The optimal method for making subway tunnel from point of view of construction and economic performance using Analytic hierarchy process (AHP) (Case Study: Ahvaz subway)

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Abstract: Choosing appropriate method of tunneling is an important subject in subway construction. Now, digging machines TBM is generally used in construction underground in Iran, which it requires spending lots of time and cost. Supplying these types of devices which for ordering to be built them, requires to survey the genus of each city individually, faces to financial and logistical constraints in Iran and asks that if using other methods can provide solutions to financial problems and also falling behind the progress plan set or not. Digging method TBM was used in subway line 1 at mega city of Ahvaz, after 6 years from start of construction, expected plan progress is %92, but the actual progress is %27, the significant part of delay is because of this kind of digging difficulties. In this disquisition, with taking advantage of analytic hierarchical process (AHP) various digging tunnels techniques are scrutinized and criterions and priorities of each digging method are analyzed by "Expert Choice" software and the final result obtained by this method will be the most appropriate one.[1,2]
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Key words: Digging tunnel, Subway, Analytic hierarchical process, AHP, Optimal method

1. Introduction

Implementation of great infrastructure projects and development is the most important government means to achieve sustained development. The main characteristic that will different this kind of projects from other ones are enormous financial needs, top level of scientific and technologic, need for extensive technical knowledge, high workload and time consuming that they cause huge impact on economic statuses, technological and even political and social of countries. So, because of these characteristics, choosing the appropriate method for preparing and implementing these kinds of projects is very important and any mistaken in this context costs a lot and also makes damages often leads to irreparable. Correct usage of these machines is possible only by choosing right kind of machine, transferring technology, strong management and considering situations of projects. Todays, subways and urban tunnels are the most important infrastructures of transportation network in metropolitan.[3]

Constructing these kinds of infrastructures in developed countries and achieving favorable results by using the mentioned constructions in order to reduce problems of urban transportation, makes it inevitable to necessity of widespread use of these constructions in developing countries. By the way, implementation of such huge projects requires significant costs in my country. It may be always, involved with challenges. Some of the most important challenges correspond to implementation phase and also digging under the groundwater that sometimes lead to lots of financial losses and fatality in case of ignorance (to safety tips). For example, it will help to reduce the problems in constructing subway, by investigating different ways of digging under groundwater and then choosing the best ways in urban areas, especially in city of Ahvaz.[3]

2. Materials and methods

2-1- Scope of Project

In this chapter, it is attempt to determine a superior plan or plans among suggested ones by technical –economic comparison. This comparison is done through analytic hierarchical process (AHP). Following, a brief introduction about this method will be provided and then tables for calculating comparison among choices will be represented.[3]

2-2- analytic hierarchical process

Analytic hierarchical process is one of the most comprehensive designed systems for decision making with multiple criterions. This technique provides possibility to formulate the subject as a hierarchal and also possibility to consider the various quantitative and qualitative criterions. This process uses various choices to decision and also has possibility of sensitivity analysis on criterions and sub criterions. This process facilitates judgments and calculations since it is based on paired comparison.

It expresses compatibility and incompatibility of the decision and it can be said it is outstanding advantage of this technique in multiple criterions decision making. This method has a strong theoretical basis and is based on axioms.[3]

2-3-creation of hierarchical:

First step in analytic hierarchical process is creating a graphical representation about the subject that in which goal, criterions and options are shown.

According to questionnaire results, five major criterions were selected among performance criterions to compare and evaluate for selecting method of digging that include:

1- Construction costs (costs of implementation and preparation of materials),

2- Repairs and maintenance,

3- Safety,

4- Availability of the construction technology

5- And Speed of digging tunnel.

Also, five main options are considered for digging method:

1- Using TBM or tunnel boring machines.

