000	3.593	1.000	3.799	1.000	4.13	1.000

Beneficial Air Amount	Fan 1	Fan 1 after normalizing	Fan 2	Fan 2 after normalizing	Fan 3	Fan 3 after normalizing	Fan 4	Fan 4 after normalizing
Fan 1	1.000	0.234	0.921	0.234	0.889	0.234	0.938	0.234
Fan 2	0.860	0.255	1.000	0.255	0.977	0.255	1.019	0.255
Fan 3	1.111	0.261	1.023	0.261	1.000	0.261	1.043	0.261
Fan 4	1.066	0.250	0.981	0.250	0.959	0.250	1.000	0.250
Total	4.263	1.000	3.925	1.000	3.835	1.000	4.000	1.000

Beneficial Use Rate	Fan 1	Fan 1 after normalizing	Fan 2	Fan 2 after normalizing	Fan 3	Fan 3 after normalizing	Fan 4	Fan 4 after normalizing
Fan 1	1.000	0.234	0.921	0.234	0.899	0.234	0.938	0.234
Fan 2	1.086	0.255	1.000	0.255	0.977	0.255	1.019	0.255
Fan 3	1.111	0.261	1.023	0.261	1.000	0.261	1.043	0.261
Fan 4	1.066	0.250	0.981	0.250	0.959	0.250	1.000	0.250
Total	4.263	1.000	3.925	1.000	3.835	1.000	4.000	1.000

Total Motor Power	Fan 1	Fan 1 after normalizing	Fan 2	Fan 2 after normalizing	Fan 3	Fan 3 after normalizing	Fan 4	Fan 4 after normalizing
Fan 1	1.000	0.161	0.489	0.161	0.644	0.161	0.619	0.161
Fan 2	2.045	0.329	1.000	0.329	1.316	0.329	1.266	0.329
Fan 3	1.553	0.250	0.760	0.250	1.000	0.250	0.962	0.250
Fan 4	1.615	0.260	0.790	0.260	1.040	0.260	1.000	0.260
Total	6.213	1.000	3.039	1.000	4.000	1.000	3.847	1.000

Table 4.12 Final results for all operational parameters and fans (weight matrix)

	Pressure	Air quantity	Beneficial use rate	Beneficial air amount at the face	Total motor power
Fan 1	0.261	0.232	0.250	0.234	0.161
Fan 2	0.278	0.264	0.250	0.255	0.329
Fan 3	0.263	0.257	0.250	0.261	0.250
Fan 4	0.242	0.264	0.250	0.250	0.260

Weights of these fans are 0.226, 0.271, 0.256, and 0.254, respectively. Based on the results, Fan 2 is found to be proper one for applying in the mine. Weight of this fan is higher than the other ones. Final step of decision making includes calculation of inconsistency index. Inconsistency index is calculated by Equation (4.1):

$$II = \frac{\lambda_{\max} - n}{n - 1} \qquad (4.1)$$

In Equation (4.1), $\lambda_{\max}$ is eigen value and n is number of switches. In second step, inconsistency ratio must be calculated, which is calculated by Equation (4.2):

$$IR = \frac{II}{IRI} \qquad (4.2)$$

In Equation (4.2), IR is inconsistency ratio, II is inconsistency index, and IRI is inconsistency random index which is calculated in Table (4.13):

Table 4.13. Inconsistency random index

n	1	2	3	4	5	6	7	8	9	10
IRI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Finally, inconsistency ratio must be lower than 0.10. On the other hand, decision maker must revise in pair-wise comparisons. Inconsistency ratio was calculated for Fan 1, which is shown below:

$$
=\begin{Bmatrix}
1 = 0.16163 \div 0.032 = 5.050937 \\
2 = 1.2088 \div 0.242 = 4.995041 \\
3 = 0.877562 \div 0.176 = 4.986147 \\
4 = 2.142866 \div 0.43 = 4.983409 \\
5 = 0.586894 \div 0.118 = 4.973677
\end{Bmatrix}
$$

$$\lambda_{max} = 4.997842$$

$$II = \frac{4.997842 - 5}{5 - 1} \cong 0$$

$$IR = \frac{II}{R} = \frac{0}{1.12} = 0$$

Inconsistency ratio was calculated for Fan 2, which is shown below:

$$
\begin{Bmatrix}
1 = 0.174052 \div 0.035 = 4.972914 \\
2 = 1.150181 \div 0.23 = 5.000439 \\
3 = 0.732306 \div 0.14655 = 5.015794 \\
4 = 1.94154 \div 0.388 = 5.003969 \\
5 = 1.001315 \div 0.2 = 5.006575
\end{Bmatrix}
$$

$$\lambda_{max} = 4.9999 \approx 5$$

$$II = \frac{5 - 5}{5 - 1} = 0$$

$$IR = \frac{II}{R} = \frac{0}{1.12} = 0$$

Inconsistency ratio was calculated for Fan 3, which is shown below:

$$
\begin{Bmatrix}
1 = 0.172212 \div 0.034 = 5.06505 \\
2 = 1.170588 \div 0.235 = 4.981225 \\
3 = 0.76728 \div 0.154 = 4.98233 \\
4 = 2.081163 \div 0.417 = 4.99079 \\
5 = 0.796511 \div 0.16 = 4.97819
\end{Bmatrix}
$$

$$\lambda_{max} = 4.9999 \approx 5$$

$$II = \frac{5 - 5}{5 - 1} = 0$$

$$IR = \frac{II}{R} = \frac{0}{1.12} = 0$$

Inconsistency ratio was calculated for Fan 4, which is shown below:

$$\begin{Bmatrix} 1 = 0.162103 \div 0.032 = 5.06571 \\ 2 = 1.149457 \div 0.231 = 4.97600 \\ 3 = 0.783962 \div 0.157 = 4.99338 \\ 4 = 2.039923 \div 0.409 = 4.98758 \\ 5 = 0.847988 \div 0.17 = 4.98816 \end{Bmatrix}$$

$$\lambda_{\max} = 5.00216 \cong 5$$

$$II = \frac{5-5}{5-1} = 0$$

$$IR = \frac{II}{R} = \frac{0}{1.12} = 0$$

All inconsistency ratios for all types of fans is equal to zero, which represents pair-wises comparisons have higher degree of consistency. All these inconsistency ratios were calculated for simple format of AHP and it contains only one expert's idea, who selected major criteria for fan selection. Therefore, it does not represent differences between experts' judgments.

All process of classical AHP is based on crisp numbers, which uses the greatest number in pairwise comparison. However, application of AHP which contains uncertainty in core is not an adequate method for DM. Thus, combination of AHP with expert systems covers lack of uncertainty might be suitable stated by Buckley (1985).

4.3 Fan Selection Using Triangular Fuzzy Analytical Hierarchy Process (FAHP)

Leung and Chao (2000) stated that wide range of literatures have addressed about impression of judgments on comparison ratios. Most of the DM problems have qualitative features. Hence, making decision about these imprecise parameters is a dilemma. Qualitative forecasting for humans is easier than quantitative predictions (Kulak and Kahraman, 2005).

Fuzzy logic (FL) as a soft computing method is utilized when linguistic indices are faced. Combination of FL and classical AHP is called Fuzzy AHP (FAHP) (Saaty, 1977; Boender *et al.*, 1989; Buckley, 1985/a; Buckley, 1985/b; Chang, 1996; Laarhoven and Pedrycz, 1983; Lootsma, 1997; Ribeiro, 1996) can cover deficiencies of classical AHP, in solving problems with vague parameters. Laarhoren and Padrycz (1983) suggested that the least squares were utilized in Fuzzy AHP. Thus, Extent Analysis (EA) was stated by Chang (1996). The authors applied Fuzzy AHP which is extension of tradition AHP Most of the complex systems have blurry parameters. Lots of methods have been introduced for decades as FAHP method. In this study, Chang's (1992) method was utilized for DM about a main fan selection.

Procedures of applying FAHP and DMs steps for fan selection based on experts comments are shown in Figure (4.3).

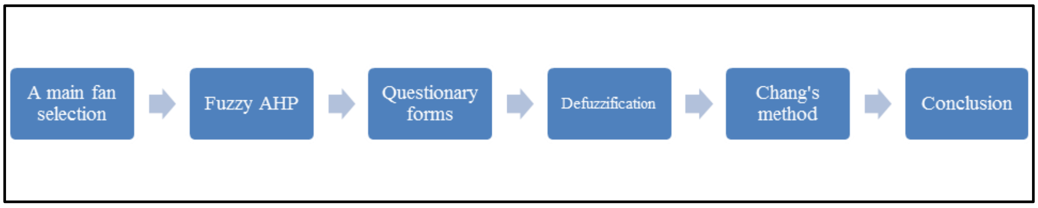

Figure 4.3 Fuzzy AHP method

Kahraman (2008) stated that Chang's (1992) method: extent analysis is done for every object-based on each goals, g_i. Hence, M, analysis value for each object exists. M value presents in Equation (4.3) (Kahraman, 2008):

$$M^1_{gi},\ M^2_{gi},\ .,\ M^m_{gi} \text{ and } \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_i, \sum_{j=1}^{m} m_i, \sum_{j=1}^{m} u_i\right) \quad i=1,2,\ldots,n \tag{4.3}$$

All the M^j_{gi} (i=1,2,…,m) are Triangle Fuzzy Numbers (TFNs). Figure (4.3) illustrates simple TFNs. First step is to calculate value of fuzzy synthetic extent with respect to i^{th} object. Equation (4.4) presents value of fuzzy synthetic (Equation. 4.4) (Kahraman, 2008):

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{4.4}$$

In the second step, degree of possibility is calculated:

$$M_2 = (l_2, m_2, u_2) \geq M_1(l_1, m_1, u_1) \quad (4.5)$$

$$v(M_2 \geq M_1) = sup_{y \geq x}\left[min\left(u_{M_1}(x), u_{M_2}(y)\right)\right] \quad (4.6)$$

or possibility degree is solved by Equation (4.5):

$$V(M_2 \geq M_1) = htg(M_1 \cap M_2):$$

$$\mu_{M_2}(d) = \begin{cases} 1 & if \quad m_2 \geq m_1 \\ 0 & if \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (4.7)$$

In Equation (4.7), d is the ordinate of highest intersection point D between μ_{M_1} and μ_{M_2} (Figure 4.4):

In the third step, the degree of possibility for a convex fuzzy number should be greater than K convex fuzzy number M_i= (i=1, 2… K), and possibility degree is defined by Equation (4.8):

$$V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) and\ (M \geq M_2) and \dots and (M \geq M_k)] = minV(M \geq M_i) \quad ,$$

i=1, 2,.., k (4.8)

In the fourth step, normalized weight vector yields Equation (4.9):

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (4.9)$$

In this section, FAHP was applied to make decision about selection of main fan, which is based on the available data (Table 4.2). The procedure of fan selection based on Fuzzy AHP is represented in Figure 4.3. All the parameters were compared by five mining engineering experts (i.e. Prof. Tevfik Güyagüler, Asst. Prof. Nuray Demirel, Asst. Prof. Hassan Moomivand Dr. Sajjad Chehreghani, and Dr. Ata Bahrami). Table 4.15 presents the fuzzy evaluation matrix with respect to the goal. An expert idea based on pressure is illustrated in Table 4.16.

Based on Chang's extent analysis method and Table 4.15 pairwise comparison weights, pressure is a major technical parameter for making decision.

W^T= (0.25, 0.5, 0, 0.25, 0)

Calculations' results represented that Fan 1 has bigger fuzzy weight when compared to other fans. Weight vector of fans based on pairwise comparison is: W^T = (1, 0, 0, 0).

