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preference of effective factors in suitable selection of microtunnel boring machines (mtbm) by using the fuzzy analytic hierarchy process (fahp) approach

preferencia de factores de efectividad en la selección apropiada de máquinas taladradoras de microtúnel (mtbm) usando el enfoque del proceso jerárquico analítico difuso (fach)

Alireza Jafari* Mohammad Ataie†
Sayed Mohammad Esmaiel Jalali‡
Ahmad Ramazanzadeh§

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Abstract

The development of underground infrastructure, environmental concerns, and economic trend is influencing society. Due to the increasingly critical nature of installations of utility systems especially in congested areas, the need for monitoring and control system has increased. The microtunneling system will therefore have to provide for possibility of minimized surface disruption. Suitable selection of Microtunneling Boring Machine (MTBM) is the most curial decision that manager must be done. Because once the trenchless excavation has started, it might be too late to make any changes in equipment without extra costs and delays. Therefore, the various factors and parameters are affecting the choice of machine. In this paper discusses a developed methodology based on Fuzzy Analytic Hierarchy Process (FAHP) in order to determine weights of the criteria and sub criteria and then ranking them. Within the proposed model, four criteria site, machinery, structural, labor force impact and 18 sub-criteria are specified. The linguistic level of comparisons produced by experts are tapped and constructed in a form of triangular fuzzy numbers in order to construct fuzzy pair wise comparison matrices. Therefore, FAHP uses the pair wise comparison matrices for determining the weights of the criteria and sub-criteria.

Keywords: Microtunnel Boring Machines (MTBMs); Fuzzy Analytic Hierarchy Process (FAHP); trenchless technology.

Resumen

El desarrollo de infraestructura subterránea, con preocupaciones ambientales y tendencias económicas, está influyendo a la sociedad. Debido a la naturaleza crecientemente crítica de las instalaciones de sistemas utilitarios, especialmente en áreas congestionadas, ha aumentado la necesidad de sistemas de monitoreo y control. Por lo tanto el sistema de microtunelación ayudará a minimizar la superficie perturbada. La selección adecuada de Máquinas Taladradoras de Microtúnel (MTBM, por sus siglas en inglés) es la decisión más juiciosa que puede hacerse, puesto que una vez que la excavación sin zanjas ha iniciado, podría ser muy tarde para hacer cambios en el equipo sin un costo ni atrasos adicionales. Luego, los diversos factores y parámetros afectan la escogencia de la máquina. En este artículo se discute una metodología desarrollada, que se basa en el

*Faculty of Mining Engineering, Petroleum & Geophysics, Shahrood University of Technology, Hafte-Tir Square, Shahrood, Iran. E-Mail: ataei@shahroodut.ac.ir

†Same address as A. Jafari. E-Mail: ataei@shahroodut.ac.ir

‡Same address as A. Jafari. E-Mail: jalalisme@shahroodut.ac.ir

§Same address as A. Jafari. E-Mail: aramezanzadeh@gmail.com

Proceso Jerárquico Analítico Difuso (FACH) para determinar pesos de los criterios y subcriterios, y luego ordenarlos. En el modelo propuesto se especifican cuatro criterios de sitio, maquinaria, estructura, impacto de la fuerza laboral y 18 subcriterios. Los niveles lingüísticos de comparaciones producidos por expertos se construyen en forma de números difusos triangulares para construir matrices de comparación difusa por parejas. Por lo tanto el FAHP usa las matrices de comparación por parejas para determinar los pesos de los criterios y subcriterios.

Palabras clave: Máquinas Taladradoras de Microtúnel (MTBMs), Proceso Jerárquico Anaítico Difuso (FAHP), tecnología sin zanjas.

Mathematics Subject Classification: 90C99.

