EXPERT CHOICE MODEL FOR CHOOSING APPROPRIATE TRENCHLESS METHOD FOR PIPE LAYING

Petar Adamović, Časlav Dunović, Maja - Marija Nahod

Abstract

Trenchless technologies of pipe laying have relatively short application in Croatia. With today's improved technologies, it is not easy to choose the right and optimal method. Each method is characterized by technical parameters such as: nominal diameters of installed pipes, the material of installed pipes, driving distances, soil types which have a possibility of installing a pipeline using a given method, the depth of cover, etc. Therefore, we made a model in ExpertChoice, to help choosing trenchless method. We consider that trenchless methods have, or at least can have application in Croatia. In this paper we give a classification of trenchless methods applied in the model, assumptions, limiting conditions, input and output quantities.

Key words: trenchless technologies, Expert Choice, pipe laying

1. Introduction

Researchers all over the world compare trenchless technologies and open-cut methods of pipe lying in new installations as well as in renovation of pipelines. They are confirming the advantages of trenchless applications in urban areas, as well as in bypassing rivers and ground construction when pipeline is needed. But after final decision to apply trenchless technology, regardless their similarity, one of them has to be chosen. With today's improved technologies, in most of the cases at least few of them are available.

In this paper we consider renovation of potable water pipelines.

The structural characteristics required from a pressure pipe liner are quite different from those of a sewer liner. The most important structural parameters are elastic modulus and wall thickness, which together provide the ring stiffness to resist buckling. Pressure pipes, except those of small diameter, fail less frequently from external loading. The most significat forces on the pipe are generally caused by the internal pressure, which creates tensile stresses in the pipe or liner. The most common pipe defects are corrosion and leakage from joints. Pressure pipe liners do not generally require as much ring stiffness as sewer liners, but they do need to withstand the bursting forces generated by internal pressure.

It is obviously that, in general, trenchless has less applications in potable water pipelines than in sewer. It looks like cost is the primary factor against trenchless on the water side (Ellison). In water system sanation there are three reasons why investors avoid trenchless solutions:

- holes generally must be excavated at each service connection so the laterals can be reconnected
- bypass systems must be installed to supply customers throughout the construction period
- manholes that provide ready access to the main to install the liner do not exist

But the truth is that trenchless in water pipelines doesn't have a clear cost advantage like in the sewer industry and that's why reasons above look enough significant.

Experts agree - more education about what trenchless can do for water infrastructure is needed becouse it has a strong future. Cut-and-cover is more disruptive in a number of ways and it influences the public more.

Unfortunately, in Croatian construction practice the only criteria for choosing method of sanation is mostly still cost of investment.

Constructing and rehabilitating underground pipelines of communal infrastructure can have other criteria and conditions of crucial matter as financial is. In some circumstances duration of sanation, probability of construction overtime, disturbance on environment, traffic disturbance, quantity of used material and conditions in which particular technological variant can be performed.

When we overcome this problem and augment number of criteria for sanation decion to criterias[3]:

- financial criteria
- technical criteria
    - financial loss in local shops and bussiness
    - traffic suspension and disturbance
    - construction time
- ecological criteria
    - noise impact
    - enviromental impact
- social crteria
    - public impact
    - local media impact

and when we concluded in current project that trenchless is better solution, we have to compare possible and available trenchless methods.

We chose one study case for this paper to show comparation between possible and available methods.

Criterias and evaluated by our own estimation as well as estimation from collected data of world wide expierence. In praxis detailed analysis should be undertaken for every criteria. It should be undertaken by particular group of experts whose evaluations would sum and give basis for sensitivity analysis and comparation of trenchless methods.

In the contruction industry values that are used in comparing calculation can't be transfered to another construction sites or projects unchanged. The reason is that external and internal conditions, which are unique, results differ values on wide construction area. This paper gives one approach and case study which can't be applied to another projects unless it is changed to particular conditions.

2. Water supply system in Zagreb

Since water-supply system is about 128 years old, porosity caused 41% water loss, while the european average is 18%. In order to reach this level, it is necessary to urgently renovate water supply system, in which, as experts estimate, must be about 110 million Є invested. In renovation and modernization of water supply system, the company "Vodoopskrba i odvodnja" plan to invest 370 million Є until 2015., toward the document ¨Strategic plans for business development¨. In these circumstances, it is very important to choose adequate technology for sanation, in every particular case.