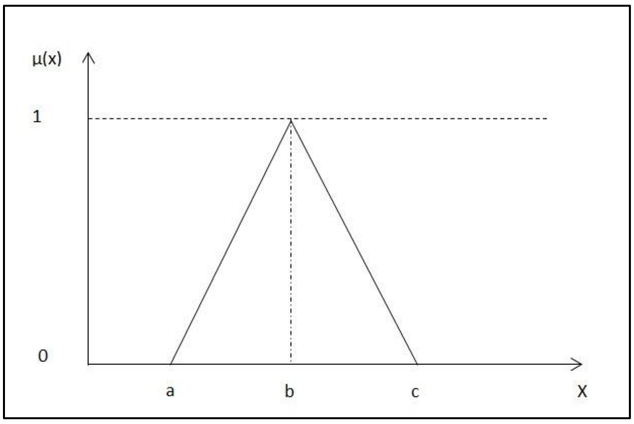

Figure 4.4 A triangular fuzzy number (TFN) (Tolga et al., 2005)

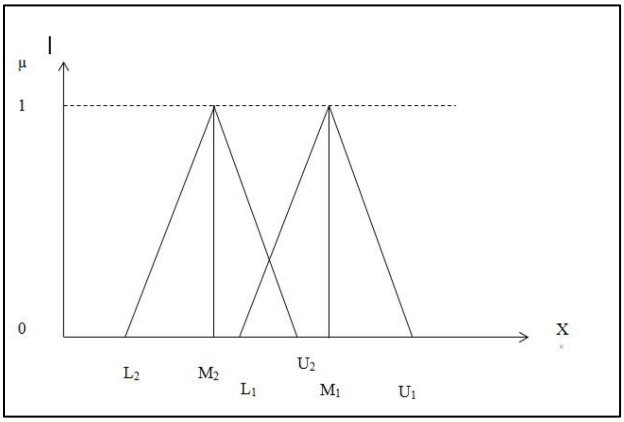

Figure 4.5 The intersection between M1 and M2 (Zhu *et al*., 1999)

Table 4.14 Triangular fuzzy numbers (Tolga et al., 2005)

Statement	TFN
Absolute	(7/2, 4, 9/2)
Very strong	(5/2, 3, 7/2)
Fairly strong	(3/2, 2, 5/2)

Weak	(2/3,1, 3/2)
Equal	(1, 1, 1)

Table 4.15 Evaluation of sub-attribute with respect to pressure

	C11	C12	C13	C14	C15
C11	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
C12	(1,1,1)	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)
C13	$(3/2,2,5/2)^{-1}$	(1,1,1)	(1,1,1)	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)
C14	(1,1,1)	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)
C15	$(3/2,2,5/2)^{-1}$	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(1,1,1)

Table 4.16 Obtained results of FAHP

Pressure	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	(7/2, 4, 9/2)	(7/2, 4, 9/2)	(5/2, 3, 7/2)
Fan 2	$(7/2,4,9/2)^{-1}$	(1,1,1)	(2/3,1, 3/2)	$(5/2, 3, 7/2)^{-1}$
Fan 3	$(7/2,4,9/2)^{-1}$	$(2/3,1,3/2)^{-1}$	(1,1,1)	$(3/2, 2, 5/2)^{-1}$
Fan 4	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)	(3/2, 2, 5/2)	(1,1,1)

4.4 Fan Selection Using Trapezoid Fuzzy Analytical Hierarchy Process (FAHP)

This part of study trapezoid fuzzy number was utilized as a tool in Fuzzy AHP method. Trapezoid fuzzy number contains four elements, which is shown by Equation (4.10):

$$t_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij}) \tag{4.10}$$

Trapezoid Fuzzy number shape is illustrated as Figure (4.6):

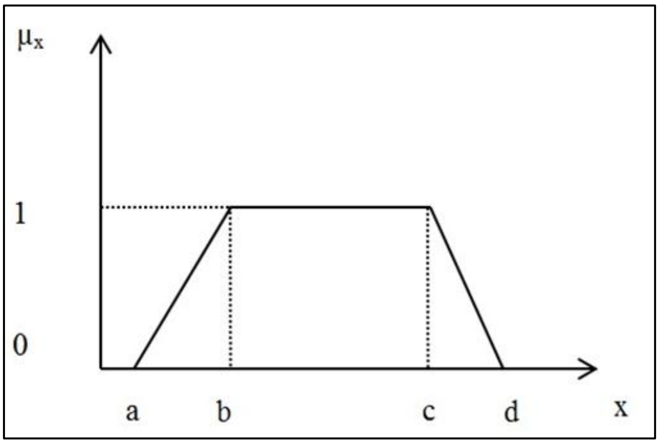

Figure 4.6 Trapezoid Fuzzy Number

In trapezoid Fuzzy AHP, questionnaires forms were prepared and an expert filled these questionnaires form. Questionnaires form contains qualitative data, based on Table (4.17) which contains Trapezoid Fuzzy AHP qualitative data were converted to quantitative data.

Table 4.17 Trapezoid Fuzzy AHP

Statement	TFN
Absolute	(4, 9/2, 11/2, 6)
Very strong	(3, 7/2, 9/2, 5)
Fairly strong	(2, 5/2, 7/2, 4)
Weak	(1, 3/2, 5/2, 3)
Equal	(1, 1, 1, 1)

Tables (4.18)-(4.19) are represented the questionnaires form and decision making matrices.

Table 4.18 Questionnaire form 1, Trapezoid Fuzzy AHP

	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	criteria
1	Air Quantity			■							Pressure
2	Air Quantity								■		Beneficial Use rate
3	Air Quantity									■	Beneficial Air Amount
4	Air Quantity		■								Total Power
5	Pressure								■		Beneficial Use Rate
6	Pressure								■		Beneficial Air Amount
7	Pressure		■								Total Power
8	Beneficial Use Rate	■									Beneficial Air Amount
9	Beneficial Use Rate		■								Total power
10	Beneficial Air Amount		■								Total Power

Table 4.19 Evaluation of sub-attributes

	Air quantity	Pressure	Beneficial use rate	Beneficial air at the face	Total motor power
Air	$(1,1,1,1)$	$\left(2,\frac{5}{2},\frac{7}{2},4\right)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(4,\frac{9}{2},\frac{11}{2},6\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$
Pressure	$\left(2,\frac{5}{2},\frac{7}{2},4\right)^{-1}$	$(1,1,1,1)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$
Beneficial use rate	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$	$(1,1,1,1)$	$\left(4,\frac{9}{2},\frac{11}{2},6\right)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$
Beneficial air at the face	$\left(4,\frac{9}{2},\frac{11}{2},6\right)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$	$\left(4,\frac{9}{2},\frac{7}{2},6\right)^{-1}$	$(1,1,1,1)$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)$
Total	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$\left(3,\frac{7}{2},\frac{9}{2},5\right)^{-1}$	$(1,1,1,1)$

As the second step, Fuzzy AHP weights must be calculated. Moreover, geometric means of rows is calculated by Equation (4.11):

$$\tilde{t}_i = \left[\prod_{j=1}^{n} \tilde{t}_{ij} \right]^{\frac{1}{n}} \tag{4.11}$$

Fuzzy weight is represented by Equation (4.12):

$$w_i = \tilde{z}_i \oplus \left[\sum_{j=1}^{n} \tilde{z}_j \right]^{-1} \tag{4.12}$$

Respectively, left and right legs of trapezoid are calculated by Equations (4.13)-(4.14):

Left leg: $\{ f_i(x) = \left[\prod_{j=1}^{n} ((b_{ij} - a_{ij})\alpha + a_{ij}) \right]^{\frac{1}{n}}, \alpha \in [0,1] \}$ (4.13)

Right leg: $\{ g_i(x) = \left[\prod_{j=1}^{n} ((c_{ij} - d_{ij})\alpha + b_{ij}) \right]^{\frac{1}{n}}, \alpha \in [0,1] \}$ (4.14)

Furthermore, a is calculated by Equations (4.15)-(4.16):

$$a_i = \left[\prod_{j=1}^{n} \tilde{t}_{ij} \right]^{\frac{1}{n}} \tag{4.15}$$

$$a = \sum_{i=1}^{n} a_i \tag{4.16}$$

In the same way, b, c, and d are calculated. The fuzzy weights are determined by Equation (4.17):

$$w_i = (\frac{a_i}{d}, \frac{b_i}{c}, \frac{c_i}{b}, \frac{d_i}{a}), \forall i \tag{4.17}$$

Defuzzification procedure for (i.e. converting trapezoid fuzzy number (a, b, c, d) to crisp number) is done by Equation (4.18):

$$N = \frac{a + 2b + 2c + d}{6} \qquad (4.18)$$

In Equation (4.7), N is crisp number.

Based on Equations (4.11), (4.15)-(4.16), geometric means were calculated for fans features:

$$a_1 = (\prod_{j=1}^{5} a_{1j})^{1/5} = (a_{11} \times a_{12} \times a_{13} \times a_{14} \times a_{15})^{1/5} = (1 \times 2 \times \frac{1}{5} \times \frac{1}{6} \times 3)^{1/5} = 0.7248$$

$$a_2 = (\prod_{j=1}^{5} a_{2j})^{1/5} = (a_{21} \times a_{22} \times a_{23} \times a_{24} \times a_{25})^{1/5} = (\frac{1}{4} \times 1 \times \frac{1}{5} \times \frac{1}{5} \times 3)^{1/5} = 0.4959$$

$$a_3 = (\prod_{j=1}^{5} a_{3j})^{1/5} = (a_{31} \times a_{32} \times a_{33} \times a_{34} \times a_{35})^{1/5} = (3 \times 3 \times 1 \times 4 \times 3)^{1/5} = 2.5508$$

$$a_4 = (\prod_{j=1}^{5} a_{4j})^{1/5} = (a_{41} \times a_{42} \times a_{43} \times a_{44} \times a_{45})^{1/5} = (4 \times 3 \times \frac{1}{6} \times 1 \times 3)^{1/5} = 1.4310$$

$$a_5 = (\prod_{j=1}^{5} a_{5j})^{1/5} = (a_{51} \times a_{52} \times a_{53} \times a_{54} \times a_{55})^{1/5} = (\frac{1}{5} \times \frac{1}{5} \times \frac{1}{5} \times \frac{1}{5} \times 1)^{1/5} = 0.2759$$

$$a = \sum_{i=1}^{5} a_i = (a_1 + a_2 + a_3 + a_4 + a_5) = (0.7248 + 0.4959 + 2.5508 + 1.4310 + 0.2759) = 5.4784$$

$$b_1 = (\prod_{j=1}^{5} b_{1j})^{1/5} = (b_{11} \times b_{12} \times b_{13} \times b_{14} \times b_{15})^{1/5} = (1 \times \frac{5}{2} \times \frac{2}{9} \times \frac{2}{11} \times \frac{7}{2})^{1/5} = 0.8122$$

$$b_2 = (\prod_{j=1}^{5} b_{2j})^{1/5} = (b_{21} \times b_{22} \times b_{23} \times b_{24} \times b_{25})^{1/5} = (\frac{2}{7} \times 1 \times \frac{2}{9} \times \frac{2}{9} \times \frac{7}{2})^{1/5} = 0.5479$$

$$b_3 = (\prod_{j=1}^{5} b_{3j})^{1/5} = (b_{31} \times b_{32} \times b_{33} \times b_{34} \times b_{35})^{1/5} = (\frac{7}{2} \times \frac{7}{2} \times 1 \times \frac{9}{2} \times \frac{7}{2})^{1/5} = 2.8647$$

$$b_4 = (\prod_{j=1}^{5} b_{4j})^{1/5} = (b_{41} \times b_{42} \times b_{43} \times b_{44} \times b_{45})^{1/5} = (\frac{9}{2} \times \frac{7}{2} \times \frac{2}{11} \times 1 \times \frac{7}{2})^{1/5} = 1.5856$$

$$b_5 = (\prod_{j=1}^{5} b_{1j})^{1/5} = (b_{51} \times b_{52} \times b_{53} \times b_{54} \times b_{55})^{1/5} = (\frac{2}{9} \times \frac{2}{9} \times \frac{2}{9} \times 9 \times 1)^{1/5} = 0.3002$$

$$b=\sum_{i=1}^{5} b_i = (b_1 + b_2 + b_3 + b_4 + b_5) = (0.8122 + 0.5479 + 2.8647 + 1.5856 + 0.3002) = 6.1106$$

$$c_1= (\prod_{j=1}^{5} c_{1j})^{1/5} = (c_{11} \times c_{12} \times c_{13} \times c_{14} \times c_{15})^{1/5} = (1 \times \frac{7}{2} \times \frac{2}{7} \times \frac{2}{9} \times \frac{9}{2})^{1/5} = 1$$

$$c_2= (\prod_{j=1}^{5} c_{2j})^{1/5} = (c_{21} \times c_{22} \times c_{23} \times c_{24} \times c_{25})^{1/5} = (\frac{2}{5} \times 1 \times \frac{2}{7} \times \frac{2}{7} \times \frac{9}{2})^{1/5} = 0.6814$$

$$c_3= (\prod_{j=1}^{5} c_{3j})^{1/5} = (c_{31} \times c_{32} \times c_{33} \times c_{34} \times c_{35})^{1/5} = (\frac{9}{2} \times \frac{9}{2} \times 1 \times \frac{11}{2} \times \frac{9}{2})^{1/5} = 3.4674$$

$$c_4= (\prod_{j=1}^{5} c_{4j})^{1/5} = (c_{41} \times c_{42} \times c_{43} \times c_{44} \times c_{45})^{1/5} = (\frac{11}{2} \times \frac{9}{2} \times \frac{2}{9} \times 1 \times \frac{9}{2})^{1/5} = 1.8999$$

$$c_5= (\prod_{j=1}^{5} c_{5j})^{1/5} = (c_{51} \times c_{52} \times c_{53} \times c_{54} \times c_{55})^{1/5} = (\frac{2}{7} \times \frac{2}{7} \times \frac{2}{7} \times \frac{2}{7} \times 1)^{1/5} = 0.3671$$

$$c=\sum_{i=1}^{5} c_i = (c_1 + c_2 + c_3 + c_4 + c_5) = (1 + 0.6814 + 3.4674 + 1.8999 + 0.3671) = 7.4158$$

$$d_1= (\prod_{j=1}^{5} d_{1j})^{1/5} = (d_{11} \times d_{12} \times d_{13} \times d_{14} \times d_{15})^{1/5} = (1 \times 4 \times \frac{1}{3} \times \frac{1}{4} \times 5)^{1/5} = 1.1076$$

$$d_2= (\prod_{j=1}^{5} d_{2j})^{1/5} = (d_{21} \times d_{22} \times d_{23} \times d_{24} \times d_{25})^{1/5} = (\frac{1}{2} \times 1 \times \frac{1}{3} \times \frac{1}{3} \times 5)^{1/5} = 0.7740$$

$$d_3= (\prod_{j=1}^{5} d_{3j})^{1/5} = (d_{31} \times d_{32} \times d_{33} \times d_{34} \times d_{35})^{1/5} = (5 \times 5 \times 1 \times 6 \times 5)^{1/5} = 3.7585$$

$$d_4= (\prod_{j=1}^{5} d_{4j})^{1/5} = (d_{41} \times d_{42} \times d_{43} \times d_{44} \times d_{45})^{1/5} = (6 \times 5 \times \frac{1}{4} \times 1 \times 5)^{1/5} = 2.0644$$

$$d_5= (\prod_{j=1}^{5} d_{5j})^{1/5} = (d_{51} \times d_{52} \times d_{53} \times d_{54} \times d_{55})^{1/5} = (\frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times 1)^{1/5} = 0.4152$$

$$d=\sum_{i=1}^{5} d_i = (d_1 + d_2 + d_3 + d_4 + d_5) = (1.1076 + 0.7740 + 3.7585 + 2.0644 + 0.4152) = 8.1197$$

Based on Equation (4.16), weights and defuzzified weight are calculated:

$$w_1 = (0.0893,0.1095,0.1636,0.2022) = 0.1396$$
$$w_2 = (0.0611,0.0739,0.1115,0.1413) = 0.0955$$
$$w_3 = (0.3141,0.3863,0.5674,0.6860) = 0.4846$$
$$w_4 = (0.1762,0.2138,0.3109,0.3768) = 0.2670$$
$$w_5 = (0.0340,0.0405,0.0601,0.0758) = 0.1555$$

Based on defuzzified weights, W_3 has higher degree of weight. Thus, beneficial used rate is the appropriate factor for decision making procedure.