1 Introduction

The conventional method (open-cut), which traditionally has been used for construction, replacement, and repair of conduit construction. This method includes direct installation of utility system into open-cut trenches (Najafi, 2005). The problems connected to this method which has resulted the open-cut method is more time consuming and does not always yield the most cost-effective method of pipe installation (FSTT, 2006). Due to the increasingly critical nature of installation of utility systems especially in congested area, which has resulted in a growing demand for trenchless technology as an alternative to traditional construction methods (Read.G, 2004). Microtunneling, one of the trenchless construction methods. According to ASCE's Standard Construction Guidelines for microtunneling, microtunneling can be defined as "a remotely controlled and guided pipe jacking technique that provides continuous support to the excavation face and does not require personnel entry into the tunnel" (ASCE, 2001). Nevertheless, microtunnel machines are very expensive and few contractors have extensive experience with this technology. Therefore, in order to make a right decision on suitable selection of microtunnel machine and eventually successful completion of a trenchless construction project requires a clear understanding of effective and major criteria that will be play important role in the selection of the suitable microtunneling machine. Because once the trenchless excavation has started, it might be too late to make any changes in equipment without extra costs and delays (Moser and Folkman, 2008). A number of related criteria make the decision making process more complicated and more difficult to reach a solution. Therefore, evaluating all known criteria related to the microtunnel machines selection by using the decision making process is extremely significant.

Therefore, the main objective of this paper is to present a systemic procedure the fuzzy analytic hierarchy process (FAHP) for determining weights of the criteria and sub criteria and then ranking them. The study was supported by results that were obtained from a questionnaire carried out to know the opinions of the experts in this subject, where expert's comparison judgments are represented as fuzzy triangular numbers in order to construct fuzzy pair wise comparison matrices. Therefore, the fuzzy analytic hierarchy process (FAHP) uses the pair wise comparison matrices for determining the weights of the criteria and sub-criteria. Therefore, first, noteworthy factors in suitable selection of Microtunnel Boring Machines are described and then the basic principles of fuzzy set theory together with FAHP in next section are illustrated.

2 Summary of parameters affecting the selection microtunnel boring machines

Four groups of factors that have relation with MTBM selection such as, geological and geotechnical properties, machinery and environmental incorporating with human are affecting the choice of MTBMs. These are considered as a major criteria. Distribution of main criteria and sub criteria are illustrated in Table 1. In order to suitable selection of MTBM with the help of site information and appropriate factors, firstly, a comprehensive questionnaire including main criteria and their sub criteria of MTBM selection is designed to quantify the degree of importance and affecting factors in the process. Then, nineteen decision makers from different areas evaluate the importance of these factors with the help of mentioned questionnaire. Each person filling the questionnaire has to mark one of the following categories for each parameter: 1: Very Weak Importance; 2: Weak Importance; 3: Moderate Importance; 4: Strong Importance; 5: Very Strong Importance.

3 Membership function

An element of the variable can be a member of the fuzzy set through a membership function that can take values in the range from 0 to 1. Membership functions (MF) can be chosen by the user arbitrarily based on the

Factors	Subcriteria
Soil characteristics	Type of soil Permeability Abrasive Granulometric Shear strength Time depended behavior Plasticity Water content Effective stress
Machine characteristics	Flexibility Thrust Torque Capability of control deviance from their path
Construction characteristics	Shape Length Diameter Depth
Environmental and labor force impact	Downfall of atmospheric Allowable of subsidence Experience and proficiency of labor force Involved Surface

Table 1: Distribution of parameters affecting the choice of MTBM.

user's experience or can also be designed using machine learning methods (e.g., artificial neural networks, genetic algorithms, etc.). There are different shapes of membership functions; triangular, trapezoidal, piecewise-linear, Gaussian, bell shaped, etc. In this study, triangular membership functions are used. In this study expert's comparison, judgments are represented as fuzzy triangular numbers in order to construct fuzzy pair wise comparison matrices. In this study, triangular membership functions are used. Triangular MF is shown in Fig. 1.