3. Analytic Hierarchy Process and Expert Choice

Expert Choice (EC) software is a multi-objective decision support tool based on the Analytic Hierarchy Process (AHP), a mathematical theory first developed at the Wharton School of the University of Pennsylvania by one of Expert Choice's founders, Thomas L. Saaty. The AHP is a powerful and comprehensive methodology designed to facilitate sound decision making by using both empirical data as well as subjective judgments of the decision-maker. This approach is suitable for dealing with complex systems related to making the choice from among several alternatives and which provides a comparison of the subdivision of the problem in the hierarchical form.

The AHP is a tool that can be used for analyzing different kinds of social, economic and technological problems, and it uses both qualitative and quantitative variables. The fundamental principle of the analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools. Among the different contexts in which the AHP can be applied, mention can be made of the creation of a list of priorities, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, the assessment of risks and planning (Saaty and Vargas, 1990.)

The steps used in AHP and EC are:

- brainstorm and structure a decision as a hierarchical Model
- pairwise compare the objectives and sub-objectives for their importance in the decision
- pairwise compare the alternatives for their preference with respect to the objectives, or assess them using one of the following:
    - utility curves, ratings or step function, or enter priorities directly
    - synthesize to determinate the best alternative
    - perform sensitivity analysis

The ¨structuring¨ consists in subdividing the problem into simple clusters that are represented in different levels in a hierarchal structure. The decomposition is carried out from the top to the bottom, starting from the objective, to the criteria and sub-criteria, to the final alternatives.

The ¨pairwise compare¨ consists in giving a rate to each cluster to measure the importance of each level in the hierarchy. Each single element is evaluted using a pairwise comparison. The comparisons are made on a 9-point scale, the so-called ¨fundamental scale of Saaty¨, which is represented in Table 1. (see Table 1., Table 2.)

Value ($i_a j_b$; $k_c l_d$)	**Explanation**
1	Objective *i* and *j* are of equal importance
3	Objective *i* is weakly more important than *j*
5	Objective *i* is strongly more important than *j*
7	Objective *i* is very strongly more important than *j*
9	Objective *i* is obsolutely more important than *j*
2,4,6,8	Intermediate values
a,b = (1,2,3,...n = number of objectives); c,d = (1,2,3,...m = number of alternatives)	

Table 1. Saaty's fundamental scale

The numerical judgments established at each level of the hierarchy make up pair matrixes.

Let n be the number of objective (criteria) in a certain level of the hierarchy and m the number of the alternatives, there are therefore n matrixes with m lines and m coumns in that level. (see table 3.)

i / j	**Objective 1**	**Objective 2**	**Objective 3**	**Objective 4**	**...**	**Objective n**
Objective 1	1	i_1j_2	i_1j_3	i_1j_4	...	i_1j_4
Objective 2	i_2j_1	1	i_2j_3	i_2j_4	...	i_1j_4
Objective 3	i_3j_1	i_3j_2	1	i_3j_4	...	i_1j_4
Objective 4	i_4j_1	i_1j_2	i_1j_3	1	...	i_1j_4
...	...	...	...	...	...	...
Objective n	i_4j_1					$i_nj_n=1$
i_aj_b : (a=1,..n; b=1,..n) = values (see table 1.)						

Table 2. Pairwise compare the objectives and sub-objectives for their importance in the decision

Objective i (i → 1,2,...n)					
k / l	**Alternative 1**	**Alternative 2**	**Alternative 3**	**...**	**Alternative m**
Alternative 1	1	k_1l_2	k_1l_3	...	k_1l_m
Alternative 2	k_2l_1	1	k_2l_3	...	k_2l_m
Alternative 3	k_3l_1	k_3l_2	1	...	k_3l_m
...	...	...	...	...	...
Alternative m	k_4l_1	k_4l_1	k_4l_1	...	$k_4l_m=1$
k_cl_d : (c=1,..m; d=1,..m) = values (see table 1.)					

