Selecting utilities placement techniques in urban underground engineering

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Abstract

Placement of utilities has not been generally accomplished in any sustainable technique resulting in a veritable maze in high density urban areas. As underground space scarcity grows in our cities due to the increasing demands for utility services, subsurface facilities such as utility tunnels are becoming more efficient in providing the required infrastructure. There is a growing public awareness of aesthetic considerations and impatience with street cuts and their associated costs, traffic interferences, noise and accidental utility cuts. Unfortunately the lack of data and the difficulty in quantifying the intangibles has made it impossible to arrive at a reasonably accurate figure of overall negative impact on the urban environment of street cuts. Due to this, current practices of traditional trenching depending only on cost indicators remain as first option in urban planning instead of more sustainable techniques, like utility tunnels. However, it is well known that intangible costs to the public and the utilities might make the utility tunnel concept to be economically feasible in the long run. This paper presents a methodology based on AHP and Delphi processes for the selection of utilities placement techniques in which the intangibles are also assessed to avoid short-sighted urban underground planning.

Highlights

Quantifying intangibles is a key factor to study negative impact of street cuts.
Only use of cost indicators make traditional trenching to remain as first option.
Intangible costs might make utility tunnel concept to be feasible in the long term.
A methodology based on AHP and Delphi avoids short-sighted underground planning.

Keywords

Urban utilities; underground space; municipal engineering; AHP Delphi

1. Introduction

The most rapid increase in the use of urban underground space began since the 19th century, due to the impetus of city development. Underground medium provides the setting for utilities that are unsecure or environmentally undesirable to install above ground. But without any doubt, there is an increasing interest on the need for sustainable planning in our cities [1-4]. Moreover, it is part of European Union policy to achieve a high level of health and environmental protection, and one of the objectives to be pursued is sustainable development [5]. In central areas of large towns, with large concentrations of population in a limited area, it has become necessary to utilize the subsurface for locating a growing number of services. This has resulted in a veritable maze of pipes and cables under the streets pavements nicknamed as spaghetti by civil engineers [6-8]. The incessant cutting of pavements to install or repair underground facilities causes traffic delays, poses safety hazards, pollutes the environment, creates aesthetic detriments, reduces the useful life of pavements and limits access to abutting properties. Moreover, when repairing one strand of spaghetti, workers sometimes damage another. To overcome these disadvantages, utility tunnels provide the means to use inventiveness and good engineering practices in developing sustainable and coordinated installations of utility systems essential to tomorrow's urban needs. Tunnelling is increasingly being used world-wide to provide the infrastructure required for sustainable cities [9-13]. Utility tunnels can house the full range of power, communications, water, gas and other distribution systems. They may well constitute the answer to the perennial problem plaguing many municipalities. There is complete agreement that the initial cost of a utility tunnel would be more than that for a traditional trenching installation. However, it should be noted that intangible costs to the public and the utility companies might make the utility tunnel concept more sustainable and economical in the long term. Unfortunately the lack of data and the difficulty in quantifying the intangibles has made it impossible to arrive at a reasonably accurate figure of overall negative impact on the urban environment of street cuts [14-15]. Sustainable development of underground space not just calls for using underground space, but using it to combine functions and to create value in doing so for society [16-23]. Establishing future sustainable strategies in urban underground engineering consists of the ability to lessen the use of traditional trenching [24,25]. This paper presents a methodology for the selection of utilities placement techniques in which the intangibles are also assessed to avoid short-sighted planning.

The Analytic Hierarchy Process is a theory of relative measurement on absolute scales capable of dealing with intangible criteria and based on paired comparison judgement of knowledgeable experts [26-30]. How to measure intangibles is the main concern of the mathematics of the AHP as this paper will show. Although AHP is subject to criticism, it is regarded as the most appropriate method for this study. This method is very suitable for complex social issues in which intangible factors cannot be neglected. The Delphi technique is well suited as a means and method for consensus-building by using a series of questionnaires to collect data from a panel of selected subjects [31-33]. The Delphi technique is performed to facilitate an efficient panel of experts' dynamic process. This is done in the form of an anonymous, written, multi-stage survey process, where feedback of the group opinion is provided. This paper proposes an AHP-Delphi model to support civil engineers' decisions in urban underground planning.