In Fig. 1, points l, m, and u in the triangular MF represent the x coordinates of the three vertices of $\mu_{M(x)}$ in a fuzzy set M (l: lower boundary and u: upper boundary where the membership degree is zero, m: the center where membership degree is 1). Each triangular has linear

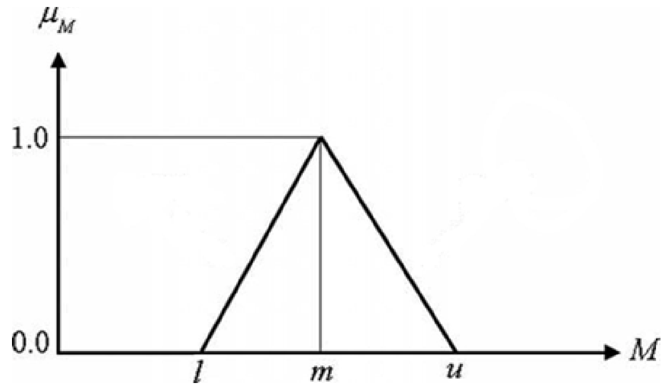

Figure 1: A triangular fuzzy number.

representations on its left and right side such that its membership function can be defined as:

$$\mu_A = \begin{cases} 0 & \text{if } x < l \\ \frac{x-l}{m-l} & \text{if } l \leq x \leq m \\ \frac{u-x}{u-m} & \text{if } m \leq x \leq u \\ 0 & \text{if } x \geq u. \end{cases}$$

These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The detailed description of FAHP method is illustrated in the following section.

4 Fuzzy Analytic Hierarchy Process (FAHP)

The analytic hierarchy process (AHP) method first proposed by Saaty (1980) shows the process of making a choice among a set of alternatives and which provides a comparison of the considered options (Saaty, 1980; Wei, Chien, & Wang, 2005). AHP divides a complicated system under study into a hierarchical system of elements. Pair-wise comparisons are made of the elements of each hierarchy by means of a nominal scale. Since the evaluation, criteria are subjective and qualitative in nature; it is difficult for the experts and decision makers to express the preferences using exact numerical values and to provide exact pair-wise comparison judgments (Felix Chan, et al, 2007). Therefore, the traditional AHP still cannot really reflect the human thinking style (Kahraman, Cebeci, & Ulukan, 2003). In order to overcome all these deficiency, FAHP methodology, which is based on the concept of fuzzy set theory, was developed for solving the hierarchical problems. FAHP can adequately handle the inherent uncertainty and imprecision of the human decision making process.

5 Methodology of FAHP

The proposed FAHP model to choice of suitable microtunnel boring machines (MTBMs) was originally introduced by Chang (1996). Put $X = \{x_1, x_2, x_3, \ldots, x_n\}$ be an object set, and $G = \{g_1, g_2, g_3, \ldots, g_n\}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, \quad i = 1, 2, \ldots, n \tag{1}$$

where all the $M_{g_i}^j$ $(j = 1, 2, \ldots, m)$ are triangular membership functions. The steps of Chang's extent analysis (Chang, 1996) are composed of the following steps:

Step 1. Quantification of fuzzy number's value with respect to the i–th object is defined as

$$s_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}. \tag{2}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} U_j \right). \tag{3}$$

And to obtain $[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j]^{-1}$, the fuzzy addition operation of $M_{g_i}^j$ $(j = 1, 2, \ldots, m)$ values is performed such as

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} U_i \right). \tag{4}$$

Detailed specification of Hamadan city sewers are illustrated in the following section. Then the inverse of the vector above is computed, such as

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} U_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right). \quad (5)$$

Step 2. As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \quad (6)$$

Moreover, can be expressed as follows:

$$\begin{aligned} V(M_2 \geq M_1) &= \mathrm{hgt}(M_1 \cap M_2) = \mu_{M_2}(d) & (7) \\ \mu_{M_2}(d) &= \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)} & \text{otherwise.} \end{cases} & (8) \end{aligned}$$

Where, d is the ordinate of the highest intersection point D between μ_{m_1} and μ_{m_2} to compare M_1 and M_2, we need both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ (see Fig. 2).