Table 3. Pairwise compare the alternatives for their preference with respect to the objectives

All the pairwise comparison matrices have two fundamental properties:

- the principal diagonal is always composed of values that are equal to one (each criterion is compared to itself)
- the matrices are reciprocal (in assigning a value from 1-9, so $i_aj_b=\frac{1}{i_bj_a}$; $k_cl_d=\frac{1}{k_dl_c}$)

When the judgement matrix of criteria comparison with respect to the goal is available, the local priorities of criteria are obtained and the consistency of the judgements is determinated.

It has be generally agreed (Saaty, 1980,2000) that criteria priorities can be estimated by finding the principal eigenvector w of the matrix A, and that is:

$$Aw= \lambda_{max}w.$$

When the vector w is normalised, it becomes the vector of criteria priorities with respect to the goal. λ_{max} is the largest eigenvalue of the matrix A and the corresponding eigenvector w contains only positive entries. The consistency of the judgement matrix can be determined by a measure called the consistency ratio (CR) which is efined as:

$CR = \frac{CI}{RI}$ CI = consistency index, RI = random index $CI = \frac{(\lambda_{\max} - n)}{(n-1)}$

RI is the consistency index of a randomly generated rciprocal matrix from the 9-point scale, with forced reciprocals. Saaty has provided average consistencies (RI values) of randomly generated matrixes (up to 11 x 11 size) for a sample size of 500. If the CR of the matrix is high, it means that the input judgements are not consistent and hence are not reliable. In general, a consistency ratio of 0.10 or less is considered acceptable. If the value is higher, the judgements are not reliable and have to be elicited again.

Using a similar procedure, the local priorities of alternatives with respect to each criterion can be estimated.

The last step of the procedure consists of an aggregation of the local priorities of elements of different levels in order to obtain final priorities of the alternatives. The final list, obtained by summing all the eigenvectors, is a vector that provides the measure of the part played by each alternative in reaching the initial goal.

4. Choosing the optimal trenchless technology

The first thing to remember about trenchless technology is that no single method is a cure-all for the various types of underground facilities, soils and site conditions. The most important criteria to consider for pipe rehabilitation projects are surface conditions, cost, subsurface conditions, condition of current pipe, and pipe capacity. Evaluation of these factors will aid the decision about method, materials and equipment required for a rehabilitation project. For example, pipe bursting may be the choice to upsize pipe diameter, while cured-in-place pipe, fold-and-form pipe, or sliplining may be used to repair the current pipe. Traditional pipe replacement may be the choice if the pipe is severely deteriorated and rehabilitation methods are not viable. Here are few other examples:

- pipe bursting is good choice where existing line and grade are adequate, but the original pipe is deteriorated or undersized
- Sliplining is often used in situations where the existing pipe has minor structural problems or corrosion. It is simple and relatively inexpensive. However, the current pipe must have enough strenght to withstand the insertion force, and there is a loss of hydraulic capacity
- Cured-in-place pipe may be applicable unless there is heavy blockage and extensive structural damage. The liner not only serves to repair deterioration of the current pipe, but also reduces inflow, infiltration and leakage, and usually improves flow conditions.
- Pipe replacement is normally considered if the pipe is: structurally damaged and unable to sustain loads; severely crushed, collapsed or deteriorated; in need of increased hydraulic capacity; relatively shallow and in an undeveloped area that has good soil conditions; or located where trench excavation is not a concern

5. Study case: Trenchless Rehabilitation to save valued spruce trees

There is 1200 m of a 300 mm diameter water distribution in the city which has to be rehabilitate. Experts chose trenchless pipe renewal process in order to avoid the removal and replacement of a number of spruce trees along the water main route. The trenchless project will make it possible to save 149 spruce trees that the city values at 450 000 €. Traditional open cut methods would have required cutting down the trees, which are valued not only in financial terms, but also their environmental significance. These trees are some of the most mature spruce trees in the city and are an important part of the local community. The boulevard that the trees line is a main thoroughfare for cars and pedestrians, giving access to Park. The existing cast iron water main that is being rehabilitated was installed in 1956. Recent inspection indicated significant deterioration. There have not been a substantial number of pipe failures, but experts decided to rehabilitating the water main, prevent future water main burst and allow uninterrupted service to the high-density residential and commercial area.