2. First questionnaire and decision hierarchy structure

It is significant to note that utility tunnel feasibility studies conducted recently found economic justification based solely on tangible factors [34,35]. However the lack of data and the difficulty in quantifying the intangibles must be taken into account in urban planning. The intangibles, like noise and aesthetic considerations, traffic delays and disturbances due to street cuts, long term deterioration of streets are not quantified [36]. Today, we have a new dimension: quantity has made way for quality. People are willing to pay the price for a pleasing landscape. The theme seems to be "don't put it here" or "put it where I can't see it" and this demands a joint cooperative effort. To overcome the lack of tangible data and the use of intangible criteria, AHP-Delphi model will be applied to advance in utilities planning. Integrating the AHP with a Delphi process provides a civil engineer with a systematic approach to evaluate multi-criteria and multi-alternative problems which requires judgements involving intangible characteristics. The Delphi first phase will be exploration of the alternatives and criteria under discussion between experts, using an anonymous questionnaire where each expert contributes with additional alternatives or criteria he feels is pertinent to the goal. The next process is to feedback the collated information and ask them to reconsider their proposals. With this anonymous feedback, experts with different perspectives contribute to each other's understanding of the topics involved and move toward a consensus. Criteria and alternatives that are accorded low importance are removed. An adequate selection of criteria is a key factor for this procedure as will be discussed later on. To understand the process, a brief description of the alternatives and criteria selected follows.

In our case, five possible alternatives for utilities placement in urban subsurface have been addressed. These alternatives are:

1. Traditional trenching, where several utilities are grouped in a multi-layer single trench.
2. Common conduit, where one or more utilities are placed in multiple ducts in a single trench.
3. Flat UT, essentially a non-walk-through utility tunnel with a removable concrete lid, which could be used as street pavement or disposed in a shallow position (< 1m).
4. Shallow UT, which is a walk-through underground structure (< 5m) containing one or more utility systems, permitting the installation, maintenance, and removal of the system without making street cuts or excavations.
5. Deep UT, similar to the previous but positioned deeper (> 5m).

To achieve the objective of selecting one of these utilities placement techniques several criteria have been proposed: urban environment, economic-financial, governance, maintenance requirements, security, liability and archaeological requirements. Environmental conditions in urban areas are a source of critical concern worldwide. The qualities and attractiveness of the cities are not only determined by the fulfilment of the material economic needs of their citizens, but also by the social and environmental conditions which prevail [37,38]. After installation under streets, utility systems are far from unobtrusive. Their presence is well indicated by the seemingly ceaseless opening of the streets to make repairs and provide new and larger systems and services. These openings, often called street cuts, cause serious delays to traffic, create noise and aesthetic disturbances, and result in excessive street maintenance requirements and in shortened overall street life [39,40]. Utility network owners install, operate, perform maintenance, and repair their network independently by working in the relatively congested underground areas beneath our narrow streets and pavements, which means in turn that different utility networks are inevitably too close to each other than is desirable from an engineering viewpoint. This increases the possibility that other utility networks might be damaged when installation, repair or refurbishment work is carried out by any one utility company [41]. Accurate location of buried utilities is a vital issue specially when using trenching techniques [42]. Financial requirements may be defined as the feasibility of obtaining the necessary capital for construction of utility tunnel systems and establishing revenues for the recovery of capital and operating costs. It is not possible to make a general statement as to the engineering-financial feasibility of utility tunnels because each situation will be different in terms of location, urban population and traffic density, utility systems to be installed, type and number of customers, costs of construction and many other factors [43]. In addition, a critical requirement in the development of urban utility tunnel systems is the cooperation and coordination of all government and utility agencies so that a workable plan can be developed [44,45]. Problems relating to the liability and security of a variety of utility systems in close proximity inside a tunnel need to be evaluated for each case by the expert panel [46-51]. Moreover, protecting heritage must in no case be neglected [52,53] and this constraint must be taken into account in the schedule of the utility projects, notably in order to allow for archaeological excavations. In this respect, it should also be recognized that sustainable underground policies, which include utility tunnels, help protect archaeological sites. Taking into account all these requirements and following the initial step of AHP [54], the goal is decomposed into a hierarchy structure shown in Fig. 1. Obviously, the criteria and alternatives to be used by any community will be tailored to local needs.

3. Second questionnaire and construction of pairwise comparison matrix for the criteria

According to Delphi process, the second questionnaire which is sent to the panel of experts will be used to assess main criteria. The Delphi process achieves interaction among the panel of experts with anonymous feedback, while AHP is used to divide the overall decision making into smaller decision components. As an example, Table 1 shows a particular questionnaire for evaluating main criteria with respect to the overall goal using 9-point scale (see Table 2). This scale has been validated for effectiveness, not only in many applications by a number of people, but also through theoretical comparisons with a large number of other scales [55]. Each expert performed a pairwise comparison to indicate his preference for each criterion. As a result, a matrix evaluating results of the main criteria with respect to the overall goal is obtained (see Table 3). Pairwise comparison matrix for the criteria is constructed using the mean value obtained from Table 3.