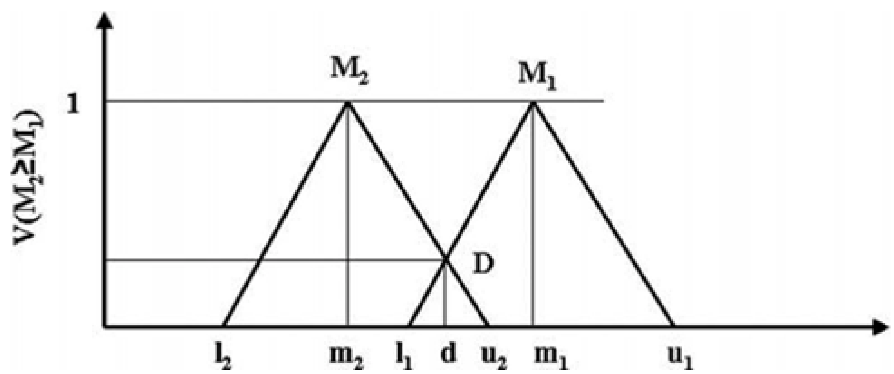

Figure 2: The intersection between M_1 and M_2.

Step 3. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy number M_i $(i = 1, 2, \ldots, k)$ can be defined by

$$\begin{aligned} V(M \geq M_1, M_2, \ldots, M_k) &= V[(M \geq M_1)]\text{and} \ldots \text{and}(M \geq M_k)] \\ &= \min V(M \geq M_i), \quad i = 1, 2, \ldots, k. \quad (9) \end{aligned}$$

Assume that $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1, 2, \ldots, n; k \neq i$. Then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{10}$$

where $A_i (i = 1, 2, \ldots, n)$ are n elements.

Step 4. Via normalization, the normalized weight vectors are

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{11}$$

where W is a non-fuzzy number.

These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. Decision makers from different backgrounds may define different weight vectors. They usually cause not only the imprecise evaluation but also serious persecution during decision process. For this reason, FAHP is proposed to consider subjective judgments and to reduce the uncertainty and vagueness in the decision process. Therefore, we proposed a group decision based on FAHP to improve pair-wise comparison. Firstly each decision maker (D), individually carry out pair-wise comparison by using Saaty's (Saaty, 1980) 1-9 scale (Table 2).

Comparison index score	
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equal	1
Intermediate values between the two adjacent judgments	2,4,6,7,8

Table 2: Pair-wise comparison scale (Saaty, 1980).

Then, a comprehensive pair-wise comparison matrix for site sub criteria is built as in Table 3 by integrating nineteen decision makers' grades through Eq. (12) (Chen, Lin, & Huang, 2006). By this way, decision makers' pair-wise comparison values are transformed into triangular fuzzy numbers as in Table 3. Moreover, for other cases pair-wise comparisons are constituted:

$$\begin{aligned} X_{ij} &= (a_{ij}, b_{ij}, c_{ij}) \\ l_{ij} &= \min_k \{a_{ijk}\}, m_{ij} = \frac{1}{k} \sum_{k=1} b_{ijk}, u_{ij} = \max_k \{c_{ijk}\}. \end{aligned} \tag{12}$$

After forming fuzzy pair-wise comparison matrix for all criteria, weights of all criteria and sub-criteria are determined by the help of FAHP. For instance, firstly synthesis values must be calculated. From (Table 3), synthesis values respect to main goal are calculated like in Eq. (2):

$$
\begin{aligned}
S_{11} &= (6.7, 13.2, 39.9) \otimes (0.004, 0.011, 0.025) = (0.028, 0.143, 0.98)\\
S_{12} &= (2.95, 9.2, 17.9) \otimes (0.004, 0.011, 0.025) = (0.012, 0.099, 0.44)\\
S_{13} &= (2.8, 9.02, 19) \otimes (0.004, 0.011, 0.025) = (0.011, 0.097, 0.47)\\
S_{14} &= (3.95, 11.1, 33.4) \otimes (0.004, 0.011, 0.025) = (0.016, 0.12, 0.82)\\
S_{15} &= (6.8, 12.2, 34.2) \otimes (0.004, 0.011, 0.025) = (0.028, 0.132, 0.84)\\
S_{16} &= (2.9, 7.4, 13.4) \otimes (0.004, 0.011, 0.025) = (0.012, 0.08, 0.33)\\
S_{17} &= (5.8, 10.9, 34.2) \otimes (0.004, 0.011, 0.025) = (0.024, 0.12, 0.84)\\
S_{18} &= (4.8, 9.7, 19.9) \otimes (0.004, 0.011, 0.025) = (0.02, 0.105, 0.49)\\
S_{19} &= (4.2, 9.8, 19.9) \otimes (0.004, 0.011, 0.025) = (0.017, 0.106, 0.75)
\end{aligned}
$$