2- Road header way or brachial machines or topical drilling machines

3- Numerical Method

4- Cut and Cover

5- Blasting [3, 4, 5]

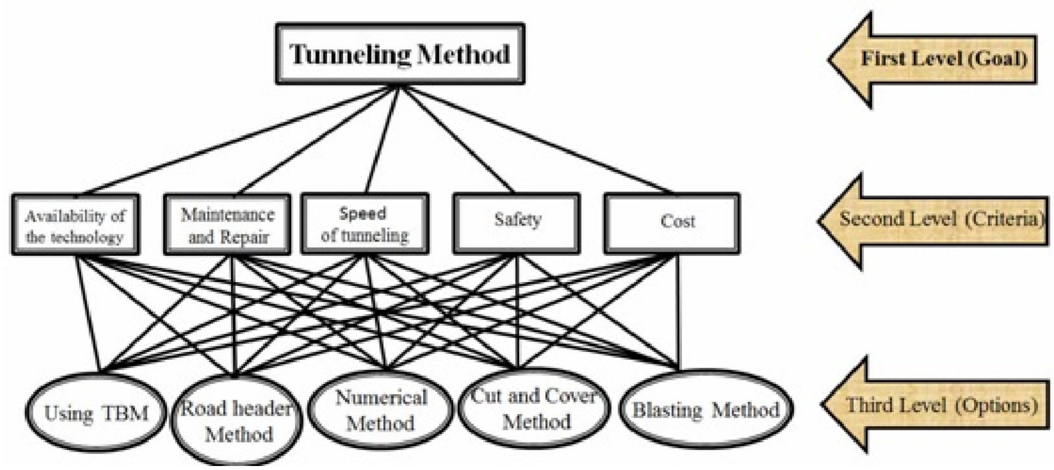

Figure 1. tree hierarchical

2-4- weight calculation:

In ingredients analytic hierarchical process, each level is compared toward its element in higher level as pairs, then its weight is calculated.

In these comparisons, decision makers will use verbal judgments, so that if element i is compared with element j, decision maker will say that importance of i over j is one of the status in table 1. [6]

The weight of each criterion in this analysis was achieved by using a questionnaire, through 20 Chief Executives who are supervisor of subway stations at Ahvaz, they mostly have more than 15 years of executive experience in digging and constructing tunnels.

Table1- Quantification of decision making

Preferences (verbal judgment)	numerical value
fully favorable	9
Very strong favorable	7
strong favorable	5
a little more favorable	3
Same favorable	1
preferences between above intervals	2,4,6,8

Table2- paired comparison of choices based on costs

Method	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting
Using TBM	1	0.5	0.2	0.167	0.25
Road header	2	1	0.334	0.25	0.5
Numerical Method	5	3	1	0.5	1.5
Cut and Cover	6	4	2	1	2
Blasting	4	2	0.667	0.5	1

Table 3- paired comparison of choices based on repairs and maintenance

Method	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting
Using TBM	1	0.5	0.25	0.2	0.167
Road header	2	1	0.5	0.334	0.25
Numerical Method	4	2	1	0.75	0.5
Cut and Cover	5	3	1.334	1	0.75
Blasting	6	4	2	1.334	1

Table 4- paired comparison of choices based on safety

Method	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting
Using TBM	1	3	4	2	6
Road header	0.334	1	1.5	0.75	3
Numerical Method	0.25	0.667	1	0.5	2
Cut and Cover	0.5	1.334	2	1	4
Blasting	0.167	0.334	0.5	0.25	1

Table 5- paired comparison of choices based on digging speed

Method	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting
Using TBM	1	2	6	4	5
Road header	0.5	1	4	2	3
Numerical Method	0.167	0.25	1	0.5	0.75
Cut and Cover	0.25	0.5	2	1	0.25
Blasting	0.2	0.334	1.334	4	1

Table 6- paired comparison of choices based on availability of technology

Method	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting
Using TBM	1	0.5	0.25	0.167	0.334
Road header	2	1	0.5	0.25	0.75
Numerical Method	4	2	1	0.5	1.5
Cut and Cover	6	4	2	1	3
Blasting	3	1.334	0.667	0.334	1

In tables 2 to 6, the results of comparison of choices are represented based on every criterion and in term of paired that are obtained through questionnaire by inputting data to the software, are shown.