4. Priority weighting of the criteria and consistency ratio

After developing the pairwise comparison matrix for the criteria (*A*), the relative priority of each individual criterion will be determined. The matrix is given by

$$A=\begin{bmatrix} 1 & 4.1333 & 7.8000 & 1.2210 & 4.6000 & 6.0000 & 5.4000 \\ 0.2419 & 1 & 7.8000 & 0.6552 & 2.0400 & 3.3333 & 3.8000 \\ 0.1282 & 0.1282 & 1 & 0.1517 & 0.1613 & 0.2590 & 0.6000 \\ 0.8190 & 1.5262 & 6.5900 & 1 & 4.0000 & 5.8000 & 7.8000 \\ 0.2174 & 0.4902 & 6.2008 & 0.2500 & 1 & 2.2000 & 3.8000 \\ 0.1667 & 0.3000 & 3.8603 & 0.1724 & 0.4545 & 1 & 1.3067 \\ 0.1852 & 0.2632 & 1.6667 & 0.1282 & 0.2632 & 0.7653 & 1 \end{bmatrix}$$

The principal eigenvector of A is the desired priority vector ω according to Saaty [56]. To find this priority vector, the linear system $A\omega = \lambda\omega$ must be solved

$$\det\left(A-\lambda I\right)=0$$

Hence, the priority vector of the criteria is as follows

$$\omega=\begin{bmatrix} 0.3467 \\ 0.1581 \\ 0.0253 \\ 0.2728 \\ 0.1024 \\ 0.0549 \\ 0.0397 \end{bmatrix}$$

One of AHP's advantages is to measure whether or not inconsistency occurs in the evaluation process. That is, experts are often not able to express consistent preferences in case of several criteria. To address this possibility, the Saaty's method measures the inconsistency of the pairwise comparison matrix and sets a consistency threshold which should not be exceeded in order to guarantee the procedure. The consistency ratio (*CR*) is used as the main indicator of ranking consistency. In practice, a *CR* of 0.1 or below is considered acceptable for order of matrix (n) equal or larger than five. Any higher score indicates that the judgements need re-examination. *CR* is calculated by dividing the consistency index (*CI*) by the random consistency index (*RCI*) obtained from Saaty (1980), as follows

$$CR=\frac{CI}{RCI}$$

In order to calculate the *CI*, largest eigenvalue ($\lambda_{máx}$) of the normalized pairwise comparison matrix should be determined. Hence, the next step is to normalize the pairwise comparison matrix. This is done by totalling the numbers in each column. Each entry in the column is then divided by the column sum to yield its normalized value. Therefore, the normalized matrix (A_N) is given by

$$A_N = \begin{bmatrix} 0.3625 & 0.5271 & 0.2234 & 0.3412 & 0.3674 & 0.3100 & 0.2278 \\ 0.0877 & 0.1275 & 0.2234 & 0.1831 & 0.1630 & 0.1722 & 0.1603 \\ 0.0465 & 0.0164 & 0.0286 & 0.0424 & 0.0129 & 0.0134 & 0.0253 \\ 0.2969 & 0.1946 & 0.1887 & 0.2794 & 0.3195 & 0.2996 & 0.3290 \\ 0.0788 & 0.0625 & 0.1776 & 0.0699 & 0.0799 & 0.1136 & 0.1603 \\ 0.0604 & 0.0383 & 0.1106 & 0.0482 & 0.0363 & 0.0517 & 0.0551 \\ 0.0671 & 0.0336 & 0.0477 & 0.0358 & 0.0210 & 0.0395 & 0.0422 \end{bmatrix}$$

Then, the consistency index (*CI*) is calculated as follows

$$CI = \frac{\lambda_{máx} - n}{n-1}$$

The process followed to determine the relative preference rating of the criteria is then completed as shown in Table 4.

5. Third questionnaire and evaluate alternatives according to criteria

The next step is to calculate the priority of alternatives with respect to each criterion. The third questionnaire which is sent to the panel of experts will be used to assess alternatives for each criterion. As an example, Table 5 shows a particular questionnaire for evaluating alternatives using Table 2 with respect to an individual criterion (C1-Urban environment) to better illustrate the use of the proposed model. Each expert has performed a pairwise comparison to indicate his preference for each alternative. Then, a pairwise comparison matrix for the alternatives is constructed using the mean value obtained from experts. As in previous steps, eigenvector method has been applied to obtain the priority vector, and consistency analysis performed for each case. All criteria assessments are shown in Table 6 to Table 12.