Table 4.20 Questionnaire form based on beneficial use rate of fan

Beneficial use rate	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1					■					Fan 2
2	Fan 1					■					Fan 3
3	Fan 1					■					Fan 4
4	Fan 2					■					Fan 3
5	Fan 2					■					Fan 4
6	Fan 3					■					Fan 4

Therefore, all fans have same weights for selection, based on Table (4.20).

4.5 Comparative Assessment of AHP and FAHP for Fan Selection

Soft computing methods related to OR are appropriate tools for DM subjects. Classical AHP, which is introduced by Saaty (1977), is one of the OR method. Differences of this method arise when qualitative and linguistic parameters are faced, which caused to combine classical AHP with soft computing method such as FL.

Table 4.21 Obtained results of FAHP for Main Fan

Sub-attributes of technical parameters					
	Air quantity	Pressure	Beneficial use rate	Beneficial air amount	Total motor power
Weight	0.480	0.380	0.000	0.204	0.000
Fan 1	0.740	1.000	1.000	1.000	0.754
Fan 2	0.000	0.000	1.000	0.000	0.000
Fan 3	0.000	0.000	1.000	0.000	0.246
Fan 4	0.260	0.000	1.000	0.000	0.000

Fans selection is not related to one or two parameters which are complex task. Selecting an optimum fan for ventilation system of a mine is dependent on many factors. Classical AHP has used in the second step, which results of AHP based on pairwise comparison of parameters. This method chooses a parameter with bigger weight in comparison procedures. Thus, application of this method showed that Fan 2 is a proper fan. Decision making process depends on experts' experiences in the selection. Hence, improving decision making procedure could be done by expert's experiences. Thus, result of FAHP shows the Fans 1, 2, and 3 are optimized fans. Moreover, Table 3.21 shows the combination of priority weight to determine the proper fan. Five experts' ideas were used in this section (Appendix A). Based on expertise, whole fan types should be utilized for proper ventilation in the mine. Finally, fan selection for this issue is completely depended on a factor which each expert selected it.

4.6 Justification and Validation of Results

In this part of dissertation, financial analysis is calculated based on the four types of fans for making final judgment of a fan selection. Features of fans and capital costs of them are represented in Table 4.22.

Table 4.22 Technical and financial analysis of fans (İnan, 2005)

Fan Number	Pressure (Pa)	Air amount into the mine (m^3/s)	Fan efficiency (%)	Capital cost of Fan ($)
Fan No.1	515.00	69.00	25.00	20000
Fan No.2	400.00	60.50	34.80	30000
Fan No.3	423.00	62.25	28.80	30000
Fan No.4	460.00	64.80	33.90	30000

Average life time of fans is ten year (Madani, 2003). Moreover, electric cost was calculated based on 7 cent/kWh; in addition fans work 365 days a year and 24 hours a day and interest rate is 12 percent (İnan, 2005). Operation cost evaluations for Fan No.1 was done as below.

For Fan No.1:

Air power (kW) =Pressure (Pa)*Air amount into the mine (m^3/s):

Air power= 515*69=35.535 kW

Power consumed = 35.535*(100/25) =142.14 kW

Annual power cost= 142.14*0.07*24*365=87.160000 $

Evaluation future vale of an annual uniform series payment utilizes Equation (4.19):

$$P = A \times \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right] \qquad (4.19)$$

Based on equation (4.19):

P=492.474000 $

Same calculations are done for other three fans, which are shown in Table 4.23.

Table 4.23 Electric costs of fans

Fan Number	Air power (kW)	Power consume (kW)	Annual power cost ($)	Future value ($)
Fan No.1	35.535	142.14	87.160000	492.474000
Fan No.2	24.200	69.54	42.641000	240.936000
Fan No.3	26.331	91.43	56.064000	316.779000
Fan No.4	29.808	87.92	53.912000	304.617000

Moreover, Table 4.24 represents capital, operational, and total financial costs analysis.

Table 4.24 Total costs of Fans

Fan number	Operational cost ($)	Capital cost ($)	Total cost ($)
Fan No.1	492.474000	40000	532.474000
Fan No.2	240.936000	30000	270.936000
Fan No.3	316.779000	30000	346.779000
Fan N0.4	304.617000	30000	334.617000

Based on financial analysis, Fan No.2 is an appropriate fan. The same result was yielded by conventional AHP, which represents Fan No.2 is adequate fan for ventilation system. Thus, the result of conventional AHP was given as the final decision.

CHAPTER 5

SELECTION OF AN APPROPRIATE PITCH ANGLE OF AN AXIAL FLOW FAN USING FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) AND NEURO-FUZZY ALGORITHM

5.1 Pitch Angle Selection by Fuzzy Analytical Hierarchy Process

In this part of dissertation, FAHP was utilized for selection of an appropriate pitch angle of a fan. Chang's method was applied as FAHP term. In Chang's method objects set defined by X={x_1, x_2,…, x_n} and goals set is U={u_1, u_2,…, u_n}. Pitch angle selection based on five parameters (element of objects set) such as: i) volume flow, ii) total pressure increase, iii) fan output, iv) acoustic power level, and v) efficiency. As an extension, subjects set and goals set are shown in Equation (5.1), Equation (5.2), and Table 5.1.

Subjects set = {volume flow, total pressure, fan output, acoustic power level, efficiency} (5.1)

Optimized pitch angles = {pitch angle 1, pitch angle 2, pitch angle 3, pitch angle 4} (5.2)

For each object, extent analysis is evaluated based on each goal, g_i, by Chang's method (Kahraman, 2008). Each of the subjects shown by M^j_{gi} letter, and M is triangular fuzzy number (TFN). Questionnaire forms were prepared by two experts (Appendix B) and these qualitative TFN deffuzified to quantitative data, as an example Table B.1 deffuzified to Table 5.2, based on Tolga TFN (Tolga *et al*., 2005).

Table 5.1 The proposed hierarchy model to select an optimum fan based on operational parameters

Goal	Criteria
Selection of appropriate pitch angle	Volume flow (C1) Total pressure increase (C2) Fan output (C3) Acoustic power level (C4) Efficiency (C5)

Table 5.2 The Fuzzy evaluation matrix with respect to the goal

	C1	C2	C3	C4	C5
C1	(1,1,1)	(1,1,1)	(1,1,1)	$(2/3,1,3/2)^{-1}$	(5/2,3,7/2)
C2	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)
C3	(1,1,1)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(1,1,1)	(1,1,1)
C4	(2/3,1,3/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(1,1,1)	(2/3,1,3/2)
C5	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)	$(2/3,1,3/2)^{-1}$	(1,1,1)

The following phases are taken (i.e., Chang method) to solve the problem. From Table 5.2, Chang's method was utilized for selection of a switch with higher priority:

$S_{C1} = (6.167, 7, 8) \otimes (1/33.134, 1/28.667, 1/25.038) = (0.186, 0.244, 0.319)$

$S_{C2} = (7.5, 9, 10.5) \otimes (1/33.134, 1/28.667, 1/25.038) = (0.226, 0.314, 0.419)$

$S_{C3} = (4.4, 4.5, 4.677) \otimes (1/33.134, 1/28.667, 1/25.038) = (0.133, 0.157, 0.186)$

$S_{C4} = (3.733, 4.5, 5.667) \otimes (1/33.134, 1/28.667, 1/25.038) = (0.112, 0.157, 0.226)$

S_{C5} = (3.238, 3.667, 4.3) ⊗ (1/33.134, 1/28.667, 1/25.038) = (0.097, 0.128, 0.172)

Applying these vectors:

$V(S_{volume\ flow} > S_{total\ increase}) = 0.57$, $V(S_{volume\ flow} > S_{fan\ output}) = 1$, $V(S_{volume\ flow} > S_{acoustic}) = 1$, $V(S_{volume\ flow} > S_{efficiency}) = 1$.

$V(S_{total\ increase} > S_{volume\ flow}) = 1$, $V(S_{total\ increase} > S_{fan\ output}) = 1$, $V(S_{total\ increase} > S_{acoustic}) = 1$, $V(S_{total\ increase} > S_{efficiency}) = 1$.

$V(S_{fan\ output} > S_{volume\ flow}) = 0$, $V(S_{fan\ output} > S_{fan\ output}) = 0$, $V(S_{fan\ output} > S_{acoustic}) = 1$, $V(S_{fan\ output} > S_{efficiency}) = 1$.

$V(S_{acoustic} > S_{volume\ flow}) = 0.31$, $V(S_{acoustic} > S_{total\ increase}) = 0$, $V(S_{acoustic} > S_{fan\ output}) = 1$, $V(S_{acoustic} > S_{efficiency}) = 1$.

$V(S_{efficiency} > S_{volume\ flow}) = 0$, $V(S_{efficiency} > S_{total\ increase}) = 0$, $V(S_{efficiency} > S_{fan\ output}) = 0.57$, $V(S_{efficiency} > S_{acoustic}) = 0.67$.

Minimum numbers from evaluations above was selected, which is (0.57, 1, 0, 0, and 0). Summation of numbers in parentheses is equal to 1.57 and division of parenthesis numbers with summation W^T was prepared.
By following this step, fuzzy weights for these five parameters are:
W^T= (0.36, 0.64, 0, 0, 0). Thus, C2 has a higher degree in contrast to other objects.

Table 5.3 Evaluation of criteria with respect to C1

C1	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$	$(5/2, 3, 7/2)^{-1}$	$(7/2, 4, 9/2)^{-1}$
Angle 2	(3/2, 2, 5/2)	(1, 1, 1)	(2/3, 1, 3/2)	$(3/2, 2, 5/2)^{-1}$
Angle 3	(5/2, 3, 7/2)	(2/3, 1, 3/2)	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$
Angle 4	(7/2, 4, 9/2)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	(1, 1, 1)

Based on Table 5.3 C1 fuzzy weights for different angles are: W^T=(0,0.087,0.232,0.681). Thus, Angle 4 has bigger impact in respect to C1.

Table 5.4 Evaluation of criteria with respect to C2

C2	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$	$(5/2, 3, 7/2)^{-1}$	$(7/2, 4, 9/2)^{-1}$
Angle 2	(3/2, 2, 5/2)	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$	$(7/2, 4, 9/2)^{-1}$
Angle 3	(5/2, 3, 7/2)	(3/2, 2, 5/2)	(1, 1, 1)	$(5/2, 3, 7/2)^{-1}$
Angle 4	(7/2, 4, 9/2)	(7/2, 4, 9/2)	(5/2, 3, 7/2)	(1, 1, 1)

Based on Table 5.4, C2 fuzzy weights for different angles are:

W^T= (0, 0, 0, 1). Thus, angle 4 has great role.

Table 5.5 Evaluation of criteria with respect to C3

C3	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$	$(5/2, 3, 7/2)^{-1}$	$(7/2, 4, 9/2)^{-1}$
Angle 2	(3/2, 2, 5/2)	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$	$(7/2, 4, 9/2)^{-1}$
Angle 3	(5/2, 3, 7/2)	(3/2, 2, 5/2)	(1, 1, 1)	$(3/2, 2, 5/2)^{-1}$
Angle 4	(7/2, 4, 9/2)	(7/2, 4, 9/2)	(3/2, 2, 5/2)	(1, 1, 1)

Based on Table 5.5 C3 fuzzy weights for different angles are:

W^T= (0, 0, 0.127, 0.872).

Table 5.6 Evaluation of criteria with respect to C4

C4	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
Angle 1	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)	$(3/2, 2, 5/2)^{-1}$
Angle 1	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
Angle 1	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(2/3, 1, 3/2)	(1, 1, 1)

Based on Table 5.6, C4 fuzzy weights for different angle are:

W^T= (0.24, 0.20, 0.24, 0.31). Thus, angle 4 has a better weight.