2-5-calculating the weight of each matrix through arithmetic mean method

First step: summation of values in each column

Second step: each element in the matrix of paired comparison must be divided by sum of its column in order to normalized the matrix of paired comparison [6]

Third step: organizing matrix preference

In tables 7 to 11 normalized comparisons matrix that are as follows:

Table7- weighted percent of choices comparison based on costs

Normalized	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting	The relative importance of alternative
Using TBM	0.055	0.048	0.048	0.069	0.048	0.0536
Road header	0.111	0.095	0.079	0.103	0.095	0.0966
Numerical Method	0.277	0.286	0.238	0.207	0.286	0.2588
Cut and Cover	0.334	0.381	0.476	0.414	0.381	0.3972
Blasting	0.223	0.19	0.159	0.207	0.19	0.1938
sum of columns	1	1	1	1	1	1

Table8- weighted percent of choices comparison based on repairs and maintenance

Normalized	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting	Relative importance of alternative
Using TBM	0.056	0.048	0.049	0.055	0.063	0.0542
Road header	0.111	0.095	0.098	0.093	0.094	0.0982
Numerical Method	0.222	0.19	0.197	0.207	0.187	0.2006
Cut and Cover	0.278	0.286	0.262	0.276	0.281	0.2766
Blasting	0.333	0.381	0.394	0.369	0.375	0.3704
sum of columns	1	1	1	1	1	1

Table9- weighted percent of choices comparison based on safety

Normalized	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting	Relative importance of alternative
Using TBM	0.444	0.474	0.444	0.444	0.375	0.4362
Road header	0.148	0.157	0.166	0.166	0.187	0.1648
Numerical Method	0.112	0.105	0.112	0.112	0.125	0.1132
Cut and Cover	0.222	0.211	0.222	0.222	0.25	0.2254
Blasting	0.074	0.053	0.056	0.056	0.063	0.0604
sum of columns	1	1	1	1	1	1

Table10- weighted percent of choices comparison based on digging speed

Normalized	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting	Relative importance of alternative
Using TBM	0.473	0.49	0.418	0.348	0.5	0.4458
Road header	0.236	0.245	0.279	0.174	0.3	0.2468
Numerical Method	0.079	0.061	0.07	0.043	0.075	0.0656
Cut and Cover	0.118	0.122	0.14	0.087	0.025	0.0984
Blasting	0.094	0.082	0.093	0.348	0.1	0.1434
sum of columns	1	1	1	1	1	1

Table11- weighted percent of choices comparison based on availability of technology

Normalized	Using TBM	Road header	Numerical Method	Cut and Cover	Blasting	Relative importance of alternative
Using TBM	0.063	0.057	0.057	0.075	0.051	0.0606
Road header	0.125	0.113	0.113	0.111	0.114	0.1152
Numerical Method	0.25	0.226	0.226	0.222	0.227	0.2302
Cut and Cover	0.375	0.453	0.453	0.444	0.456	0.4362
Blasting	0.187	0.151	0.151	0.148	0.152	0.1578
sum of columns	1	1	1	1	1	1

2-6- summary of steps 1 and 2

In first step (in matrix of weight), all of the choices are compared with each criterion in pairs, and relative weight value is given to each of them. In second step, the matrix is normalized and is computed by using the weight arithmetic mean of each choice corresponding to specified criterions. Questionnaire and also opinion of experts is used for other choices. All of the choices are compared with each criterion in pairs and table 12 represents summary of steps one and two for digging method.[3,6]

Table12- summary of normalized weights

Method \ Criteria	Speed of tunneling	Cost	Safety	availability of the technology	Maintenance and Repair
Using TBM	0.446	0.054	0.436	0.061	0.054
Road header	0.247	0.097	0.165	0.115	0.098
Numerical Method	0.066	0.259	0.113	0.23	0.201
Cut and Cover	0.098	0.397	0.225	0.436	0.277
Blasting	0.143	0.194	0.06	0.158	0.37
sum of columns	1	1	1	1	1

2-7- paired comparison of criterions

In third step, criterions are compared in pairs in the same method. In this step, comparison is made more widely and checks different viewpoints in order to provide appropriate strategies. In other words, it is considered in each scenario that superiority of one criterion is tangible than other criterions in order to decision making will be done due to the requirements and factors (tables 13 and 14) Also, in diagram 1, relative importance of criterions is shown in percentage. [3,6]

Table13- paired comparison of criterions-determining preference of criterions

Criteria	Speed of tunneling	Cost	Safety	availability of the technology	Maintenance and Repair
Speed of tunneling	1	8	7	9	5
Cost	0.125	1	2	1	3
Safety	0.143	0.5	1	3	2
The availability of the technology	0.112	1	0.334	1	4
Maintenance and Repair	0.2	0.334	0.5	0.25	1