The last step is to obtain overall priorities. First, a matrix of priority vectors for alternatives is constructed as shown in Table 13. And finally, the overall priority result (see Table 14) is done by matrix multiplication between the matrix of priority vectors for alternatives and the priority vector of the criteria (ω).

6. Results and discussions

Results show that in our example deep and shallow utility tunnels, with an overall priority of 28.78% and 25.12% respectively, are preferred solutions for this case (see Table 14). The weights of each alternative for each criterion are illustrated in Fig. 2. However, because Fig. 2 is not considering the prioritization of the criteria, special attention must be given to the fact that this figure seems at first sight to refute misleadingly the use of utility tunnels. This result is not surprising; because criteria C1-Urban Environment and C4-Maintenance requirements have been rated by experts as the most significant factors (see Fig. 3). It is interesting to note, however, that to another community where the criterion C2-Economic-financial is preferred, the result would be different. This methodology is tailored to the needs of each community, and therefore the importance given to each criterion in a particular case by the panel of experts is decisive in the selection procedure as pointed previously.

As cities continue to grow, establishing future sustainable strategies in urban underground engineering will require suitable procedures for complex issues in which intangible factors cannot be neglected. This paper has proposed the use of AHP for making decisions in an organised way to generate priorities in urban underground, and the Delphi technique to facilitate an efficient group dynamic process for achieving consensus. The hierarchy of the decision has been constructed based on the panel of experts' suggestions derived by using Delphi procedure. That is, each expert has been asked to identify possible alternatives and criteria that could affect the selection of utilities placement techniques in urban underground through several questionnaires until a consensus has been reached. Once the hierarchy was established, experts' knowledge has been collected through questionnaires to construct a set of pairwise comparison matrices to prioritize criteria and alternatives using AHP technique. Finally, the results obtained will be used to support civil engineers' decisions in selecting utilities placement techniques. In conclusion, the AHP-Delphi model proposed in this paper has been shown as a reliable method in urban underground planning to overcome intangible factors and scarcity of knowledge.

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Figure 1

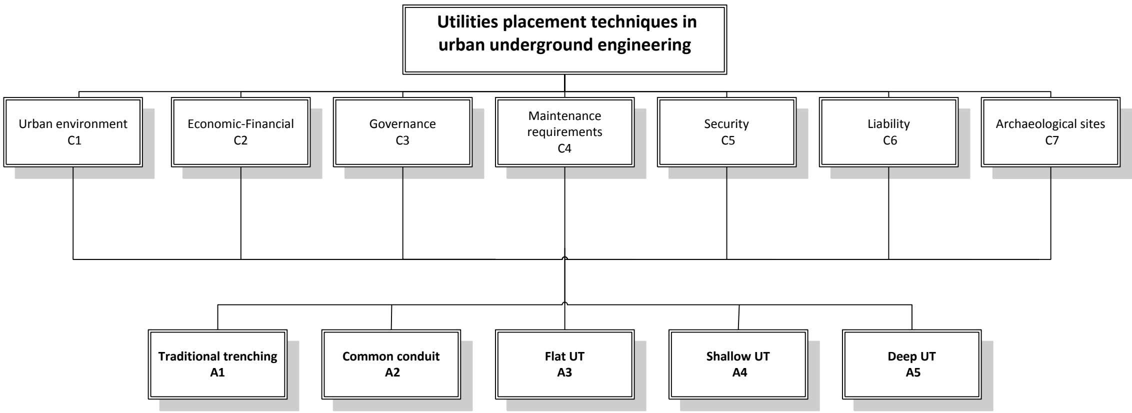

Fig. 1. Hierarchy to determine the technique for utilities placement in urban underground