6. Available trenchless methods to concern

After prelimary analysis of available possibilities, for mentioned study case, we considered five structural methods: Sliplining, Cured in place pipe – inverted in place, Pipe bursting, horizontal directional drilling and Cros section method – fold and form.

We can apply those methods to current sanation. Every single one of them would satisfy required conditions more or less, but there are still some differences between them. They all could imbed pipeline of Ø300 mm, but praxis tells us that all of them are best at smaller range of diameter. We choose trenchless technology becouse cost od sanation wasn't the only criteria in choosing the solution. It is a matter of concrete situation, since in some cases, for example, construction time will be critical and will have bigger priority than other criterias. Sometimes even two or three days means a lot. In some cases some of characteristics could be so similar that we can ignore them or put them in the Expert Choice model with equal values of priority, since some of participants in our decision team might think differ from us.

7. AHP Model for study case

The goal of the analysis was to define which trenchless method was most compatible, from the point of view of public and private actors who are involved. The first step of the analysis is the definition of the hierarchical structure which could correctly represent the analysis problem. We concluded that there are four main criteria which we have to treat: financial, social, technical and ecological criteria. Alternatives were trenchless methods: sliplining, cured-in-place pipe, pipe bursting, horizontal directional drilling and fold-and-form.

Financial criteria

According to data collected, here are the avarage cost of trenchless techniques with more than five data records, which we used to estimate financial criteria of choosing trenchless technique. Their ratio is what we need for our analysis – a comparation. (see Table 4.)

Method	Overal average cost (€/mm dia./m length)	Diameter range				# of data records
		Small (≤300) (€ /m)	Medium (330-940) (€ /m)	Large (960-1830) (€ /m)	Very large (>1830) (€ /m)	
Sliplining	1.01	169	723	1786	2567	16
Cured in place pipe	1.01	219	389	1942	-	39
Pipe Bursting	1.61	531	852	-	-	11
Horizontal directional drilling	2.17	194	1310	4565	-	10
Cross section method – fold and form	0.97	164	717	-	-	5

Table 4. Cost of considering trenchless technologies

Social criteria

Social criteria consists on public impact and traffic disturbance. They are very similar to trenchless techniques that we considered, but in some cases there can be a little differ which model could take effort.

Technical criteria

Each of the trenchless rehabilitation methods can be used for various ranges of pipe size and length. A comparation is shown below. [2] (see Table 5.)

Method	Diameter Range (mm)	Maximum Installation(m)	Liner Material
Sliplining - segmental	90-1000	300	PE, PP, PVC, GRP
Cured in place pipe	100-2700	900	Thermoset, Resin/Fabric, Composite
Pipe Bursting	100-600	230	PE, PP, PVC, GRP
Horizontal directional drilling	100-1200	500	
Cross section method – fold and form	100-400	210	PVC
PE = Polyethylene PP = Polypropylene PVC = Poly Vinyl Chloride GRP = Glassfiber Reinforced Polyester			

Table 5. Characteristics of installations

We consider diameter, pipe material, possible complications, minimum manholes and construction time needed.

Ecological criteria

We consider noise and environmental impact. In some cases environmental protection is one of the biggest priorities. Noise of equipment and machines in quiet regions and urban areas can also be one of the important factors to compare.

Other possible criteria

Analysis of the unsuccessful renovations indicates that during the design process one should considerate some additional criteria:

- criteria of maximum elongation of material – structure durability solutions applied in pipeline renovations
- operational criteria, which allows to execute the next future renovation by using as many as possible available techniques
- criteria which allows in the future building up the connections or laterals in the renovated pipeline and which enables to find and precisely localize the possible leakage

8. Analysis & Results

The Expert Choice model has objectives (criteria) on the left side and alternatives on the right side of the sheet. (see Figure 1.)