Table14- normalizing weights of criterions preference

Normalized	Speed of tunneling	Cost	Safety	availability of the technology	Maintenance and Repair	Relative importance of the criteria
Speed of tunneling	0.633	0.739	0.646	0.631	0.333	0.5964
Cost	0.079	0.092	0.185	0.07	0.2	0.1252
Safety	0.091	0.046	0.092	0.211	0.134	0.1148
availability of the technology	0.071	0.092	0.031	0.07	0.267	0.1062
Maintenance and Repair	0.126	0.031	0.046	0.018	0.066	0.0574
sum of columns	1	1	1	1	1	1

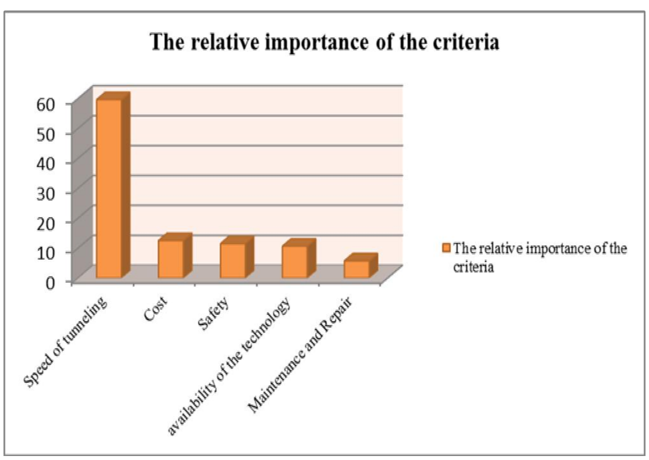

Diagram1- relative importance of criterions in digging method (in percentage)

For facilitating in decision making and also for achieving true weights of criterions, sensitivity analysis was done, that in each scenario, superior choice was determined. It can be seen in table 15, summary of suggested scenarios with superiority of choices. In table 15, suggested choices are compared with each other in pairs, by several basic factors. In this comparison, superior choice was determined for each scenario. In first scenario, with respect to two superior criterions, which are digging speed and safety, it is said that these two criterions are evaluated with higher percentage than other criterions, and finally, first choice was selected as a premier plan. Scenario4, (The main priority are cost and availability of technology) is second suggested plan because of low cost in construction and also easily accessible of technology. Also in diagram2 comparisons of digging choices based on criterions are shown in percentage. [1,2,3]

Table15-various scenarios about selecting superior choice and percentage of each criterion

No.	Method\Criteria	Speed of tunneling	Cost	Safety	availability of the technology	Maintenance and Repair
1	Using TBM	44.6	5.4	43.6	6.1	5.4
2	Road header	24.7	9.7	16.5	11.5	9.8
3	Numerical Method	6.6	25.9	11.3	23	20.1
4	Cut and Cover	9.8	39.7	22.5	43.6	27.7
5	Blasting	14.3	19.4	6	15.8	37
The sum of columns (percent)		100	100	100	100	100