Then the degree of possibility of M_i over M_j $(i \neq j)$ can be determined by Eq. (8) for structure sub-criteria as below:

$$V(s_{11} \geq s_{12}) = 1, V(s_{11} \geq s_{13}) = 1, V(s_{11} \geq s_{14}) = 1, V(s_{11} \geq s_{15}) = 1,$$

$$V(s_{11} \geq s_{16}) = 1, V(s_{11} \geq s_{17}) = 1, V(s_{11} \geq s_{18}) = 1, V(s_{11} \geq s_{19}) = 1,$$

$$V(s_{12} \geq s_{11}) = 0.9, V(s_{12} \geq s_{13}) = 1, V(s_{12} \geq s_{14}) = 0.95,$$

$$V(s_{12} \geq s_{15}) = 0.93, V(s_{12} \geq s_{16}) = 1, V(s_{12} \geq s_{17}) = 0.96,$$

$$V(s_{12} \geq s_{18}) = 0.99, V(s_{12} \geq s_{19}) = 0.99, V(s_{13} \geq s_{11}) = 0.91,$$

$$V(s_{13} \geq s_{12}) = 1, V(s_{13} \geq s_{14}) = 0.95, V(s_{13} \geq s_{15}) = 0.93,$$

$$V(s_{13} \geq s_{16}) = 1, V(s_{13} \geq s_{17}) = 0.96, V(s_{13} \geq s_{18}) = 0.98,$$

$$V(s_{13} \geq s_{19}) = 0.98.$$

$$V(s_{14} \geq s_{11}) = 0.97, V(s_{14} \geq s_{12}) = 1, V(s_{14} \geq s_{13}) = 1,$$

$$V(s_{14} \geq s_{15}) = 0.98, V(s_{14} \geq s_{16}) = 1, V(s_{14} \geq s_{17}) = 1,$$

$$V(s_{14} \geq s_{18}) = 1, V(s_{14} \geq s_{19}) = 1, V(s_{15} \geq s_{11}) = 0.99,$$

$$V(s_{15} \geq s_{12}) = 1, V(s_{15} \geq s_{13}) = 1, V(s_{15} \geq s_{14}) = 1,$$

$$V(s_{15} \geq s_{16}) = 1, V(s_{15} \geq s_{17}) = 1, V(s_{15} \geq s_{18}) = 1,$$

$$V(s_{15} \geq s_{19}) = 1, V(s_{16} \geq s_{11}) = 0.83, V(s_{16} \geq s_{12}) = 0.94,$$
$$V(s_{16} \geq s_{13}) = 0.95, V(s_{16} \geq s_{14}) = 0.89, V(s_{16} \geq s_{15}) = 0.85,$$
$$V(s_{16} \geq s_{17}) = 0.89, V(s_{16} \geq s_{18}) = 0.92, V(s_{16} \geq s_{19}) = 0.92,$$
$$V(s_{17} \geq s_{11}) = 0.97, V(s_{17} \geq s_{12}) = 1, V(s_{17} \geq s_{13}) = 1,$$
$$V(s_{17} \geq s_{14}) = 1, V(s_{17} \geq s_{15}) = 0.98, V(s_{17} \geq s_{16}) = 1,$$
$$V(s_{17} \geq s_{18}) = 1, V(s_{17} \geq s_{19}) = 1, V(s_{18} \geq s_{11}) = 0.92,$$
$$V(s_{18} \geq s_{12}) = 1, V(s_{18} \geq s_{13}) = 1, V(s_{18} \geq s_{14}) = 0.97,$$
$$V(s_{18} \geq s_{15}) = 0.94, V(s_{18} \geq s_{16}) = 1, V(s_{18} \geq s_{17}) = 0.97,$$
$$V(s_{18} \geq s_{19}) = 1, V(s_{19} \geq s_{11}) = 0.95, V(s_{19} \geq s_{12}) = 1,$$
$$V(s_{19} \geq s_{13}) = 1, V(s_{19} \geq s_{14}) = 0.98, V(s_{19} \geq s_{15}) = 0.96,$$
$$V(s_{19} \geq s_{16}) = 1, V(s_{19} \geq s_{17}) = 0.98, V(s_{19} \geq s_{18}) = 1.$$