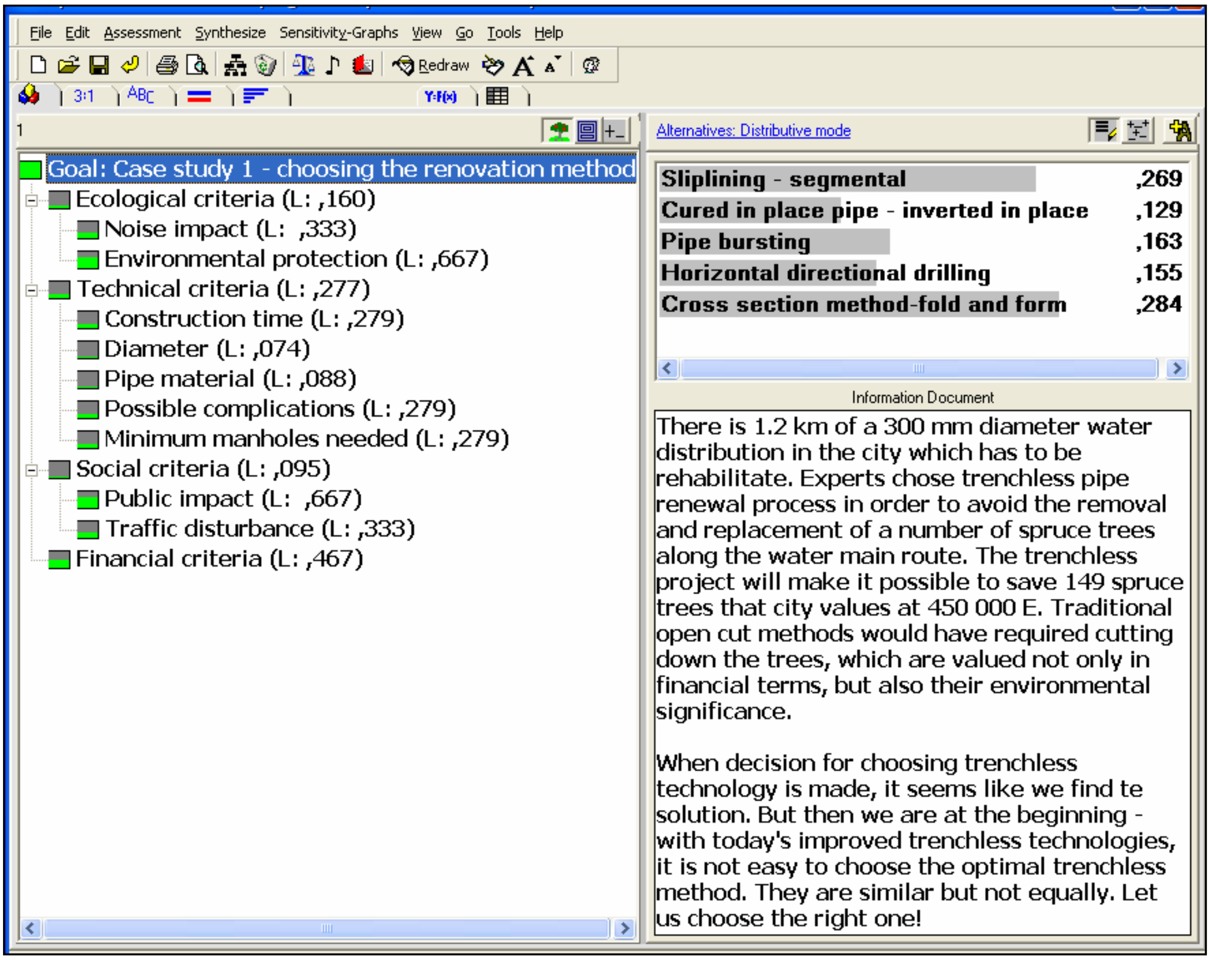

Figure 1. Expert Choice model for study case

Sensitivity analyses from the Goal node will show the sensitivity of the alternatives with respect to all the objectives below the goal. When performing a sensitivity analysis you may vary the priorities of the objectives and observe how the priorities of the alternatives would change. There are five types of sensitivity analysis: Dynamic, Performance, Gradient, Head to Head and Two-Dimensional (2D Plot). We can open four types of sensitivity analyses at once (see Figure 2.) or each one separately (see Figure 3.).Each graph has its own unique menu commands and each sensitivity analysis can be compared to a "what-if" analysis because the results are temporary. (see Figure 4.: What if we change priorities?)