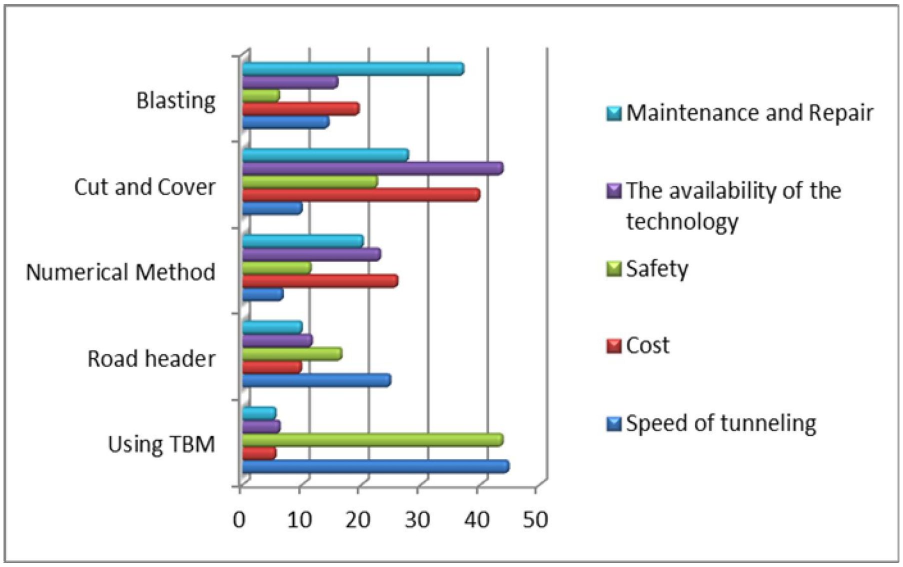

Diagram2- comparison of digging choices based on criterions in percentage

2-8- evaluation`s results of digging tunnel methods with use of analytical hierarchy process in Expert Choice method.

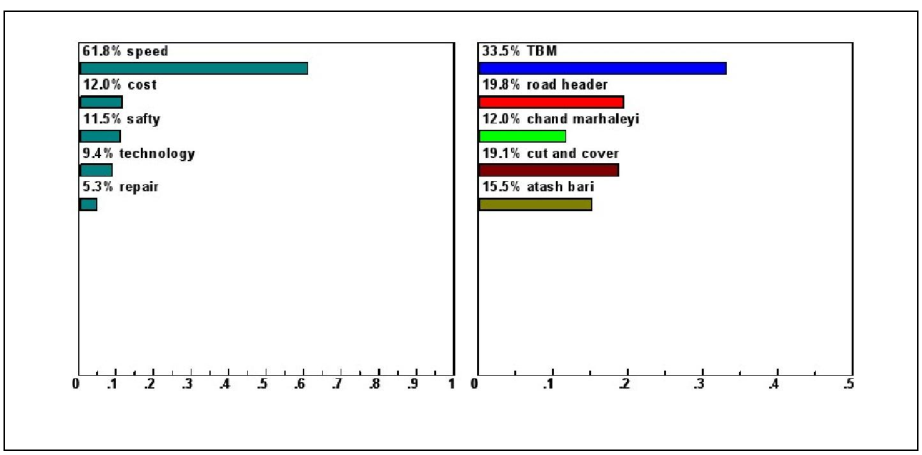

Figure 2- dynamic sensitivity for each option

Figure 2 shows the final weights for options and criterion in percentage separately in bar graph. Among criterions, digging speed is the most important with 61.8% and also among the options TBM method achieved heaviest weight that is 33.5%.

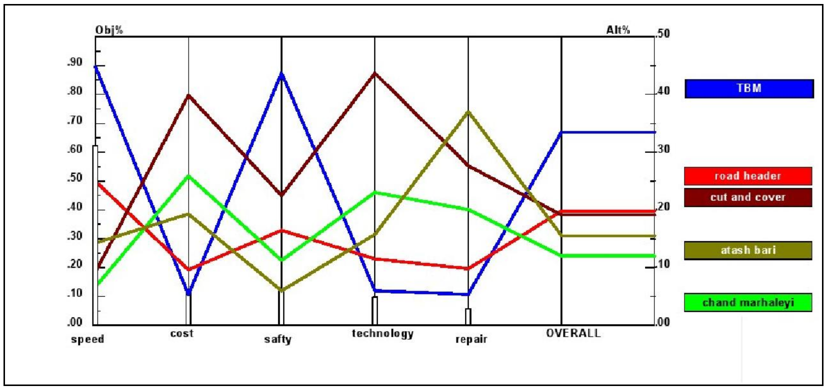

Figure3- sensitivity of performance for each option

In figure 3 final percentage of choices weights was determined that superior choice is use of tunnel boring machines with the maximum weight.