Table 5.7 Evaluation of criteria with respect to C5

C5	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1, 1, 1)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)
Angle 1	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
Angle 1	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
Angle 1	(1, 1, 1)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)

Based on Table 5.7, C5 fuzzy weights for different angle are:

W^T= (0.25, 0.25, 0.25, 0.25). Thus, all weights have the same value.

All the obtained results of this method are presented in Table 5.8. Table 5.8 reveals criteria numbers 2 has a greater fuzzy weight. Moreover, angle 4 has a bigger value in comparison to other angles, so angle 4 is adequate one. On the other hand, DM for this method should do based on C2, so angle 4 has value 1 which the other values are 0.

Table 5.8 Obtained results of FAHP for pitch angle

Criteria of selection optimized pitch angle					
	C1	**C2**	**C3**	**C4**	**C5**
weights	0.360	0.640	0.000	0.000	0.000
Angle.1	0.000	0.000	0.000	0.240	0.250
Angle.2	0.087	0.000	0.000	0.200	0.250
Angle.3	0.232	0.000	0.127	0.240	0.250
Angle.4	0.681	1.000	0.872	0.310	0.250

5.2 Pitch Angle Selection by Neuro-Fuzzy Algorithm

Selection of an appropriate pitch angle is a complex task due to technical parameters of a main fan and environmental factors. As an extension, lots of parameters which have complicated relationship with each other, so expert systems were applied in deal with complications.

Fuzzy Inference System (FIS) is method based on expert ideas, which stories its essential components in the rule base and the database. FIS performs fuzzy reasoning to infer the overall output value. Moreover, extracting experts suggestion and adapt them in FIS is not an easy task. Thus, application of learning algorithms is undeniable. In addition, Kahraman (2008) noted that forecasting, function estimation, and classification is done based on historical data of problem. Artificial Neural Network (ANN) is a learning mechanism which does not have any relation with human expertise.

Hence, combination of FIS and ANN will be helpful for designers, when they do not have any experiences about a topic or have limited time. Table 4.9 presents combination of FIS and ANN. Relations between input and output sets, called training data set, represent weights. Moreover, these weights are coefficient of mapping between input sets and output sets. Thus, these weights illustrate mapping structure. One of FIS method for expressing expert ideas is Mamdani rule base method, which represent by if-then rule (Mamdani *et al*., 1975).

Table 5.9 Definition of ANN and FIS

ANN	FIS
Black Box	Interpretable
Learning from scratch	Making use of linguistic knowledge

In this study learning data set was gotten from characteristic curves, which were contained four pitch angles. These pitch angles are [-10 -5 0 5], which includes volume flow, total pressure increase, fan output, acoustic power level and efficiency parameters. Hence, these pitch angles are named angle 1-4, respectively. Moreover, around 500 points was picked up from characteristics curves and these dots applied as learning data set in ANN. In this study, an adaptive network based fuzzy inference system was applied (ANFIS). Hypothetical mine operational curve was drawn on the fan characteristic curve, so intersection' points of the mine curve and pitch angles shown in Table 5.10.

Table 5.10 Intersection points of a hypothetical mine operational curve and a fan characteristic curve

	Volume flow (m^3/s)	Total pressure increase (Pa)	Fan output (kW)	Acoustic power level (dB(A))	Efficiency (%)
Angle 1	2.60	650	2.2	101.8	75
Angle 2	3.20	760	2.8	100.0	80
Angle 3	3.57	890	3.8	101.8	80
Angle 4	3.80	1038	4.8	104.4	75

The first step of modeling was done by creating Takagi, Sugeno and Kang (TSK) model in MATLAB platform. Number of inputs is five i) volume flow, ii) total pressure increase, iii) fan output, iv) acoustic power level, and v) efficiency. Furthermore, number of output is one, this phase is illustrates in Figure 5.1 and this phase is called variable identification. Inputs with higher degree of impression on the output were selected and this degree of impression is identified by Fuzzy Logic (Sahu, 2010). In this study, Pi sign function has applied for normalizing the crisp numbers. These Pi sign membership functions of inputs presented in Figures 5.2-5.6. In addition, an output of model has infinity singleton, which was illustrated in Figure 5.7.

Mapping between the inputs and the output was presented in the form of If-Then rules. In TSK model the mapping rules are produced by ANFIS model (Figure. 5.8). However, the output membership function in TSK model is constant and linear. Sahu (2010) stated that TSK contains fuzzy sets and if-then rules for controlling were written as follow:

R_r: IF X_1 is $S^{(1)}$, X_2 is $S_r^{(2)}$,…, X_p is $S_r^{(n)}$ then

$Y_r = f_r(X_1,X_2,..,X_n)$

$S_r^{(I)}$ is fuzzy set, which is related to X_1 variable. Moreover, n is the number of inputs , f_r is function which represents mapping between inputs and Y_r is the output for r^{th} output.

The general algorithm of the TSK inference system is expressed as follows. It is assumed that there are R_r (r =1,2,3, ..., k) rules in the above mentioned form. Every elements of R_i, function of f_i produces Y_i, which represented by Equation (5.1).

$$Y_i = f_i(X_1,X_2,\ldots,X_n) = C_r(0)+C_r(1)X_1+\ldots+C_r(n)X_n \quad (5.1)$$

Moreover, weights of membership are calculated by Equation (5.2).

$$r_r=(m^r{}_1\wedge m^r{}_2\wedge\ldots\wedge m^r{}_n)P^r \quad (5.2)$$

In Equation (5.2):

$m^r{}_1, m^r{}_2,\ldots, m^r{}_n$ = the α cuts of MFs according to input values for r^{th} rule.
Sahu (2010) argued that "an α cut of the fuzzy set A(Aα) is a crisp set, which contains all the elements in U that have membership values greater than or equal to α(x εU|MF) ≥ α in A. The universe of discourse U is the n-dimensional Euclidean space R^n. Thus, application of TSK in learning and achieving best results is helpful. In this study, ANFIS was utilized for learning; on the other hand, ANFIS consists of TSK.

ANN is black box for FL, which has major ability in learning. Because of this ability, ANN is applied for recognizing data trend. ANFIS is utilized ANN as its black box, which is useful when data have constant or linear trend. In this study, data for learning took from Howden's fan curves (Howden handbook, 2010). Main future of this type of fan is their slope of curves, which are linear line. Thus, ANFIS has a good adaption with these curves. Moreover, ANFIS applies a back propagation learning algorithm to identify the membership function parameters of single output. A combination of least-square and back propagation gradient descent methods are applied for training FIS membership function parameters to model a given set of input /output data. Crisp numbers are taken from fan curves by image processing methods. In the next step, ANN parameter for training was adjusted (Table 5.11).

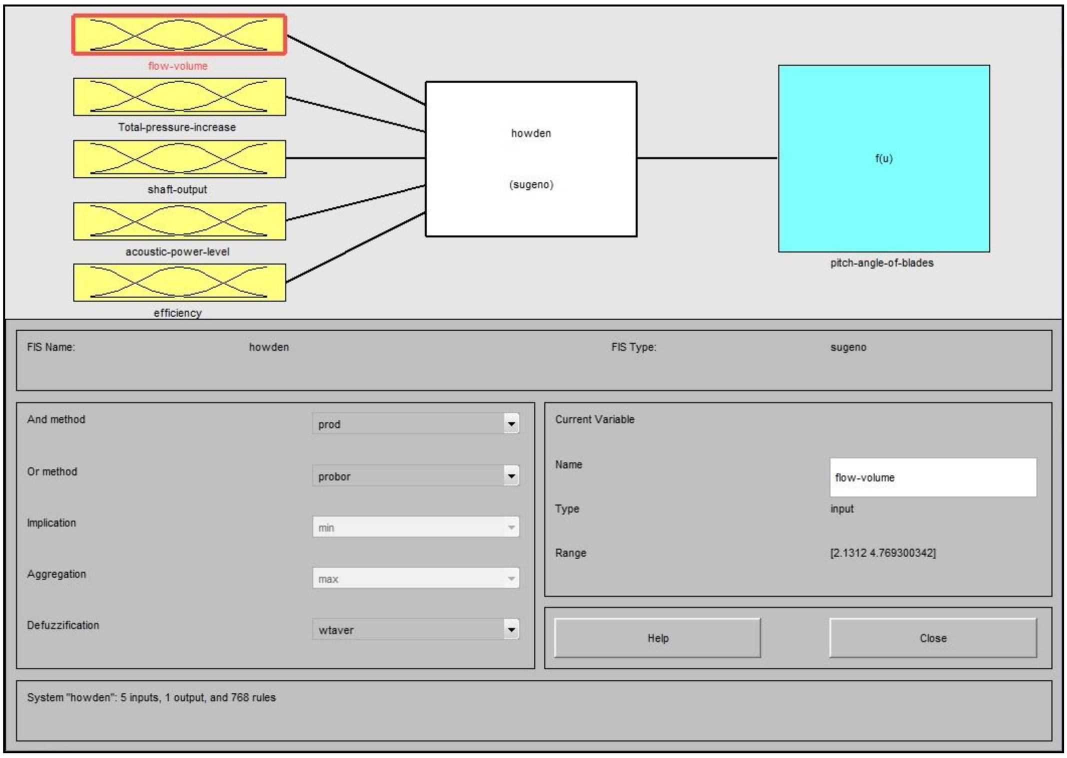

Figure 5.1 TSK model in MATLAB platform

Table 5.11 Input parameters selected for training

Input parameters for training	Values
Error tolerance	0.010
Learning rate (β)	0.025
Momentum parameters (α)	0.020
Noise factor (NF)	0.010
Number of epochs	1000000
Number of hidden layer	45.000
Number of input layer neuron (I)	5.000
Number of output layer neuron (O)	1.000

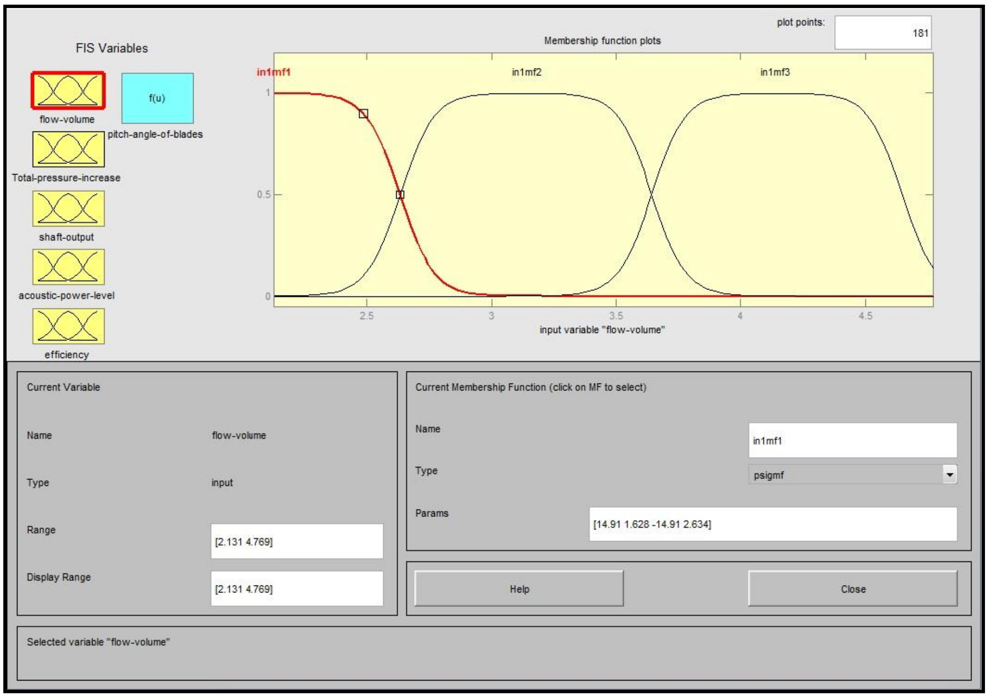

Figure 5.2 Fuzzy representation of flow volume

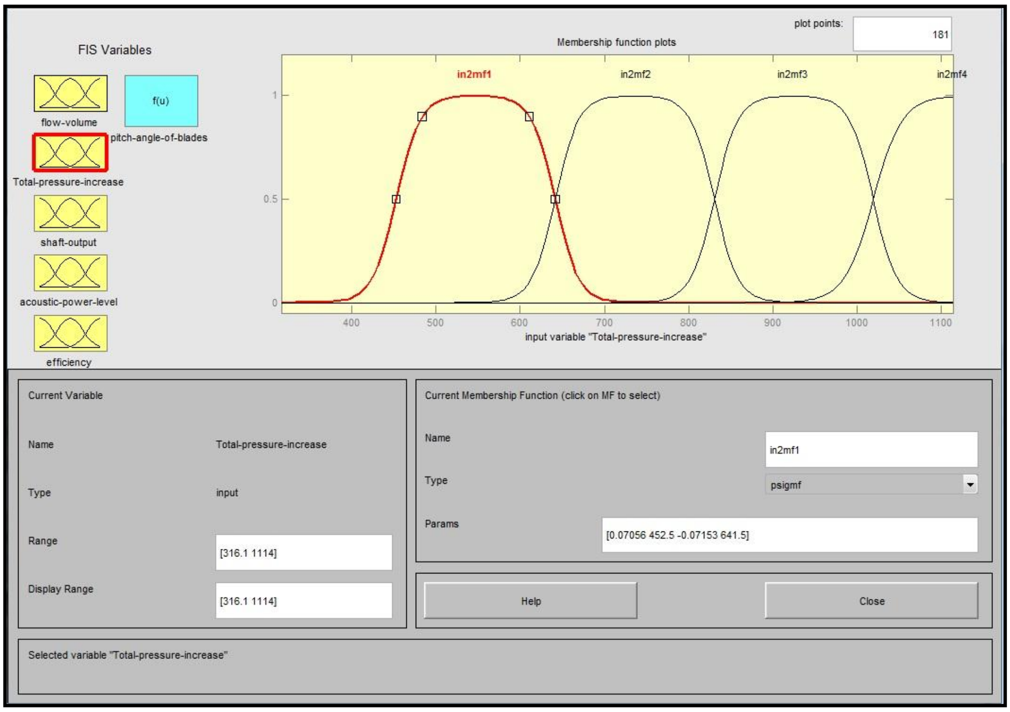

Figure 5.3 Fuzzy representation of total pressure increase

In Figure 5.2, data were applied in ANN approach and data range was found with TSK method. Range of data for flow volume is [2.131 4.769] and range of data is the same for display range. Moreover, number of shape used for flow volume is three. As an extension, range of data is [316.1 1114] for total pressure increase and number of shape which is utilized for making decision is 5 (Figure 5.3). Data range is [1.378 4.934] for fan output which has S curves of FL (Figure 5.4). In Figure 5.5, range of data for acoustic power level is [98.17 106.3] and number of curves are four. Furthermore, efficiency (Figure 4.6) data range is [65 80] and has four curves.