Figure 2

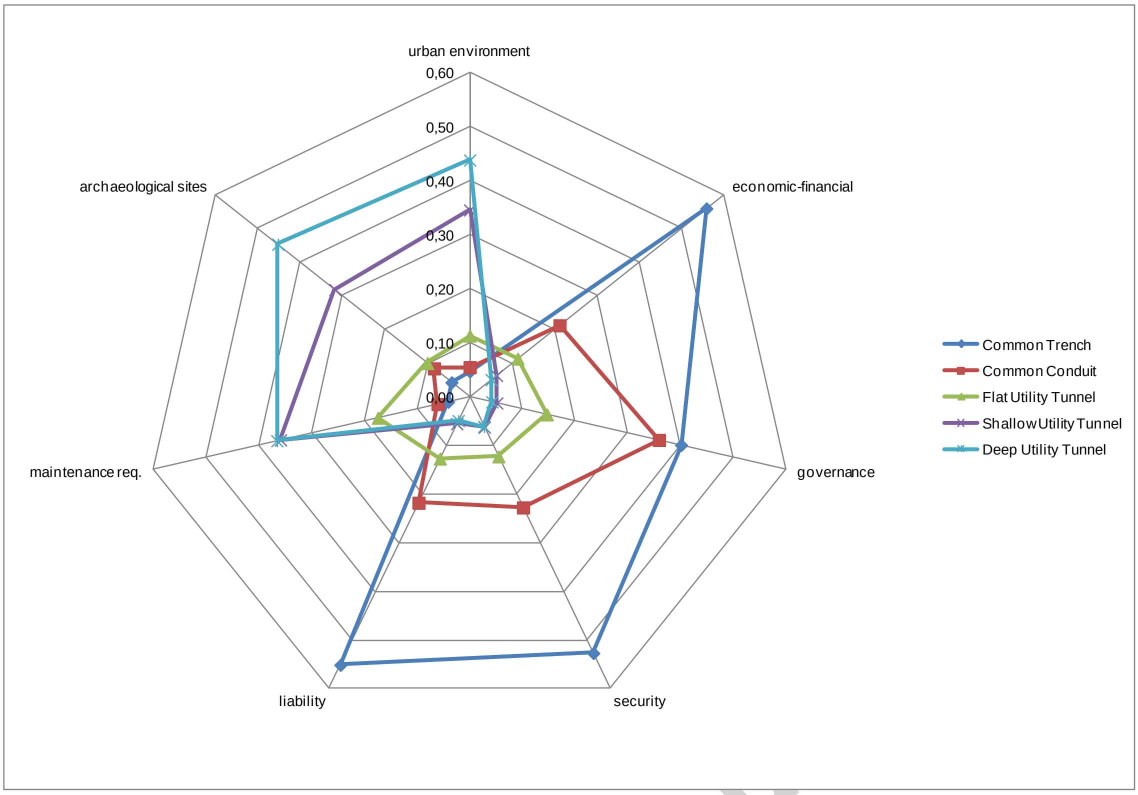

Fig. 2. The weights of each alternative for each criterion.