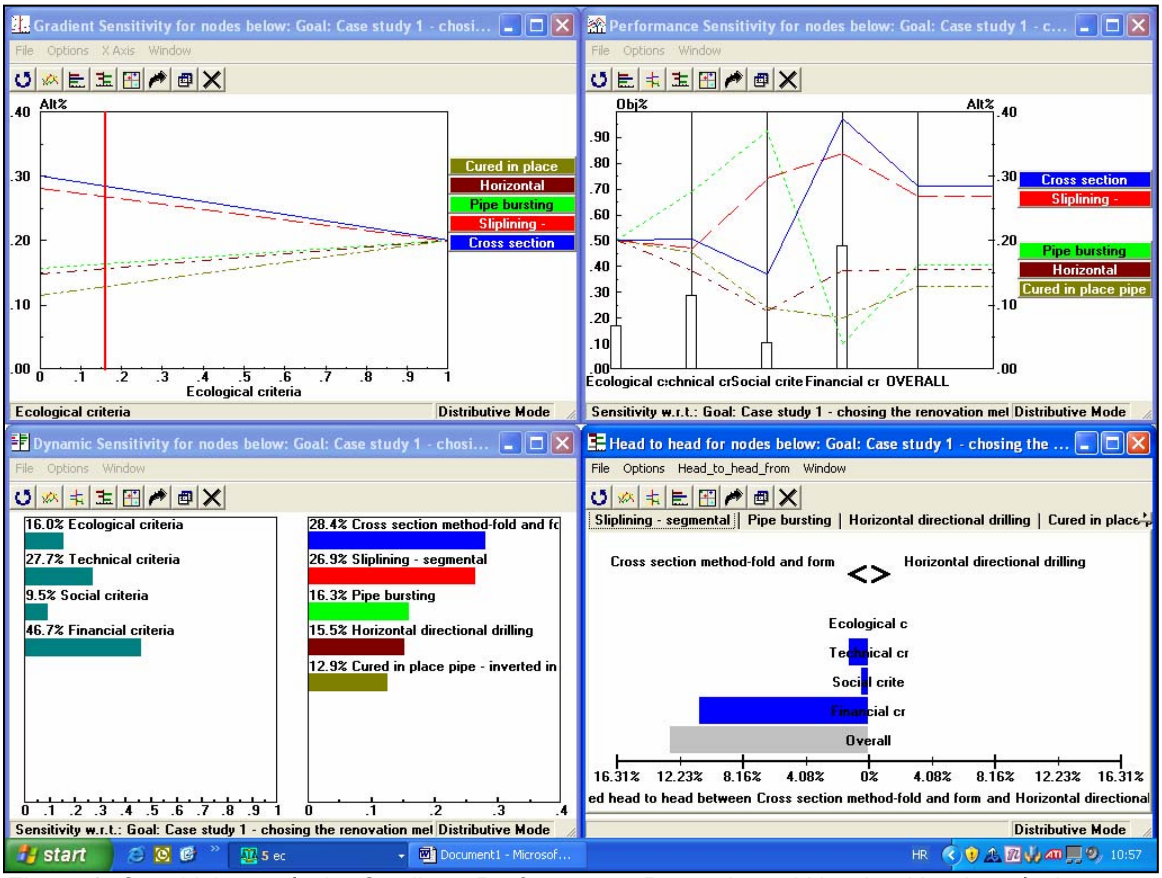

Figure 2. Sensitivity analysis: Gradient, Performance, Dynamic and Head to Head analysis