5.3 Comparative Assessment of FAHP and Neuro-Fuzzy for Pitch Angle Selection

Fuzzy AHP and Neuro-Fuzzy were utilized in decision making about the adequate pitch angle for a fan. Therefore, Fuzzy AHP method represents pitch angle 4 is an appropriate preference in applying in a mine. ANFIS trained by data from curve which is digitized. In ANFIS method TSK was used as rule terming, which is suitable in data with constant or linear trend, and pitch angle 4 was selected by Neuro-Fuzzy algorithm. The results for Fuzzy AHP and Neuro-Fuzzy are the same, so application of Neuro-Fuzzy as a soft computing method is a better preference in contrast to Fuzzy AHP. Because Neuro-fuzzy is applied in vague and complex data ranges, but Fuzzy AHP requires experts' ideas to complete DM procedure. Moreover, ANFIS run in MATLAB program and it can represent one output only. Therefore, writing a code for Neuro-Fuzzy algorithm which is applicable for DM subjects is a necessary task.

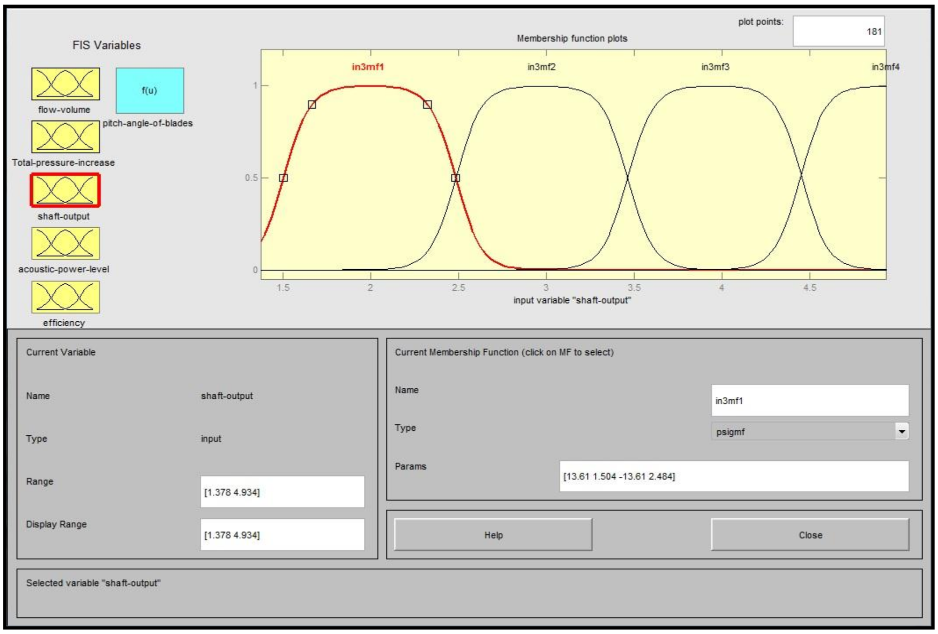

Figure 5.4 Fuzzy representation of fan output

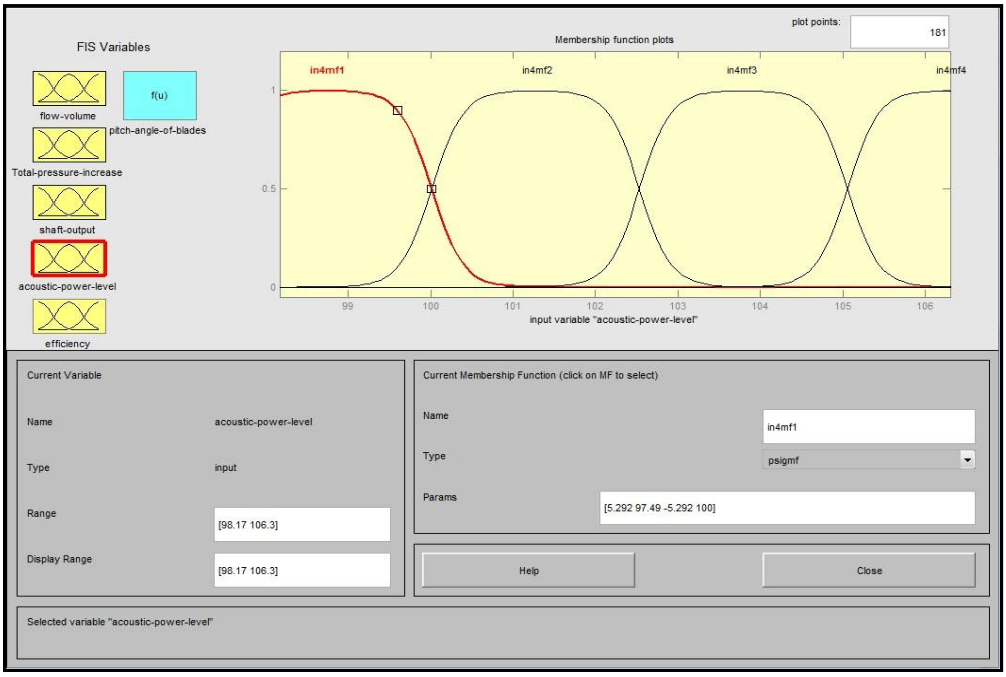

Figure 5.5 Fuzzy representation of acoustic power level

Finally, the result of Neuro-Fuzzy algorithm for selection of the optimized pitch angle is: the pitch angle 4. Hence, results of Fuzzy AHP and Neuro-

Fuzzy are same, so application of Neuro-Fuzzy as a method which gets same results in decision making issues was beneficial method in this study. However, pitch angle selection depends to variety types of mechanical factors, so decision making about pitch angle is not an easy task which be solvable by Neuro-Fuzzy Algorithm or FAHP method.

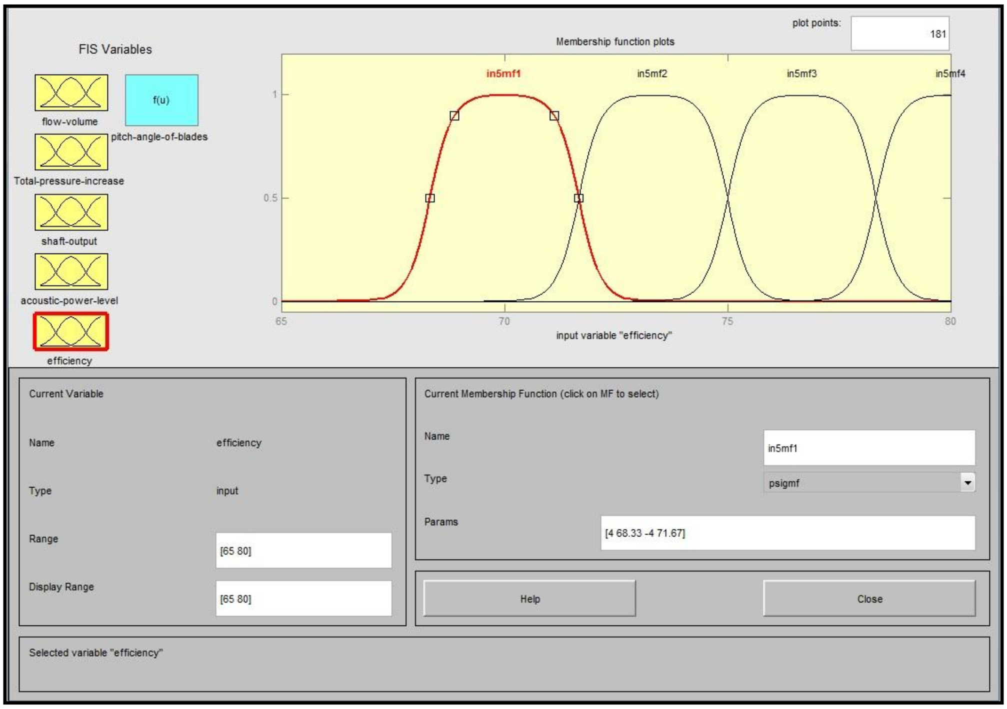

Figure 5.6 Fuzzy representation of efficiency

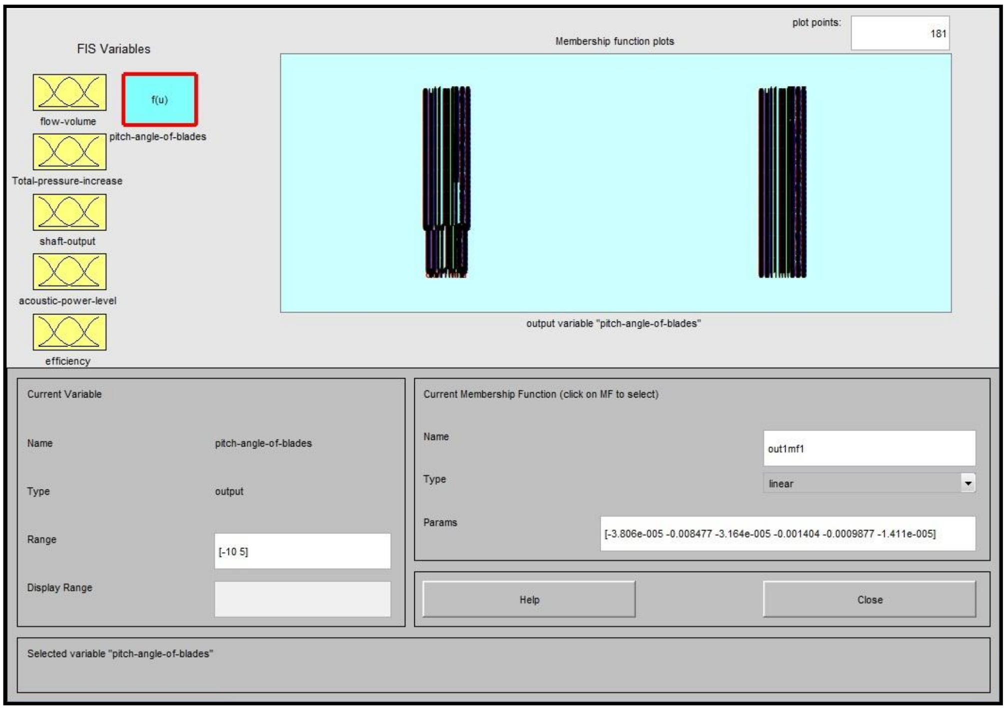

Figure 5.7 Fuzzy representation of output

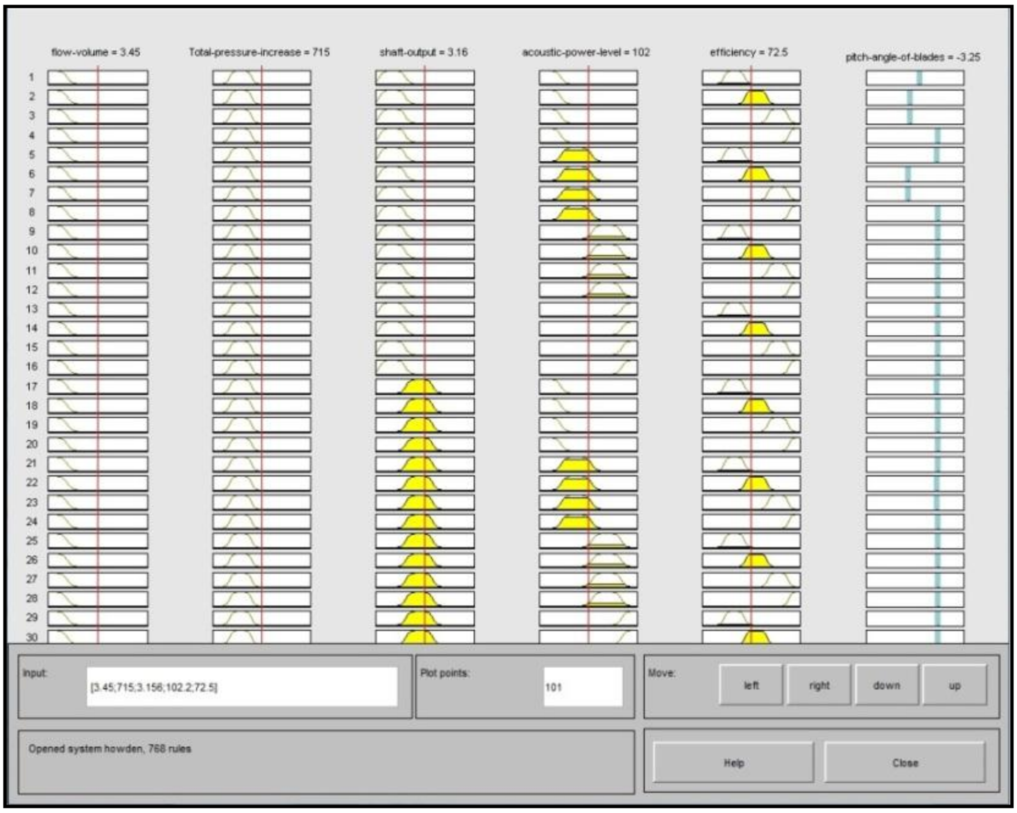

Figure 5.8 Representation of linguistic rule-base in MATLAB platform

CHAPTER 6

.CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main conclusions in this dissertation are:

1. The conventional method of the main fan selection depends on two parameters, which are air flow and pressure. Thus, these parameters are not sufficient in decision making about fan selection. Therefore, classical AHP method was utilized which is based on pairwise comparison algorithm. In this study, DM of the main fan selection was based on five parameters, such as i) air quantity, ii) pressure, iii) beneficial air amount at the face, iv) beneficial use rate, and v) total motor power. AHP was utilized and the appropriate fan has been selected for the mine. In addition Fuzzy AHP was used for the main fan selection. Fuzzy AHP contains higher degree of expertise in contrast to conventional AHP, which are shown as fuzzy weights. However, the result of AHP was close to desired out-put. AHP and financial analysis represent the same result for the fan selection procedure.

2. Conventional model, which is based on air quantity and pressure, represents Fan 3 as an effective fan for mine. However, conventional AHP method which is related to pairwise comparison presented Fan 2 as an appropriate one. On the other hand, FAHP (i.e. triangular and trapezoid fuzzy numbers) which contains ventilation designers' experiences, yields Fan 1, 2, 3, and 4 are proper

fans. Thus, Fans 1, 2, 3, and 4 can be appropriate fan in this DM issue based on FAHP method. Application of different types of membership degree in Fuzzy AHP method is not suitable, always. In this study, utilization of trapezoid fuzzy number in Fuzzy AHP makes data very vague, so this complexity is a disadvantage for Fuzzy AHP method. On the other hand, Utilization of triangular fuzzy number in Fuzzy AHP helps decision makers to simplify their calculation procedures. Utilization of FAHP presented fan selection depends on the factors which play major role in selection process in this study. This procedure of DM represents that selection of fan depends on a variety of the factors and recognizing mapping between these factors is a vital duty, so DM in ventilation operation requires experts’ judgments.

3. Wide variety types of factors have impression on efficiency of a main fan. One of these factors is pitch angle of fans’ blades, which is an alterable factor. Thus, selection of an appropriate pitch angle has a great influence on efficiency of fan. Decision making about pitch angle depends on five parameters, i) volume flow, ii) total pressure increase, iii) fan output, iv) acoustic power level, and v) efficiency. In this study, Fuzzy AHP method was utilized for selection of pitch angle and based on experts’ ideas angle 4 was selected as an appropriate angle. In addition, Neuro-Fuzzy method was used for pitch angle selection, and the result for proper pitch angle revealed angle 4 as the proper one. In Neuro-Fuzzy method, TSK was utilized for learning. Moreover, In Neuro-Fuzzy method S sign of degree shapes were used for fuzzifying the data.

Utility of Fuzzy AHP and Neuro-Fuzzy methods had a same result for the pitch angle selection. Utilization of Neuro-fuzzy and FAHP for pitch angle selection was successful in this study. Therefore, pitch angle selection depends on more mechanical factors, so application of Neuro-fuzzy and FAHP may not be suitable for pitch angle selection in the future studies.

4. Fuzzy AHP concretes AHP comparison method and human rule thinking method. Utilization of this method has great aftermaths on DM, and it is utilized in a situation which includes low number of data. On the other hand,

large number of data makes the data set complicated and ambiguous, so reasoning based on large data set is a hard task. Thus, application of Nuero-Fuzzy as soft computing method solves this problem. Logically, learning rate of ANN increases in data set with a high number of data. In conclusion, Neuro-Fuzzy utilization is an appropriate method for decision making subjects.

6.2 Recommendations

The main recommendations for this study as:

1. In this study, Takagi, Sugeno and Kang method was utilized as Neuro-Fuzzy algorithm. However, Takagi, Sugeno and Kang model is used for data which have a linear or constant trim. Thus, usage of a method which is applicable in non-linear trim of data is a vital task.

2. MATLAB was utilized for programming of Neuro-Fuzzy method, but this program has defects in capsulation of different type of codes, which were written parallel. Thus, application of the program which has least bugs will be suitable.

3. In this study, data of one type of fan was utilized by Neuro-Fuzzy algorithm, so for acquisition of better learning results, necessity of a larger range of data is undeniable.

4. AHP contains uncertainty in core of it, and this uncertainty depends on mapping of judgments and numbers. Utilization of expert system might be decreased uncertainty ratio in AHP. Therefore, the combine method of Fuzzy Logic and AHP was utilized, in this study. However, FAHP increased uncertainty ratio, so making decision based on higher degree of uncertainty made the decision making subject so harder for selection.

5. For future studies, Membership function should be optimized and based on optimal membership function model can be selected.

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QUESTIONNAIRE FORMS FOR FAN SELECTION

Question Form for Evaluation

Expert 1:

With respect to the main criterion “Technical attributes”:

Question 1: How important is “Air quantity” when it is compared with “pressure”?

Question 2: How important is “Air quantity” when it is compared with “beneficial use rate”?

Question 3: How important is “Air quantity” when it is compared with “Beneficial air amount”?

Question 4: How important is “Air quantity” when it is compared with “total power”?

Question 5: How important is “pressure” when it is compared with “Beneficial use rate”?

Question 6: How important is “pressure” when it is compared with “Beneficial air amount”?

Question 7: How important is “pressure” when it is compared with “Total power”?

Question 8: How important is “Beneficial use rate” when it is compared with “Beneficial air amount”?

Question 9: How important is “Beneficial use rate” when it is compared with “Total power”?

Question 10: How important is “Beneficial air amount” when it is compared with “Total power”?

Table A.1 Questionnaire form 1 FAHP

	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	criteria
1	Air Quantity			■							Pressure
2	Air Quantity								■		Beneficial Use rate
3	Air Quantity									■	Beneficial Air Amount
4	Air Quantity		■								Total Power
5	Pressure								■		Beneficial Use Rate
6	Pressure								■		Beneficial Air Amount
7	Pressure		■								Total Power
8	Beneficial Use Rate	■									Beneficial Air Amount
9	Beneficial Use Rate		■								Total power
10	Beneficial Air Amount		■								Total Power

With respect to the main criterion “Pressure”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.2 Questionnaire form 2 FAHP

pressure	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1			■							Fan 2
2	Fan 1			■							Fan 3
3	Fan 1				■						Fan 4
4	Fan 2						■				Fan 3
5	Fan 2							■			Fan 4
6	Fan 3						■				Fan 4

With respect to the main criterion “Air quantity”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.3 Questionnaire form 3 FAHP

Air quantity	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1			■							Fan 2
2	Fan 1			■							Fan 3
3	Fan 1				■						Fan 4
4	Fan 2						■				Fan 3
5	Fan 2						■				Fan 4
6	Fan 3						■				Fan 4

With respect to the main criterion “Beneficial use rate”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.4 Questionnaire form 4 FAHP

Beneficial use rate	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1										Fan 2
2	Fan 1										Fan 3
3	Fan 1										Fan 4
4	Fan 2										Fan 3
5	Fan 2										Fan 4
6	Fan 3										Fan 4

With respect to the main criterion “Beneficial air amount at the face”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.5 Questionnaire form 5 FAHP

Beneficial air amount at the face	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1										Fan 2
2	Fan 1										Fan 3
3	Fan 1										Fan 4
4	Fan 2										Fan 3
5	Fan 2										Fan 4
6	Fan 3										Fan 4

With respect to the main criterion “Total power”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.6 Questionnaire form 6 FAHP

Total power	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1							■			Fan 3
3	Fan 1							■			Fan 4
4	Fan 2		■								Fan 3
5	Fan 2			■							Fan 4
6	Fan 3							■			Fan 4

Question Form for Evaluation

Expert 2:

With respect to the main criterion “Technical attributes”:

Question 1: How important is “Air quantity” when it is compared with “pressure”?

Question 2: How important is “Air quantity” when it is compared with “beneficial use rate”?

Question 3: How important is “Air quantity” when it is compared with “Beneficial air amount”?

Question 4: How important is “Air quantity” when it is compared with “total power”?

Question 5: How important is “pressure” when it is compared with “Beneficial use rate”?

Question 6: How important is “pressure” when it is compared with “Beneficial air amount”?

Question 7: How important is “pressure” when it is compared with “Total power”?

Question 8: How important is “Beneficial use rate” when it is compared with “Beneficial air amount”?

Question 9: How important is “Beneficial use rate” when it is compared with “Total power”?

Question 10: How important is “Beneficial air amount” when it is compared with “Total power”?

Table A.7 Questionnaire form 7 FAHP

	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	criteria
1	Air Quantity								■		Pressure
2	Air Quantity			■							Beneficial Use rate
3	Air Quantity			■							Beneficial Air Amount
4	Air Quantity		■								Total Power
5	Pressure		■								Beneficial Use Rate
6	Pressure			■							Beneficial Air Amount
7	Pressure		■								Total Power
8	Beneficial Use Rate							■			Beneficial Air Amount
9	Beneficial Use Rate				■						Total power
10	Beneficial Air Amount		■								Total Power

Table A.7. was converted to decision making matrix which is shown as Table (…).

Table A.8 Evaluation of sub-attribute

	C11	C12	C13	C14	C15
C11	(1,1,1)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)
C12	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)	(5/2,3,7/2)
C13	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)	$(3/2,2,5/2)^{-1}$	(2/3,1,3/2)
C14	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)
C15	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(2/3,1,3/2)	$(5/2,3,7/2)^{-1}$	(1,1,1)

$$s_1 = (6.786, 8.333, 9.9) \otimes (0.025, 0.029, 0.036) = (0.169, 0.241, 0.356)$$

$$s_2 = (10, 12, 14) \otimes (0.025, 0.029, 0.036) = (0.25, 0.348, 0.504)$$

$$s_3 = (2.752, 3.333, 3.966) \otimes (0.025, 0.029, 0.036) = (0.068, 0.096, 0.142)$$

$$s_4 = (5.685, 6.833, 7.952) \otimes (0.025, 0.029, 0.036) = (0.142, 0.198, 0.286)$$

$$s_5 = (2.523,3,3.7) \otimes (0.025,0.029,0.036) = (0.063,0.087,0.133)$$

$$V(s_1 > s_2) = 0.497 \,;\; V(s_1 > s_3) = 1 \,;\; V(s_1 > s_4) = 1 \,;\; V(s_1 > s_5) = 1$$

$$V(s_2 > s_1) = 1 \,;\; V(s_2 > s_3) = 1 \,;\; V(s_2 > s4) = 1 \,;\, V(s_2 > s_4) = 1 \,;\; V(s_2 > s_5) = 1$$

$$V(s_3 > s_1) = 0 \,;\; V(s_3 > s_2) = 0 \,;\; V(s_3 > s_4) = 0 \,;\; V(s_3 > s_5) = 1$$

$$V(s_4 > s_1) = 0.775 \,;\; V(s_4 > s_2) = 0.193 \,;\; V(s_4 > s_3) = 1 \,;\; V(s_4 > s_5) = 1$$

$$V(s_5 > s_1) = 0 \,;\; V(s_5 > s_2) = 0 \,;\; V(s_5 > s_3) = 0.878 \,;\; V(s_5 > s_4) = 0$$

W^T= (0.294,0.591,0,0.114,0)

With respect to the main criterion “Pressure”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.9 Questionnaire form 9 FAHP

Pressure	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1							■			Fan 3
3	Fan 1		■								Fan 4
4	Fan 2			■							Fan 3
5	Fan 2		■								Fan 4
6	Fan 3		■								Fan 4

Table A.10 Evaluation of attributes

Pressure	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(5/2,3,7/2)
Fan 2	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)
Fan 3	(3/2,2,5/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(5/2,3,7/2)
Fan 4	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)