With the help of eq. (10), the minimum degree of possibility can be stated as below:

$$\begin{aligned}
d'(c_{11}) &= \min(1,1,1,1,1,1,1,1) = 1\\
d'(c_{12}) &= \min(0.9,1,0.95,0.93,1,0.96,0.99,0.99) = 0.9\\
d'(c_{13}) &= \min(0.91,1,0.95,0.93,1,0.96,0.98,0.98) = 0.91\\
d'(c_{14}) &= \min(0.97,1,1,0.98,1,1,1,1) = 0.97\\
d'(c_{15}) &= \min(0.99,1,1,1,1,1,1,1) = 0.99\\
d'(c_{16}) &= \min(0.83,0.94,0.95,0.89,0.85,0.89,0.92,0.92) = 0.83\\
d'(c_{17}) &= \min(0.97,1,1,1,0.98,1,1,1) = 0.97\\
d'(c_{18}) &= \min(0.92,1,1,0.97,0.94,1,0.97,1) = 0.92\\
d'(c_{19}) &= \min(0.95,1,1,0.98,0.96,1,0.98,1) = 0.95.
\end{aligned}$$

	Type of soil	Permeability	Abrasive	Granulometry	Strength
Type of soil	(1, 1, 1)	(0.7,1.7,9)	(0.7,1.8,9)	(0.6,1.3,2.3)	(0.7,1.1,1.8)
Permeability	(0.1,0.8,1,4)	(1,1,1)	(0.3,1.2,3)	(0.2,1,3)	(0.2,0.8,1.4)
Abrasive	(0.1,0.8,1.4)	(0.3,1.1,3)	(1,1,1)	(0.14,1,3)	(0.14,0.8,1.4)
Granulometry	(0.4,0.9,1.8)	(0.3,1.4,7)	(0.3,1.5,7)	(1,1,1)	(0.3,0.9,1.8)
Strength	(0.6,0.97,1.4)	(0.7,1.5,7)	(0.6,1.6,7)	(0.6,1.3,3)	(1,1,1)
Time depended behavior	(0.1,0.6,1)	(0.4,0.9,1.7)	(0.4,0.9,2)	(0.14,0.9,2)	(0,14,0.7,1)
Plasticity	(0.6,0.9,1.8)	(0.6,1.4,7)	(0.6,1.5,7)	(0.6,1.1,3)	(0.6,0.9,1.4)
Water table	(0.3,0.8,1.4)	(0.6,1.2,3)	(0.4,1.3,3)	(0.3,1.1,3)	(0.3,0.9,1.4)
Effective stress	(0.3,0.8,1.4)	(0.4,1.3,7)	(0.4,1.4,7)	(0.3,1,2.3)	(0.3,0.8,1.4)

	Time depended behavior	Plasticity	Water table	Effective stress
Type of soil	(1,2.1,9)	(0.6,1.3,1.8)	(0.71,1.4,3)	0.7,1.5,3)
Abrasive	(0.4,1.3,2)	(0.14,0.9,1.8)	(0.3,1,2.3)	(0.14,1.14,2)
Granulometry	(0.4,1.8,7)	(0.3,1.1,1.8)	(0.3,1.2,3)	(0.4,1.3,3)
Strength	(1,1.9,7)	(0.7,1.2,1.8)	(0.7,1.3,3)	(1,1.4,3)
Time depended behavior	(1,1,1)	(0.14,0.8,1.4)	(0.3,0.8,1)	(0.14,0.9,1.7)
Plasticity	(0.7,1.7,7)	(1,1,1)	(0.6,1.2,3)	(0.7,1.3,3)
Water table	(1,1.4,3)	(0.3,1,1.8)	(1,1,1)	(1.1,1.3,3)
Effective stress	(0.6,1.5,7)	(0.3,0.9,1.4)	(0.4,1,2.3)	(1,1,1)

Table 3: Fuzzy comprehensive pair-wise comparison matrix for sub criteria of site.