Figure 3

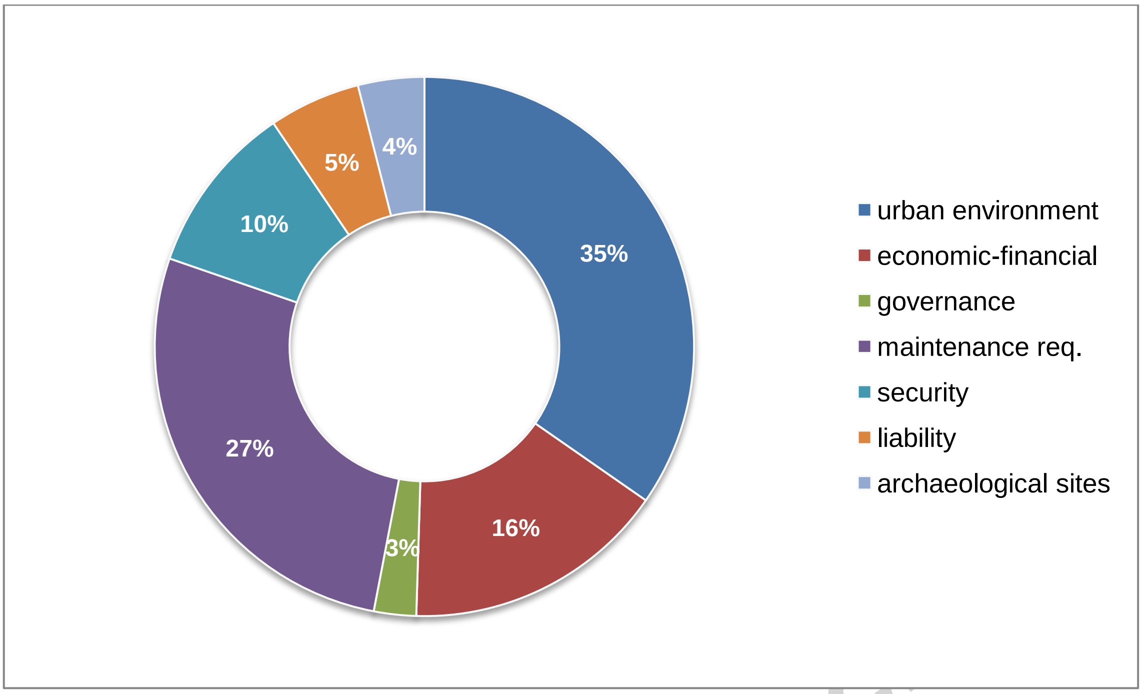

Fig. 3. The weights of each criterion for the overall goal.

Table 1

With respect to the overall goal, possible alternatives for utilities placement in urban subsurface	
Q1	How important is **urban environment** (C1) when it is compared to **economic-financial** (C2)
Q2	How important is **urban environment** (C1) when it is compared to **governance** (C3)
Q3	How important is **urban environment** (C1) when it is compared to **maintenance requirements** (C4)
Q4	How important is **urban environment** (C1) when it is compared to **security** (C5)
Q5	How important is **urban environment** (C1) when it is compared to **liability** (C6)
Q6	How important is **urban environment** (C1) when it is compared to **archaeological sites** (C7)
Q7	How important is **economic-financial** (C2) when it is compared to **governance** (C3)
Q8	How important is **economic-financial** (C2) when it is compared to **maintenance requirements** (C4)
Q9	How important is **economic-financial** (C2) when it is compared to **security** (C5)
Q10	How important is **economic-financial** (C2) when it is compared to **liability** (C6)
Q11	How important is **economic-financial** (C2) when it is compared to **archaeological sites** (C7)
Q12	How important is **governance** (C3) when it is compared to **maintenance requirements** (C4)
Q13	How important is **governance** (C3) when it is compared to **security** (C5)
Q14	How important is **governance** (C3) when it is compared to **liability** (C6)
Q15	How important is **governance** (C3) when it is compared to **archaeological sites** (C7)
Q16	How important is **maintenance requirements** (C4) when it is compared to **security** (C5)
Q17	How important is **maintenance requirements** (C4) when it is compared to **liability** (C6)
Q18	How important is **maintenance requirements** (C4) when it is compared to **archaeological sites** (C7)
Q19	How important is **security** (C5) when it is compared to **liability** (C6)
Q20	How important is **security** (C5) when it is compared to **archaeological sites** (C7)
Q21	How important is **liability** (C6) when it is compared to **archaeological sites** (C7)

Table 1. Questionnaire to assess main criteria.

Table 2

Notation	Meaning	Intensity of importance
EP	A criterion or alternative is **extremely preferred** to another	9
VP	A criterion or alternative is **very strongly preferred** to another	7
MP	A criterion or alternative is **moderately preferred** to another	5
SP	A criterion or alternative is **slightly preferred** to another	3
QP	A criterion or alternative is **equally preferred** to another	1
SN	A criterion or alternative is **slightly non-preferred** to another	1/3
MN	A criterion or alternative is **moderately non-preferred** to another	1/5
VN	A criterion or alternative is **very strongly non-preferred** to another	1/7
EN	A criterion or alternative is **extremely non-preferred** to another	1/9

Table 2. 9-point scale for pairwise comparisons in AHP for evaluation, linguistic terms and their meaning.