$s_1 = (4.185,4.833,5.3) \otimes (0.039,0.044,0.052) = (0.163,0.212,0.275)$

$s_2 = (7.5,9,10.5) \otimes (0.039,0.044,0.052) = (0.292,0.396,0.546)$

$s_3 = (5.4,6.5,7.4) \otimes (0.039,0.044,0.052) = (0.210,0.286,0.384)$

$s_4 = (1.857,2,2.2) \otimes (0.039,0.044,0.052) = (0.072,0.088,0.114)$

$V(s_1 > s_2) = 0$; $V(s_1 > s_3) = 0.467$; $V(s_1 > s_4) = 1$

$V(s_2 > s_1) = 1$; $V(s_2 > s_3) = 1$;$V(s_2 > s_4) = 1$

$V(s_3 > s_1) = 0$; $V(s_3 > s_2) = 0.455$; $V(s_3 > s_4) = 1$

$V(s_4 > s_1) = 0$; $V(s_4 > s_2) = 0$; $V(s_4 > s_3) = 0$

W^T=(0,1,0,0)

With respect to the main criterion “Air quantity”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.11 Questionnaire form 11 FAHP

Air quantity	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1								■		Fan 3
3	Fan 1								■		Fan 4
4	Fan 2			■							Fan 3
5	Fan 2					■					Fan 4
6	Fan 3							■			Fan 4

Table A.12 Evaluation of attributes

Air quantity	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)
Fan 2	$(5/2,3,7/2)^{-1}$	(1,1,1)	(3/2,2/5/2)	(1,1,1)
Fan 3	$(5/2,3,7/2)^{-1}$	$(3/2,2/5/2)^{-1}$	(1,1,1)	$(3/2,2/5/2)^{-1}$
Fan 4	$(5/2,3,7/2)^{-1}$	(1,1,1)	(3/2,2/5/2)	(1,1,1)

With respect to the main criterion “Beneficial use rate”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.13 Questionnaire form 13 FAHP

Beneficial use rate	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1										Fan 2
2	Fan 1										Fan 3
3	Fan 1										Fan 4
4	Fan 2										Fan 3
5	Fan 2										Fan 4
6	Fan 3										Fan 4

Table A.14 Evaluation of attributes

Beneficial use rate	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

With respect to the main criterion “Beneficial air amount at the face”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.15 Questionnaire form 15 FAHP

Beneficial air amount at the face	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1								■		Fan 3
3	Fan 1							■			Fan 4
4	Fan 2							■			Fan 3
5	Fan 2			■							Fan 4
6	Fan 3										Fan 4

Table A.16 Evaluation of attributes

Beneficial air amount at the face	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$
Fan 2	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)
Fan 3	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$
Fan 4	(3/2,2,5/2)	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)	(1,1,1)

With respect to the main criterion “Total power”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.17 Questionnaire form 17 FAHP

Total power	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1							■			Fan 3
3	Fan 1								■		Fan 4
4	Fan 2			■							Fan 3
5	Fan 2			■							Fan 4
6	Fan 3							■			Fan 4

Table A.18 Evaluation of attributes

Total power	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$
Fan 2	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
Fan 3	(3/2,2,5/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	$(3/2,2,5/2)^{-1}$
Fan 4	(5/2,3,7/2)	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)	(1,1,1)

Question Form for Evaluation

Expert 3:

With respect to the main criterion “Technical attributes”:

Question 1: How important is “Air quantity” when it is compared with “pressure”?

Question 2: How important is “Air quantity” when it is compared with “beneficial use rate”?

Question 3: How important is “Air quantity” when it is compared with “Beneficial air amount”?

Question 4: How important is “Air quantity” when it is compared with “total power”?

Question 5: How important is “pressure” when it is compared with “Beneficial use rate”?

Question 6: How important is “pressure” when it is compared with “Beneficial air amount”?

Question 7: How important is “pressure” when it is compared with “Total power”?

Question 8: How important is “Beneficial use rate” when it is compared with “Beneficial air amount”?

Question 9: How important is “Beneficial use rate” when it is compared with “Total power”?

Question 10: How important is “Beneficial air amount” when it is compared with “Total power”?

Table A.19 Questionnaire form 19 FAHP

	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	criteria
1	Air Quantity		■								Pressure
2	Air Quantity			■							Beneficial Use rate
3	Air Quantity								■		Beneficial Air Amount
4	Air Quantity			■							Total Power
5	Pressure			■							Beneficial Use Rate
6	Pressure								■		Beneficial Air Amount
7	Pressure			■							Total Power
8	Beneficial Use Rate								■		Beneficial Air Amount
9	Beneficial Use Rate			■							Total power
10	Beneficial Air Amount		■								Total Power

Table A.20 Evaluation of sub-attribute

	C11	C12	C13	C14	C15
C11	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)
C12	$(5/2,3,7/2)^{-1}$	(1,1,1)	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)
C13	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(1,1,1)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)
C14	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)
C15	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)

$$s_1 = (6.785, 8.333, 9.9) \otimes (0.024, 0.029, 0.035) = (0.162, 0.241, 0.346)$$

$$s_2 = (4.572, 5.667, 6.8) \otimes (0.024, 0.029, 0.035) = (0.109, 0.164, 0.238)$$

$$s_3 = (3.585, 4.333, 5.233) \otimes (0.024, 0.029, 0.035) = (0.086, 0.125, 0.183)$$

$$s_4 = (11, 13, 15) \otimes (0.024, 0.029, 0.035) = (0.164, 0.377, 0.525)$$

$$s_5 = (2.485, 2.833, 3.4) \otimes (0.024, 0.029, 0.035) = (0.059, 0.082, 0.119)$$

$V(s_1 > s_2) = 1$; $V(s_1 > s_3) = 1$; $V(s_1 > s_4) = 0.572$; $V(s_1 > s_5) = 1$

$V(s_2 > s_1) = 0.496$; $V(s_2 > s_3) = 1$; $V(s_2 > s_4) = 0.257$; $V(s_2 > s_5) = 1$

$V(s_3 > s_1) = 0.153$; $V(s_3 > s_2) = 0.654$; $V(s_3 > s_4) = 0.07$; $V(s_3 > s_5) = 1$

$V(s_4 > s_1) = 1$; $V(s_4 > s_2) = 1$; $V(s_4 > s_3) = 1$; $V(s_4 > s_5) = 1$

$V(s_5 > s_1) = 0$; $V(s_5 > s_2) = 0.108$; $V(s_5 > s_3) = 0.434$; $V(s_5 > s_4) = 0$

W^T=(0.301,0.135,0.036,0.526,0)

With respect to the main criterion “Pressure”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.21 Questionnaire form 21 FAHP

pressure	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1							■			Fan 3
3	Fan 1			■							Fan 4
4	Fan 2			■							Fan 3
5	Fan 2		■								Fan 4
6	Fan 3			■							Fan 4

Table A.22 Evaluation of attributes

Pressure	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)
Fan 2	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)

Fan 3	(3/2,2,5/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(3/2,2,5/2)
Fan 4	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(1,1,1)

With respect to the main criterion "Air quantity":

Question 1: How important is "Fan 1" when it is compared with "Fan 2"?

Question 2: How important is "Fan 1" when it is compared with "Fan 3"?

Question 3: How important is "Fan 1" when it is compared with "Fan 4"?

Question 4: How important is "Fan 2" when it is compared with "Fan 3"?

Question 4: How important is "Fan 2" when it is compared with "Fan 4"?

Question 5: How important is "Fan 3" when it is compared with "Fan 4"?

Table A.23 Questionnaire form 23 FAHP

Air quantity	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1							■			Fan 3
3	Fan 1								■		Fan 4
4	Fan 2		■								Fan 3
5	Fan 2					■					Fan 4
6	Fan 3								■		Fan 4

Table A.24 Evaluation of attributes

Air quantity	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$
Fan 2	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(1,1,1)
Fan 3	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(1,1,1)	$(5/2,3,7/2)^{-1}$
Fan 4	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(1,1,1)

With respect to the main criterion "Beneficial use rate":

Question 1: How important is "Fan 1" when it is compared with "Fan 2"?

Question 2: How important is "Fan 1" when it is compared with "Fan 3"?

Question 3: How important is "Fan 1" when it is compared with "Fan 4"?

Question 4: How important is "Fan 2" when it is compared with "Fan 3"?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.25 Questionnaire form 25 FAHP

Beneficial use rate	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1										Fan 2
2	Fan 1										Fan 3
3	Fan 1										Fan 4
4	Fan 2										Fan 3
5	Fan 2										Fan 4
6	Fan 3										Fan 4

Table A.26 Evaluation of attributes

Beneficial use rate	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

With respect to the main criterion “Beneficial air amount at the face”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.27 Questionnaire form 27 FAHP

Beneficial air amount at the face	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1								■		Fan 3
3	Fan 1								■		Fan 4
4	Fan 2							■			Fan 3
5	Fan 2		■								Fan 4
6	Fan 3		■								Fan 4

Table A.28 Evaluation of attributes

Beneficial air	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$
Fan 2	(5/2,3,7/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$	(5/2,3,7/2)
Fan 3	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)
Fan 4	(5/2,3,7/2)	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)

$$s_1 = (1.857,2,2.2) \otimes (0.037,0.043,0.05) = (0.068,0.086,0.110)$$

$$s_2 = (6.4,7.5,8.666) \otimes (0.037,0.043,0.05) = (0.236,0.322,0.433)$$

$$s_3 = (7.5,9,10.5) \otimes (0.037,0.043,0.05) = (0.277,0.387,0.525)$$

$$s_4 = (4.071,4.666,5.3) \otimes (0.037,0.043,0.05) = (0.150,0.200,0.265)$$

$$V(s_1 > s_2) = 0;\ V(s_1 > s_3) = 0;\ V(s_1 > s_4) = 0$$

$$V(s_2 > s_1) = 1;\ V(s_2 > s_3) = 0.705;\ V(s_2 > s_4) = 1$$

$$V(s_3 > s_1) = 1;\ V(s_3 > s_2) = 1;\ V(s_3 > s_4) = 1$$

$$V(s_4 > s_1) = 1;\ V(s_4 > s_2) = 0.192;\ V(s_4 > s_3) = 0$$

W^T= (0,0.260,0.369,0)

With respect to the main criterion “Total power”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A. 29 Questionnaire form 29 FAHP

Total power	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1								■		Fan 3
3	Fan 1							■			Fan 4
4	Fan 2			■							Fan 3
5	Fan 2		■								Fan 4
6	Fan 3							■			Fan 4

Table A.30 Evaluation of attributes

Total power	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$
Fan 2	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)
Fan 3	(5/2,3,7/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	$(3/2,2,5/2)^{-1}$
Fan 4	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)	(1,1,1)

Question Form for Evaluation

Expert 4:

With respect to the main criterion “Technical attributes”:

Question 1: How important is “Air quantity” when it is compared with “pressure”?

Question 2: How important is “Air quantity” when it is compared with “beneficial use rate”?

Question 3: How important is “Air quantity” when it is compared with “Beneficial air amount”?

Question 4: How important is “Air quantity” when it is compared with “total power”?

Question 5: How important is “pressure” when it is compared with “Beneficial use rate”?

Question 6: How important is “pressure” when it is compared with “Beneficial air amount”?

Question 7: How important is “pressure” when it is compared with “Total power”?

Question 8: How important is “Beneficial use rate” when it is compared with “Beneficial air amount”?

Question 9: How important is “Beneficial use rate” when it is compared with “Total power”?

Question 10: How important is “Beneficial air amount” when it is compared with “Total power”?

Table A.31 Questionnaire form 31 FAHP

	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	criteria
1	Air Quantity		■								Pressure
2	Air Quantity		■								Beneficial Use rate
3	Air Quantity			■							Beneficial Air Amount
4	Air Quantity		■								Total Power
5	Pressure			■							Beneficial Use Rate
6	Pressure								■		Beneficial Air Amount
7	Pressure		■								Total Power
8	Beneficial Use Rate								■		Beneficial Air Amount
9	Beneficial Use Rate		■								Total power
10	Beneficial Air Amount		■								Total Power

Table A.32 Evaluation of sub-attribute

	C11	C12	C13	C14	C15
C11	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)
C12	$(5/2,3,7/2)^{-1}$	(1,1,1)	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)
C13	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(1,1,1)	$(5/2,3,7/2)^{-1}$	(5/2,3,7/2)
C14	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)
C15	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)

$$s_1 = (7.785, 9.333, 10.900) \otimes (0.021, 0.025, 0.030) = (0.163, 0.233, 0.327)$$

$$s_2 = (5.571, 6.666, 7.800) \otimes (0.021, 0.025, 0.030) = (0.116, 0.166, 0.234)$$

$$s_3 = (4.471, 5.166, 5.966) \otimes (0.021, 0.025, 0.030) = (0.093, 0.129, 0.178)$$

$$s_4 = (11, 13, 15) \otimes (0.021, 0.025, 0.030) = (0.234, 0.325, 0.450)$$

$$s_5 = (4.471, 5.166, 5.966) \otimes (0.021, 0.025, 0.030) = (0.093, 0.129, 0.178)$$

$$V(s_1 > s_2) = 1;\ V(s_1 > s_3) = 1;\ V(s_1 > s_4) = 0.502;\ V(s_1 > s_5) = 1$$

$V(s_2 > s_1) = 0.514$; $V(s_2 > s_3) = 1$; $V(s_2 > s_4) = 0$; $V(s_2 > s_5) = 1$