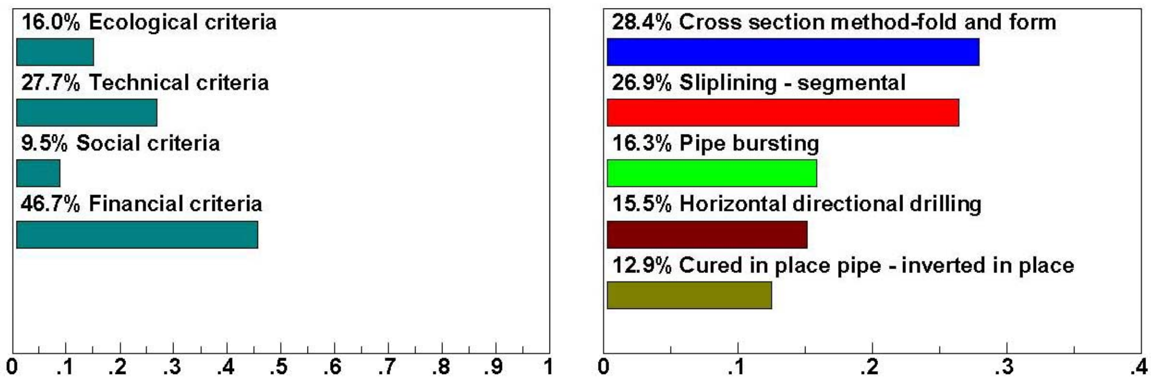

Figure 3. Dynamic Sensitivity analysis

By dragging the objective's priorities back and forth in the left column, the priorities of the alternatives will change in the right column. If a decision-maker thinks an objective might be more or less important than originally indicated, the decision-maker can drag that objective's bar to the right or left to increase or decrease the objective's priority and see the impact on alternatives. (see Figure 4.)

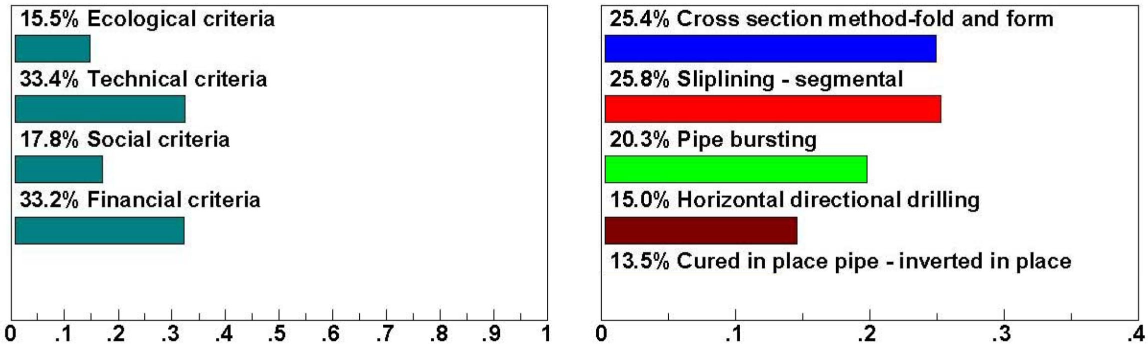

Figure 4. Dynamic Sensitivity analysis - changing the priorities

The synthesis (distributive mode) distributes the weight of each covering objective to the alternatives in direct proportion to the alternative priorities under each covering objective. (see Figure 5.)

Now we can conclude that modified cross-section method – fold and form, will help to prevent future water main bursts and allow uninterrupted service to the high-density residential and commercial area, with respecting our input criteria (see Figure 3.), their priorities and available methods that we considered. (see Figure 5.)

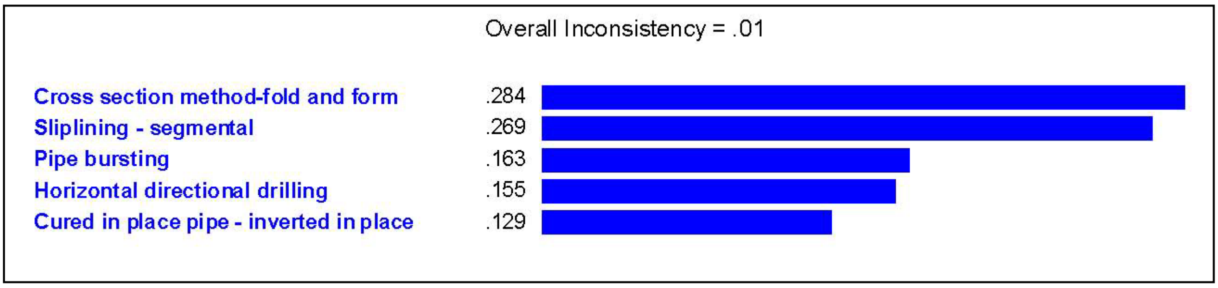

Figure 5. Synthesis: Summary

9. Expert Choice Team

Expert Choice can be used by a team to enhance the quality of group decisions by bringing structure to the decision making process and by synthesizing different points of view. The Facilitator builds the EC model and facilitates the group decision-making process or session. (Sometimes in practice, one person may act as the Facilitator in building the model and another person to facilitate the group interaction.) Individual members of the group or team will be referred to as Participants.