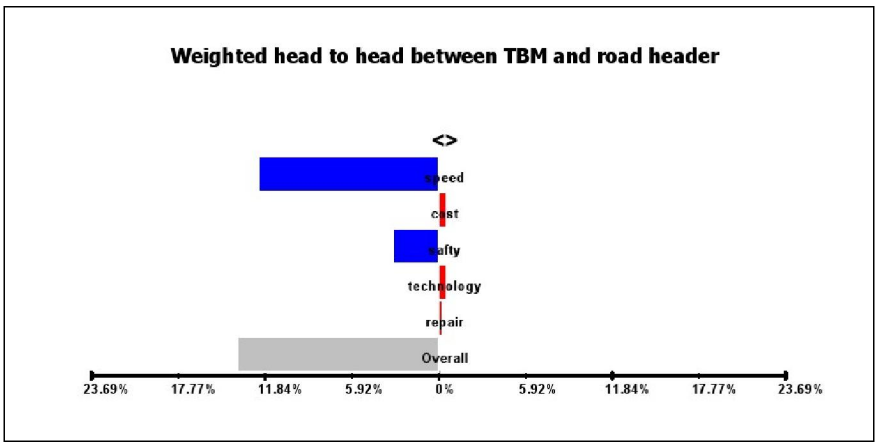

Figure4- comparison in pairs between choices: Road Header and TBM

In figure 4 the two choices Road Header and TBM were compared in pairs based on all criterions.

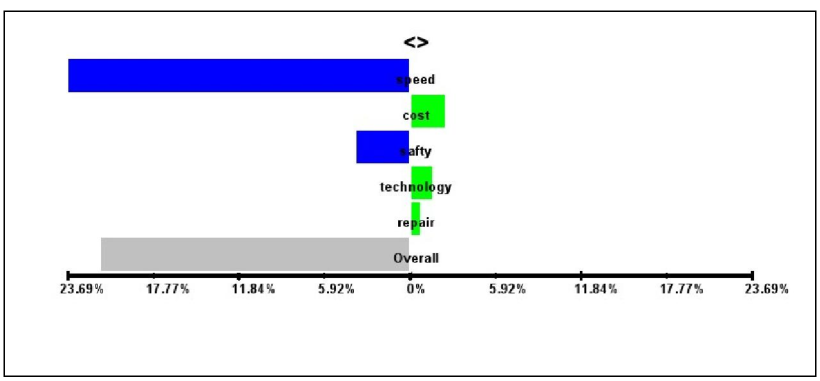

Figure5- comparison in pairs between choices: multiple step method and TBM

In figure 5 the two choices multiple step method and TBM were compared in pairs based on all criterions.

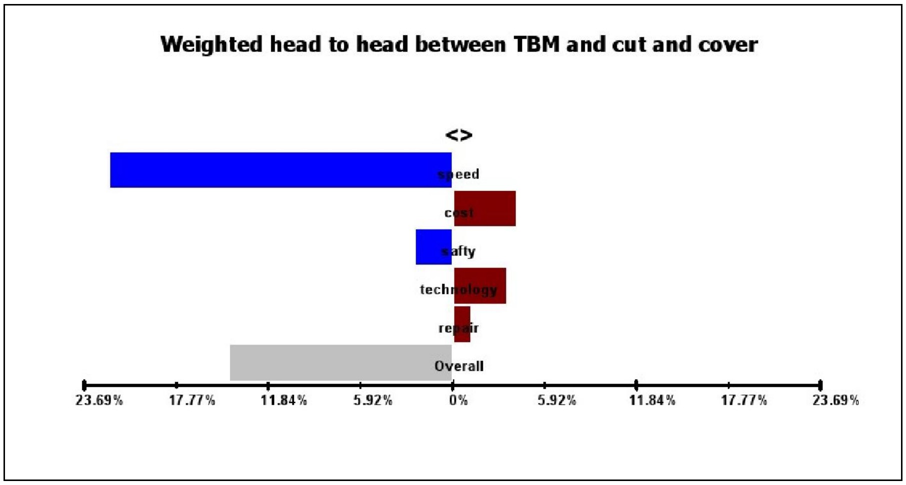

Figure6- comparison in pairs between choices: Cut and Cover and TBM

In figure 6 the two choices: Cut and Cover and TBM were compared in pairs based on all criterions.