$V(s_3 > s_1) = 0.126$; $V(s_3 > s_2) = 0.626$; $V(s_3 > s_4) = 0$; $V(s_3 > s_5) = 1$

$V(s_4 > s_1) = 1$; $V(s_4 > s_2) = 1$; $V(s_4 > s_3) = 1$; $V(s_4 > s_5) = 1$

$V(s_5 > s_1) = 0.126$; $V(s_5 > s_2) = 0.521$; $V(s_5 > s_3) = 1$; $V(s_5 > s_4) = 0$

W^T= (0.334,0,0,0.652,0)

With respect to the main criterion “Pressure”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.33 Questionnaire form 33 FAHP

pressure	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1								■		Fan 3
3	Fan 1			■							Fan 4
4	Fan 2		■								Fan 3
5	Fan 2		■								Fan 4
6	Fan 3		■								Fan 4

Table A.34 Questionnaire form 34 FAHP

Pressure	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(3/2,2,5/2)
Fan 2	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)
Fan 3	(5/2,3,7/2)	$(5/2,3,7/2)^{-1}$	(1,1,1)	(5/2,3,7/2)
Fan 4	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)

With respect to the main criterion “Air quantity”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.35 Questionnaire form 35 FAHP

Air quantity	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1							■			Fan 3
3	Fan 1								■		Fan 4
4	Fan 2		■								Fan 3
5	Fan 2					■					Fan 4
6	Fan 3							■			Fan 4

Table A.36 Evaluation of attributes

Air quantity	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$
Fan 2	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	(1,1,1)
Fan 3	(3/2,2,5/2)	$(5/2,3,7/2)^{-1}$	(1,1,1)	$(3/2,2,5/2)^{-1}$
Fan 4	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)

With respect to the main criterion “Beneficial use rate”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.37 Questionnaire form 37 FAHP

Beneficial use rate	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1										Fan 2
2	Fan 1										Fan 3
3	Fan 1										Fan 4
4	Fan 2										Fan 3
5	Fan 2										Fan 4
6	Fan 3										Fan 4

Table A.38 Evaluation of attributes

Beneficial use rate	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 2	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 3	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Fan 4	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

With respect to the main criterion “Beneficial air amount at the face”:

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.39 Questionnaire form 39 FAHP

Beneficial air amount at the face	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1							■			Fan 2
2	Fan 1							■			Fan 3
3	Fan 1								■		Fan 4
4	Fan 2							■			Fan 3
5	Fan 2			■							Fan 4
6	Fan 3			■							Fan 4

Table A.40 Evaluation of attributes

Beneficial air	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$
Fan 2	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)
Fan 3	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
Fan 4	(5/2,3,7/2)	$(3/2,2,5/2)^{-1}$	$(3/2,2,5/2)^{-1}$	(1,1,1)

$$s_1 = (2.085,2.333,2.733) \otimes (0.042,0.050,0.061) = (0.087,0.116,0.166)$$

$$s_2 = (4.4,5.5,6.666) \otimes (0.042,0.050,0.061) = (0.184,0.275,0.406)$$

$$s_3 = (5.5,7,8.5) \otimes (0.042,0.050,0.061) = (0.231,0.350,0.518)$$

$$s_4 = (4.3,5,5.833) \otimes (0.042,0.050,0.061) = (0.180,0.250,0.355)$$

$$V(s_1 > s_2) = 0;\ V(s_1 > s_3) = 0;\ V(s_1 > s_4) = 0$$

$$V(s_2 > s_1) = 1;\ V(s_2 > s_3) = 0.700;\ V(s_2 > s_4) = 1$$

$$V(s_3 > s_1) = 1;\ V(s_3 > s_2) = 1;\ V(s_3 > s_4) = 1$$

$$V(s_4 > s_1) = 1;\ V(s_4 > s_2) = 0.872;\ V(s_4 > s_3) = 0.553$$

W^T= (0,0.310,0.443,0.245)

With respect to the main criterion "Total power":

Question 1: How important is “Fan 1” when it is compared with “Fan 2”?

Question 2: How important is “Fan 1” when it is compared with “Fan 3”?

Question 3: How important is “Fan 1” when it is compared with “Fan 4”?

Question 4: How important is “Fan 2” when it is compared with “Fan 3”?

Question 4: How important is “Fan 2” when it is compared with “Fan 4”?

Question 5: How important is “Fan 3” when it is compared with “Fan 4”?

Table A.41 Questionnaire form 41 FAHP

Total power	Importance (or preference) of one sub-criteria over another										
Questions	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Fan 1								■		Fan 2
2	Fan 1								■		Fan 3
3	Fan 1							■			Fan 4
4	Fan 2		■								Fan 3
5	Fan 2			■							Fan 4
6	Fan 3							■			Fan 4

Table A.42 Evaluation of attributes

Total power	Fan 1	Fan 2	Fan 3	Fan 4
Fan 1	(1,1,1)	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(3/2,2,5/2)^{-1}$
Fan 2	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)
Fan 3	(5/2,3,7/2)	$(5/2,3,7/2)^{-1}$	(1,1,1)	$(3/2,2,5/2)^{-1}$
Fan 4	(3/2,2,5/2)	$(3/2,2,5/2)^{-1}$	(3/2,2,5/2)	(1,1,1)

QUESTIONNAIRE FORMS FOR PITCH ANGLE SELECTION

Question Form for Evaluation

With respect to the main criterion “Technical attributes”:

Question 1: How important is “Flow volume” when it is compared with “Total pressure”?

Question 2: How important is “Flow volume” when it is compared with “Fan output”?

Question 3: How important is “Flow volume” when it is compared with “Acoustic power level”?

Question 4: How important is “Flow volume” when it is compared with “Efficiency”?

Question 5: How important is “Total pressure” when it is compared with “Fan output”?

Question 6: How important is “Total pressure” when it is compared with “Acoustic power level”?

Question 7: How important is “Total pressure” when it is compared with “Efficiency”?

Question 8: How important is “Fan output” when it is compared with “Acoustic power level”?

Question 9: How important is “Fan output” when it is compared with “Efficiency”?

Question 10: How important is “Acoustic power level” when it is compared with “Efficiency”?

Table B.1 Questionnaire form 1 FAHP

	Importance (or performance) of our sub-criteria over another										
Question No.	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Flow Volume					■					Total Pressure
2	Flow Volume					■					Fan output
3	Flow Volume						■				Acoustic Power Level
4	Flow Volume		■								Efficiency
5	Total Pressure			■							Shaft Output
6	Total Pressure			■							Acoustic Power Level
7	Total Pressure		■								Efficiency
8	Fan output					■					Acoustic Power Level
9	Fan output					■					Efficiency
10	Acoustic Power Level					■					Efficiency

With respect to the main criterion “Flow volume”:

Question 1: How important is “Angle 1” when it is compared with “Angle 2”?

Question 2: How important is “Angle 1” when it is compared with “Angle 3”?

Question 3: How important is “Angle 1” when it is compared with “Angle 4”?

Question 4: How important is “Angle 2” when it is compared with “Angle 3”?

Question 4: How important is “Angle 2” when it is compared with “Angle 4”?

Question 5: How important is “Angle 3” when it is compared with “Angle 4”?

Table B.2. was converted to decision making matrix which is shown as Table (B.3).

Table B.3 Evaluation of sub-attribute

	C11	C12	C13	C14	C15
C11	(1,1,1)	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(5/2,3,7/2)
C12	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)
C13	(1,1,1)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(1,1,1)	(1,1,1)
C14	(2/3,1,3/2)	$(3/2,2,5/2)^{-1}$	(1,1,1)	(1,1,1)	(1,1,1)
C15	$(5/2,3,7/2)^{-1}$	$(5/2,3,7/2)^{-1}$	(1,1,1)	(1,1,1)	(1,1,1)

With respect to the main criterion "Flow volume":

Question 1: How important is "Angle 1" when it is compared with "Angle 2"?

Question 2: How important is "Angle 1" when it is compared with "Angle 3"?

Question 3: How important is "Angle 1" when it is compared with "Angle 4"?

Question 4: How important is "Angle 2" when it is compared with "Angle 3"?

Question 4: How important is "Angle 2" when it is compared with "Angle 4"?

Question 5: How important is "Angle 3" when it is compared with "Angle 4"?

Table B.4 Questionnaire form 2 FAHP

Flow Volume	Importance (or performance) of one sub-criteria over another										
Question	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Angle 1							■			Angle 2
2	Angle 1								■		Angle 3
3	Angle 1									■	Angle 4
4	Angle 2						■				Angle 3
5	Angle 2							■			Angle 4
6	Angle 3							■			Angle 4

Table B.5 Evaluation of attributes

Flow Volume	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(7/2,4,9/2)^{-1}$
Angle 2	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	$(3/2,2,5/2)^{-1}$
Angle 3	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$
Angle 4	(7/2,4,9/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)

With respect to the main criterion "Total pressure":

Question 1: How important is "Angle 1" when it is compared with "Angle 2"?

Question 2: How important is "Angle 1" when it is compared with "Angle 3"?

Question 3: How important is "Angle 1" when it is compared with "Angle 4"?

Question 4: How important is "Angle 2" when it is compared with "Angle 3"?

Question 4: How important is "Angle 2" when it is compared with "Angle 4"?

Question 5: How important is "Angle 3" when it is compared with "Angle 4"?

Table B.6 Questionnaire form 3 FAHP

Total pressure	Importance (or performance) of one sub-criteria over another										
Question	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Angle 1							■			Angle 2
2	Angle 1								■		Angle 3
3	Angle 1									■	Angle 4
4	Angle 2							■			Angle 3
5	Angle 2									■	Angle 4
6	Angle 3								■		Angle 4

Table B.7 Evaluation of attributes

Total pressure	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(7/2,4,9/2)^{-1}$
Angle 2	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(7/2,4,9/2)^{-1}$
Angle 3	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	$(5/2,3,7/2)^{-1}$
Angle 4	(7/2,4,9/2)	(7/2,4,9/2)	(5/2,3,7/2)	(1,1,1)

With respect to the main criterion “Fan output”:

Question 1: How important is “Angle 1” when it is compared with “Angle 2”?

Question 2: How important is “Angle 1” when it is compared with “Angle 3”?

Question 3: How important is “Angle 1” when it is compared with “Angle 4”?

Question 4: How important is “Angle 2” when it is compared with “Angle 3”?

Question 4: How important is “Angle 2” when it is compared with “Angle 4”?

Question 5: How important is “Angle 3” when it is compared with “Angle 4”?

Table B.8 Questionnaire form 4 FAHP

Fan output	Importance (or performance) of one sub-criteria over another										
Question	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Angle 1							■			Angle 2
2	Angle 1								■		Angle 3
3	Angle 1									■	Angle 4
4	Angle 2							■			Angle 3
5	Angle 2									■	Angle 4
6	Angle 3							■			Angle 4

Table B.9 Evaluation of attributes

Fan output	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(5/2,3,7/2)^{-1}$	$(7/2,4,9/2)^{-1}$
Angle 2	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$	$(7/2,4,9/2)^{-1}$
Angle 3	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	$(3/2,2,5/2)^{-1}$
Angle 4	(7/2,4,9/2)	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)

With respect to the main criterion “Acoustic power level”:

Question 1: How important is “Angle 1” when it is compared with “Angle 2”?

Question 2: How important is “Angle 1” when it is compared with “Angle 3”?

Question 3: How important is “Angle 1” when it is compared with “Angle 4”?

Question 4: How important is “Angle 2” when it is compared with “Angle 3”?

Question 4: How important is “Angle 2” when it is compared with “Angle 4”?

Question 5: How important is “Angle 3” when it is compared with “Angle 4”?

Table B.10 Questionnaire form 5 FAHP

Acoustic Power Level	Importance (or performance) of one sub-criteria over another										
Question	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Angle 1				■						Angle 2
2	Angle 1					■					Angle 3
3	Angle 1						■				Angle 4
4	Angle 2						■				Angle 3
5	Angle 2							■			Angle 4
6	Angle 3						■				Angle 4

Table B.11 Evaluation of attributes

Acoustic Power Level	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)
Angle 2	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	$(3/2,2,5/2)^{-1}$
Angle 3	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)
Angle 4	c	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

With respect to the main criterion “Efficiency”:

Question 1: How important is “Angle 1” when it is compared with “Angle 2”?

Question 2: How important is “Angle 1” when it is compared with “Angle 3”?

Question 3: How important is “Angle 1” when it is compared with “Angle 4”?

Question 4: How important is “Angle 2” when it is compared with “Angle 3”?

Question 4: How important is “Angle 2” when it is compared with “Angle 4”?

Question 5: How important is “Angle 3” when it is compared with “Angle 4”?

Table B.12 Questionnaire form 6 FAHP

Efficiency	Importance (or performance) of one sub-criteria over another										
Question	Criteria	Absolute	Very Strong	Fairly Strong	Weak	Equal	Weak	Fairly Strong	Very Strong	Absolute	Criteria
1	Angle 1				■						Angle 2
2	Angle 1				■						Angle 3
3	Angle 1					■					Angle 4
4	Angle 2					■					Angle 3
5	Angle 2						■				Angle 4
6	Angle 3						■				Angle 4

Table B.13 Evaluation of attributes

Efficiency	Angle 1	Angle 2	Angle 3	Angle 4
Angle 1	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)
Angle 2	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)
Angle 3	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)
Angle 4	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)