Priority weights form vector $W' = (1, 0.9,\ 0.91,\ 0.97,\ 0.99,\ 0.83,\ 0.97,\ 0.92,\ 0.95)$. After the normalization of these values priority weights respect to main goal are calculated as $W = (0.12,\ 0.11,\ 0.11,\ 0.12,\ 0.12,\ 0.01,\ 0.11,\ 0.11,\ 0.11)$. The importance of sub criteria must be computed, after computation of each criterion. Likewise the pervious stages in order to the importance of pair wise matrix for each criterion are computed, which their final weights are shown Fig. 3 to Fig. 6.

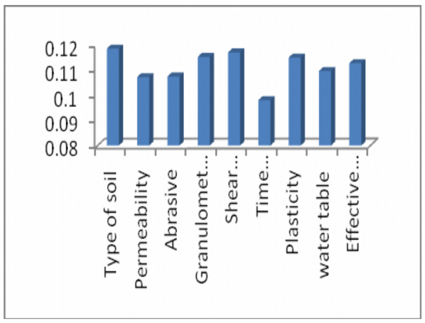

Figure 3: Global priority weights of site sub criteria.

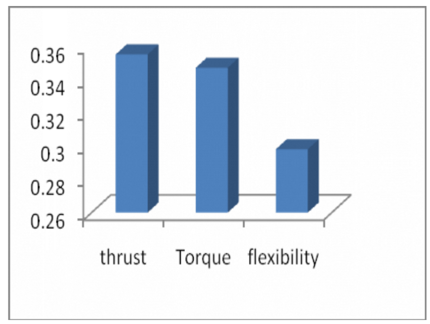

Figure 4: Global priority weights of machinery's sub criteria.

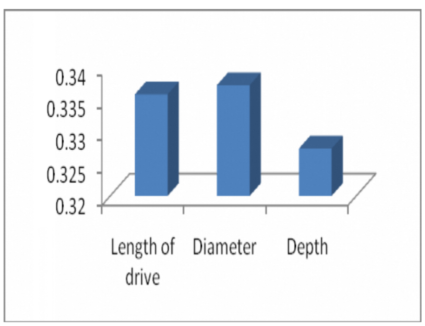

Figure 5: Global priority weights of structural's sub criteria.

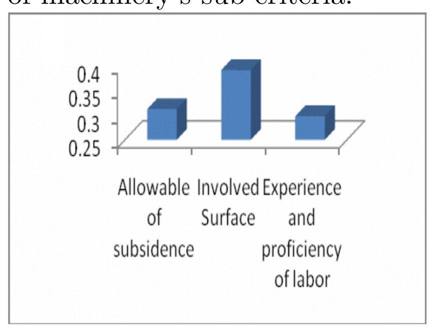

Figure 6: Global priority weights of environmental and labor force impact sub criteria.

According to Fig. 3 to Fig. 6, type of soil, thrust, diameter and involved surface with get highest local weight 0.12, 0.36, 0.34, 0.4 respectively among their sub criteria are known as effective agent among them.

6 Conclusion

Suitable MTBM selection is a key factor to success in trenchless projects from the safety, time saving and associated costs point of views. On the other hand, the decision making process for selecting the appropriate MTBM poses a complex task which needs to consider many technical, economical, social and environmental factors. In this paper, the FAHP method has been presented to reduce the difficulties in taking into consideration the many decision criteria and to handle the inherent uncertainty and imprecision of the human decision making process. Based on the developed FAHP approach, soil type, strength, flexibility, diameter and interference with traffic can be considered as the critical factors.

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