Table 3

Pairwise criteria	Results for every expert									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Urban environment **vs.** economic-financial	MP	SP	SP	VP	QP	MP	SN	EP	QP	VP
Urban environment **vs.** governance	EP	VP	VP	EP	MP	EP	VP	VP	EP	EP
Urban environment **vs.** maintenance requirements	MN	SN	SP	SP	QP	VN	MN	SN	SP	QP
Urban environment **vs.** security	EP	MP	SP	MP	VP	QP	MP	SP	QP	VP
Urban environment **vs.** liability	VP	VP	MP	MP	SP	EP	VP	EP	MP	SP
Urban environment **vs.** archaeological sites	MP	EP	VP	VP	SP	QP	VP	VP	SP	MP
Economic-financial **vs.** governance	VP	EP	EP	EP	MP	VP	EP	EP	MP	EP
Economic-financial **vs.** maintenance requirements	QP	SN	SN	MN	QP	SP	VN	MN	VN	MN
Economic-financial **vs.** security	SP	SP	QP	MP	MN	MN	SP	QP	QP	SP
Economic-financial **vs.** liability	SP	SP	MP	QP	MP	MP	SN	QP	MP	MP
Economic-financial **vs.** archaeological sites	MP	MP	MP	QP	SP	SP	MP	MP	QP	MP
Governance **vs.** maintenance requirements	VN	EN	EN	VN	MN	SN	VN	EN	EN	EN
Governance **vs.** security	VN	VN	MN	VN	VN	SN	VN	EN	EN	VN
Governance **vs.** liability	MN	VN	VN	VN	QP	SN	MN	VN	VN	VN
Governance **vs.** archaeological sites	SN	QP	QP	SN	SN	SN	QP	QP	SN	SN
Maintenance requirements **vs.** security	SP	VP	SP	MP	MP	SP	SP	MP	SP	SP
Maintenance requirements **vs.** liability	VP	VP	VP	MP	SP	MP	VP	MP	MP	VP
Maintenance requirements **vs.** archaeological sites	EP	EP	VP	VP	VP	EP	EP	MP	VP	EP
Security **vs.** liability	QP	QP	QP	SP	MP	QP	SP	SP	QP	SP
Security **vs.** archaeological sites	QP	SP	MP	QP	VP	MP	MP	MP	QP	MP
Liability **vs.** archaeological sites	SN	QP	SN	MN	SP	SP	MN	QP	QP	SP

Table 3. Evaluation results of the main criteria with respect to the overall goal.

Table 4

	C1	C2	C3	C4	C5	C6	C7	Priority Vector
C1	1	4.1333	7.8000	1.2210	4.6000	6.0000	5.4000	0.3467
C2	0.2419	1	7.8000	0.6552	2.0400	3.3333	3.8000	0.1581
C3	0.1282	0.1282	1	0.1517	0.1613	0.2590	0.6000	0.0253
C4	0.8190	1.5262	6.5900	1	400000	5.8000	7.8000	0.2728
C5	0.2174	0.4902	6.2008	0.2500	1	2.2000	3.8000	0.1024
C6	0.1667	0.3000	3.8603	0.1724	0.4545	1	1.3067	0.0549
C7	0.1852	0.2632	1.6667	0.1282	0.2632	0.7653	1	0.0397

Table 4. Priority vector and consistency analysis of the pairwise comparison matrix for the seven criteria.

Table 5

Pairwise criteria	Results for every expert									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Traditional Trench **vs.** Common Conduit	QP	SP	SP	MP	MP	QP	SP	MP	SP	SP
Traditional Trench **vs.** Flat UT	SP	MP	MP	MP	VP	MP	MP	MP	VP	SP
Traditional Trench **vs.** Shallow UT	EP	VP	EP	EP	EP	EP	VP	EP	EP	EP
Traditional Trench **vs.** Deep UT	EP	EP	EP	EP	EP	EP	EP	EP	EP	EP
Common Conduit **vs.** Flat UT	SP	QP	QP	SP	SP	QP	QP	QP	SP	QP
Common Conduit **vs.** Shallow UT	MP	SP	SP	SP	MP	MP	SP	MP	SP	SP
Common Conduit **vs.** Deep UT	MP	MP	MP	SP	MP	MP	MP	MP	MP	SP
Flat UT **vs.** Shallow UT	SP	QP	QP	SP	QP	QP	QP	SP	QP	SP
Flat UT **vs.** Deep UT	SP	SP	SP	SP	QP	QP	QP	SP	QP	SP
Shallow UT **vs.** Deep UT	QP	SP	SP	QP	QP	QP	QP	QP	QP	QP

Table 5. Evaluation results of the main criteria with respect to the overall goal.

Table 6

C1	A1	A2	A3	A4	A5	Priority Vector
A1	1	0.7333	0.5067	0.1270	0.1111	**0.0470**
A2	1.3636	1	0.3467	0.1644	0.1422	**0.0550**
A3	1.9737	2.8846	1	0.2800	0.2533	**0.1134**
A4	7.8750	6.0811	3.5714	1	0.6667	**0.3461**
A5	9.0000	7.0313	3.9474	1.5000	1	**0.4385**

λ_{max} = 5.07 CI = 0,018 CR = 0.0163 < 0.1 OK

Table 6. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 1 (C1-Urban environment).