Participants can make judgments about the various facets of the decision problem including:

- making paired comparisons
- entering Ratings or data
- creating notes explaining their judgments as well as other issues or concerns

Participants can review their own decision model; perform a synthesis; display sensitivity graphs as well as review the contents of the Data Grid. All information can be printed. If permitted by the facilitator, participants can view and print one or more of the combined results.

10. Conclusion

In this paper we gave the possible model of comparison the trenchless technologies, in order to choose the optimum one.

It's neccessary to consider all relevant criteria and make judgments according to professional experience, so that models and results give us adequate answers.

This model could reach its peak if we would have an opportunity to work in team. Since there's not enough praxes and applying of trenchless methods in our region, and it is obviously that it is neccesary to develop it in the future, the idea is to promote and accelerate the transfer of experiance in trenchless methods, by:

- creating a team with experts in trenchless technology as participants
- choosing the Facilitator who will create a model similar to one in this paper
- publishing and opening a Group model on the world-wide-web
- Group decision making using the Web

11. References

1. S. Gokhale, M. Hastak: ¨Decision aids for the selection of installation technology for underground municipal infrastructure systems ¨, www.sciencedirect.com

2. Office of Water Washington: Collection Systems O&M Fact Sheet, Trenchless Sewer Rehabilitation, United States, Environmental Protection Agency, September 1999.

3. D. Piškorić: Use of multicriterial analysis in the selection of sewer pipe remediation methods, Građevinar, p. 407-412., br.5, Zagreb, 2007.

4. M. Bottero, D. Peila: The use of the Analytic Hierarchy Process for the comparison between microtunneling and trench excavation, Tunneling and Underground Space Technology 20, p. 501-513, 2005.

5. Kuliczkowski, A.: Future technologies of trenchless renovation of the pipelines which has earlier been no-dig renovated

6. B. Foster: Maxi Rings: What to consider before making that purchase (Directional Drilling), www.trenchlessonline.com, Trenchless Technology, 2007.

7. N. Swarup: Trenchless Pipeline Management, Indian Society for Trenchless Technology, www.istt.com, 2006.

8. Trenchless Technologies Resource Centre: Pipeline Renovation Technologies, www.istt.com, second edition, 2006.

9. I. Clarke: Community Involvement, Team Work and Lateral Thinking Brings Trenchless Technology to London's Water Mains, Trenchless Technology International, www.trenchlessonline.com, 2006.

10. A. Zwierzchowska: The optimum of trenchless Pipe Lying technologies, Tunnelling and Underground Space Technology, Volume 21, Issue 6, November 2006, Pages 696-699

11. C. Evins, G. Stephenson, I.C. Waren, S.M. Williams: Planning the Rehabilitation of Water Distribution Systems, Water Research Centre, 1989.

12. A. W. Barlas: Overview of Horizontal Directional Drilling for Utility Construction, Master's Report, University of Florida, 1999.

13. IETC Urban Environmental Series (1): Trenchless Technology Systems – An Environmentally Sound Approach for Underground Services - An Introductory Guide for Decision-makers

14. www.istt.com, www.trenchlessonline.com, www.idswater.com, www.ukstt.org.uk, expertchoice.com

15. A. D. Russell, A. Udaipurwala, M. Alldritt: ¨Computer system for the selection of trenchless and conventional methods for underground utilities¨, www.sciencedirect.com

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Prof. Petar Adamović, M.Sc.C.E.
University of Zagreb, Politechnics in Zagreb, Department for civil engineering
Časlav Dunović, M.Eng., C.E.
University of Zagreb, Politechnics in Zagreb, Department for civil engineering
Maja-Marija Nahod, M.Eng., C.E.
University of Zagreb, Faculty of Civil Engineering, Department od Construction Management, Croatia