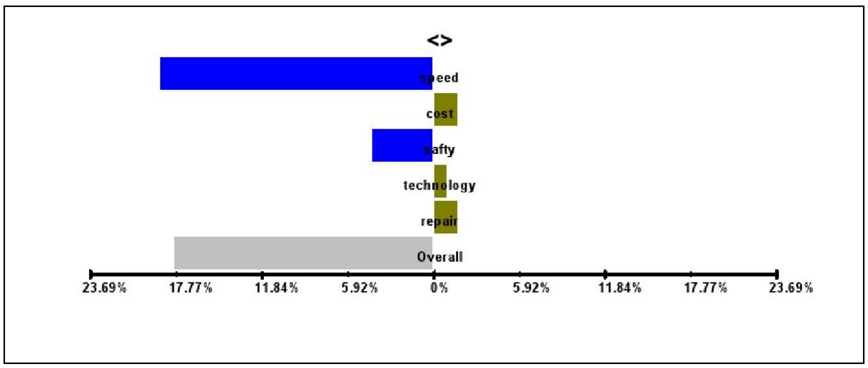

Figure7- comparison in pairs between choices: Blasting and TBM

In figure 7 the two choices: Blasting and TBM were compared in pairs based on all criterions.

In final step, matrix of criterions weights is multiplied by matrix of choices weights to compute percentage of each choice to the total ones according to provided criterions. (Table 16 and figure8)

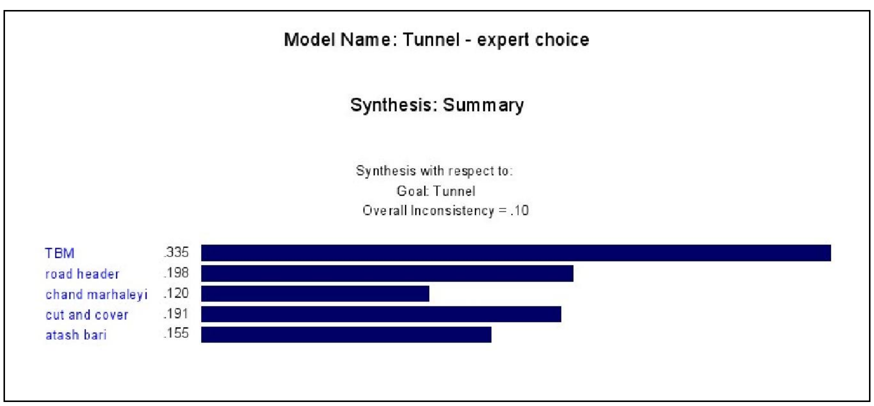

Figure 8- final results and choices weights in order to select the digging method

In figure 8 final results and choices weights in order to select the digging method are shown in bar graph.

Table16- priorities to selecting digging method based on analytical hierarchy process

Method	Weighted rate	Priority
Using TBM	0.335	1
Road header	0.198	2
Cut and Cover	0.191	3
Blasting	0.155	4
Numerical Method	0.120	5

Conclusion:

Successful widespread performing of digging tunnels by TBM in the world in subway construction projects, generally in urban areas, can provide potential use of this digging method with the same favorable result. According to great sections of digging in subway tunnels and also due to loose ground conditions (like the city of Ahvaz), digging section is inevitable. So, use of any mentioned digging method in this research, must be according to side effects, effects of digging on the ground surface, municipal facilities, and specially amount of subsidence in ground surface in short term and long term. It will be more important when subway lines pass under the city facilities and buildings. There are several methods for digging tunnels. Considering high cost of digging, on one hand, and time consuming on the other hand, causes it important to choose the appropriate digging method that has a great impact on project progress and financial development. For this purpose, in this study, different methods of digging tunnels were examined and results were analyzed by software Expert Choice, then the results are as follow:

The best suggested choice that usable as digging method is TBM, and its weighted rate is 0.332.

Weighted rate of criterions in TBM are as follow:

Cost of using this method with weighted rate of 0.054

Digging speed with weighted rate of 0.446

Safety with weighted rate of 0.436

Repairs and maintenance with weighted rate of 0.054

Availability of technology with weighted rate of 0.061

And second suggested choice that usable as digging method is cut and cover, weighted rate of this parameter is 0.196, effective sub parameters of using cut and cover method are:

Cost of using this method with weighted rate of 0.098

Digging speed with weighted rate of 0.397

Safety with weighted rate of 0.225

Repairs and maintenance with weighted rate of 0.436

Availability of technology with weighted rate of 0.227

Note that it is not possible to use one procedure as a best way for all of the projects with different specifications, so according to specification of each project the best procedure must be selected.

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