Table 7

C2	A1	A2	A3	A4	A5	Priority Vector
A1	1	3.2000	5.0000	8.6000	9.0000	**0.5596**
A2	0.3125	1	1.8000	3.8000	4.6000	**0.2125**
A3	0.2000	0.5556	1	1.8000	2.2000	**0.1134**
A4	0.1163	0.2632	0.5556	1	1.4000	**0.0635**
A5	0.1111	0.2174	0.4545	0.7143	1	**0.0510**

$\lambda_{max} = 5.20$ CI = 0,049 CR = 0.0440 < 0.1 OK

Table 7. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 2 (C2-Economic Financial).

Table 8

C3	A1	A2	A3	A4	A5	Priority Vector
A1	1	1.1867	3.2000	8.2000	7.8000	**0.4010**
A2	0.8427	1	3.3333	7.0000	6.8000	**0.3589**
A3	0.3125	0.3000	1	4.2000	3.6000	**0.1464**
A4	0.1220	0.1429	0.2381	1	1.8000	**0.0514**
A5	0.1282	0.1471	0.2778	0.5556	1	**0.0423**

λ_{max} = 5.21 CI = 0,052 CR = 0.0467 < 0.1 OK

Table 8. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 3 (C3-Governance).

Table 9

C4	A1	A2	A3	A4	A5	Priority Vector
A1	1	0.6533	0.1848	0.1295	0.1263	**0.0409**
A2	1.5306	1	0.3467	0.1714	0.1651	**0.0608**
A3	5.4124	2.8846	1	0.4267	0.4133	**0.1741**
A4	7.7206	5.8333	2.3438	1	1.0000	**0.3587**
A5	7.9146	6.0577	2.4194	1.0000	1	**0.3656**

λ_{max} = 5.27 CI = 0,069 CR = 0.0614 < 0.1 OK

Table 9. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 4 (C4-Maintenance requirements).

Table 10

C5	A1	A2	A3	A4	A5	Priority Vector
A1	1	3.2000	4.2000	7.2000	7.2000	**0.5269**
A2	0.3125	1	2.1333	4.0000	4.0000	**0.2274**
A3	0.2381	0.4688	1	2.1333	2.1333	**0.1225**
A4	0.1389	0.2500	0.4688	1	1.0667	**0.0624**
A5	0.1389	0.2500	0.4688	0.9375	1	**0.0609**

$\lambda_{max} = 5.32$ CI = 0,080 CR = 0.0718 < 0.1 OK

Table 10. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 5 (C5-Security).

Table 11

C6	A1	A2	A3	A4	A5	Priority Vector
A1	1	2.8000	6.2000	7.8000	8.8000	**0.5511**
A2	0.3571	1	2.2000	4.0000	4.0000	**0.2179**
A3	0.1613	0.4545	1	3.0000	3.4000	**0.1269**
A4	0.1282	0.2500	0.3333	1	1.2000	**0.0552**
A5	0.1136	0.2500	0.2941	0.8333	1	**0.0489**

λ_{max} = 5.34 CI = 0,084 CR = 0.0750 < 0.1 OK

Table 11. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 6 (C6-Liability).

Table 12

C7	A1	A2	A3	A4	A5	Priority Vector
A1	1	0.5600	0.3867	0.1238	0.1143	**0.0430**
A2	1.7857	1	0.5867	0.4400	0.1600	**0.0845**
A3	2.5862	1.7045	1	0.2438	0.1771	**0.1003**
A4	8.0769	2.2727	4.1016	1	0.8000	**0.3187**
A5	8.7500	6.2500	5.6452	1.2500	1	**0.4535**

λ_{max} = 5.27 CI = 0,068 CR = 0.0611 < 0.1 OK

Table 12. Priority vector and consistency analysis of the pairwise comparison matrix for the five alternatives with respect to criterion 7 (C7-Archaeological sites).

Table 13

	C1	C2	C3	C4	C5	C6	C7
A1	0.0470	0.5596	0.4010	0.0409	0.5269	0.5511	0.0430
A2	0.0550	0.2125	0.3589	0.0608	0.2274	0.2179	0.0845
A3	0.1134	0.1134	0.1464	0.1741	0.1225	0.1269	0.1003
A4	0.3461	0.0635	0.0514	0.3587	0.0624	0.0552	0.3187
A5	0.4385	0.0510	0.0423	0.3656	0.0609	0.0489	0.4535

Table 13. Priority matrix for selecting utilities placement techniques in urban underground.

Table 14

Alternative	Overall priority result
A1 – Traditional trenching	0.2121
A2 – Common conduit	0.1169
A3 – Flat utility tunnel	0.1319
A4 – Shallow utility tunnel	0.2512
A5 – Deep utility tunnel	0.2878

Table 14. Global priorities for each of the alternatives.