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Preliminary assessment of the technical condition of water supply infrastructures

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Abstract

To ensure sustainability and reliability of water supply infrastructure, we must apply a basic pre-condition, which is, its continual renewal. For renewal planning, there are many methods, techniques and software tools for decision support, but most of them, in many cases, focus only on water mains. Water supply systems, however, consist of different parts and structures than just water pipes. It is therefore not appropriate to invest in the renewal planning only in relation to one part of the water supply infrastructure. The knowledge of the current technical condition of the water supply infrastructure is crucial to maintain its planned performance and optimise its maintenance and renewal. Effective detailed evaluation of the technical condition requires deployment of specialists, reliable database, considerable amount of time and instrumentation and software. Therefore, it is preferable to perform the first rapid and efficient preliminary identification of problematic areas and elements of water supply systems. This paper presents the methodology and the Technical Energy Audit (TEA Water), the effective preliminary assessment of the technical state of water supply systems (WSS). The paper presents the structure of the proposed technical indicators, the method of their determination and evaluation, including the presentation of case studies of implementing the methodology and software tool in the Czech Republic.

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Keywords: water supply infrastructures; technical condition; technical auditing; water resources

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1. Introduction

The water supply infrastructure aging and its renewal is a global problem. The continuous renewal of the water supply infrastructure and investments in the renewal call for huge funds to be invested. It is estimated that over the next 20 years it will be necessary to make investments in the water supply systems in the USA totalling USD 77 billion. Similarly in Canada, the investments in the water supply infrastructure over the next 15 years will amount to 12.5 billion dollars a year according to Al-Barqawi [1]. In the Czech Republic, the annual investments in the water supply infrastructure total about EUR 592 million according to Barák [2]. The situation is similar in other European countries.

Funds for continuous renewal are restricted and therefore they must be spent efficiently wherever needed most. The decisions on investments in the water supply infrastructure are based on Infrastructure asset management (IAM). IAM of urban water infrastructures is a set of processes. The first and basic process within the IAM is objective knowledge of the current technical condition of the water supply infrastructure. Setting up the assessment criteria, metrics and targets is a crucial stage for establishing the technical audit of water supply infrastructure according to Alegre [3]. Since 2005, the biannual LESAM (Leading-Edge Strategic Asset Management) conferences of the International Water Association have clearly demonstrated the increasing interest and recognition of this field of knowledge according to Alegre [4].

The assessment of the technical condition of the water supply infrastructure is, to some extent, limited by legal requirements in each country. In some countries, the law lays down a relatively precise process and recommends the method of assessing the technical condition of the water supply infrastructure according to Heywood [6] and US EPA [7]. Other countries, such as the Czech Republic, do not have any legal method defined, neither a method of assessing the technical condition. Under the current law of the Czech Republic, each water utility assesses the system by the percentage of degradation on a discretionary basis. However, this means that it is not possible to objectively compare the technical condition of the water supply systems assessed by various water utilities.

Therefore, as part of dealing with the below said projects, in cooperation with selected Czech water utilities, we have developed the **TEA Water** methodology, which permits a preliminary assessment of the technical condition of the water supply infrastructure so as to enable not only to efficiently identify hot spots and parts of drinking water supply systems but also to compare the assessed systems and their individual components among themselves.

2. Methodology

The draft methodology of preliminary assessment of the technical condition of the water supply system components is based on the general method, the FMEA. The FMEA method (Failure Mode and Effects Analysis) allows for semi-quantitative assessment of the relevant system and its components. To assess the water supply systems using the FMEA is necessary to establish specific **technical indicators** for each of the water supply system component and structure. For each technical indicator we must subsequently define their determination method, necessary input data, physical dimensions and method of assessment and presentation.

In order to assess the various components of WSS, the methodology is, just like the water supply system, divided into the following separate modules:

- **Module TEAR:** water resources;
- **Module TEAT**: water treatment plants;
- **Module TEAM**: water transmission mains;
- **Module TEAA**: water tanks;
- **Module TEAP**: pumping stations;
- **Module TEAN**: water distribution networks;
- **Module TEAS**: water mains.

The total assessment of the relevant structure or components of the assessed WSS by the relevant module is based on the evaluation of two basic parts of each structure or component of the WSS:

- **Structural Technical part (ST)**
- **Technological Operating part (TO)**

The evaluation of these specific **parts** consists of:

- **Structural Technical part (ST) –** assessment of ***Structural Technical indicators ($ST_1,\ldots,ST_n$)***, where for each module a set of ST indicators is proposed for each **ST i**n order to capture the actual structural and technical condition of the assessed structure.
- **Technological Operating part (TO)** – assessment of ***Technological Operating indicators ($TO_1,\ldots,TO_n$)***, where for each module a set of indicators is proposed in order to capture the actual operating parameters of the assessed structure.

Compared to the standard FMEA method, the proposed methodology is expanded by another level - **factors (F).** Technical indicators are not assessed directly, but their evaluation is based on a set of factors proposed for each technical indicator. For each and every factor we have a uniform 4-point rating assessment system with specifications and recommendations for the specific score for each factor. Each factor and each technical indicator also comes with a **weight**, which reflects the importance of the relevant factor, indicator in the proposed assessment system. The factors are the only level, which is assessed on the basis of defined input data. Assessment made at higher levels (indicators, parts of structures, structures) are calculated based on the relevant indicator factor assessment. The point ranking of factors is as follows:

- **0** – factor not assessed, insufficient input data to assess the relevant factor
- **1, 2 or 3** – where the value of 1 is the most favourable condition, while the value of 3 is the least favourable condition of the factor assessment

Technical condition assessment structure based on the proposed methodology is presented in the following scheme:

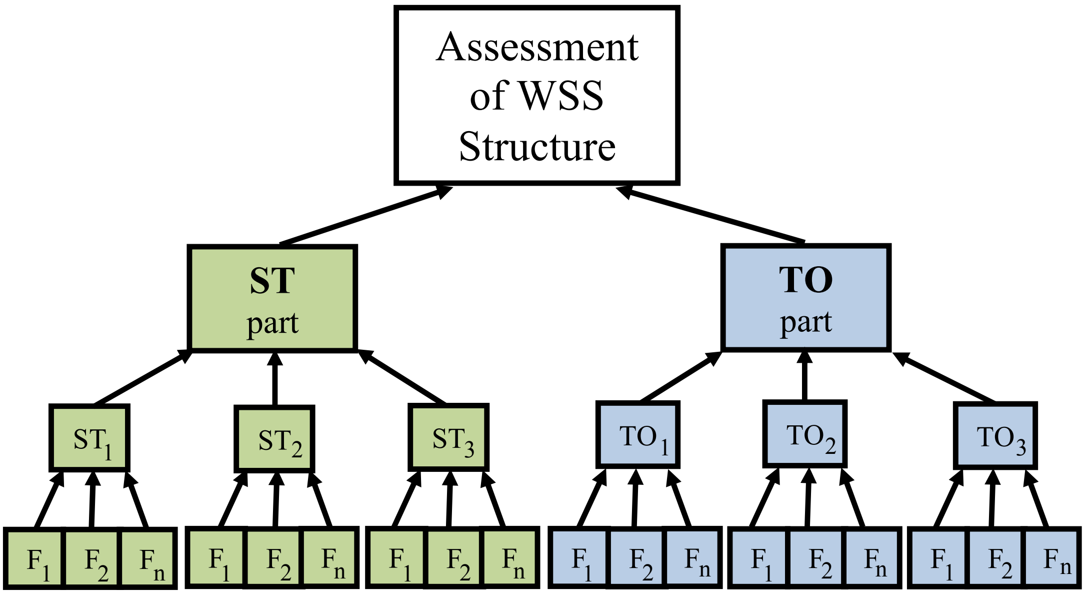

Fig. 1. Structure of technical condition assessment

Based on the assessment, the assessed **structures**, their **ST** and **TO parts** and their **indicators** may fall within the following assessment categories:

Table 1. Assessment categories

Structure	Part	Indicator	Description of assessment
A+, A, A-	**A**	**1**	optimal condition, no measures to change the assessment of this structure are required (indicators)
B+, B, B-	**B**	**2**	very good condition of the structure (indicator), no major immediate measures are required
C+, C, C-	**C**	**3**	average assessment, no immediate solution is required, but the structure (indicator) should be monitored in the near future
D+, D, D-	**D**	**4**	critical assessment of the condition, planned measures should potentially be implemented promptly to address the condition
F	**F**	**5**	undesirable condition calling for an immediate solution to improve the condition of the structure, its part or relevant indicator
N	**N**	**N**	insufficient input data to assess the structure or its part or indicators

This is a multi-criteria assessment. The proposed methodology is based on the weighted sum method. For this method it is particularly important to set the weights of the individual factors and indicators. The sum of the weights of various factors of the relevant indicator equals one. The same applies to the weight of indicators in the ST or TO parts of the structures. The proposed methodology is used to set the weights based on the knowledge and experience of the research team obtained also during discussions with water utility technicians. We also performed a sensitivity analysis of the influence of the proposed weights of the factors and indicators for real and fictitious water supply systems for all 7 modules.

2.1. Weight sensitivity analysis

The overall rating of the structure was originally proposed in 5 categories without the intermediate stage + and -. The sensitivity analysis of the effects of the weights of the factors and indicators on the overall assessment of the structure was carried out in such a way that all structure factors were first assessed by extreme rating 3. The assessment was then changed to the opposite extreme and 1; however, in a sequence from the factor with lowest effect (weight) on the assessment of the relevant indicator (1st testing series). Subsequently, using the full set of the factor assessment based on the extreme rating 3, there was a change to the opposite extreme 1; however, the sequence started with factors that have, on the contrary, the greatest effect on the overall rating of the structure. This testing indicates that despite the low effect of some of the factors, their change from rating 1 to 3, or conversely, may result in a change in the overall assessment of the structure by one full category. This mainly happens if the assessment is close to the borders between categories. However, in practice this could mean that if there is incomplete information about any of the factor and it is still assessed, this could considerably influence the achieved result by a single mistake or incomplete information in the input data. The rating is also influenced by a mistake because it is only a five-point ranking. Therefore, after consultations with experts from the field of water management we decided to extend the general assessment of structures by the category + and -, for example, B- and B +.

A key role for this method is played by setting the weights for the individual factors and indicators. Therefore, great attention was paid to weights set for various levels in the sensitivity analysis. The initial weight setup was based on the findings of the research team and based on discussions with experts who have practical experience from water utilities. This setup was tested by using a random number generator with uniform distribution probability in order to generate a rating for all factors in the tested structure. All four options to assess each factor had the same probability of generation. The results for the initial weight setup are shown in Figure 2 (left red column). The distribution of the obtained results showed a tendency in the final assessment of the structure towards the middle category C. This means that the influence of weights on the specific levels showed very little effect (factors, indicators). After discussions with experts and using the Saaty method according to Saaty [5] we decided to revise the set weights. After changing the weight settings, all the assessed structures were reassessed by means of the same random ranking of the factors as during the initial weight setting. The achieved results provide for a more balanced overall assessment of the assessed structures (right blue column). However, the methodology allows user customisation with respect to the factor and indicator weight setting.

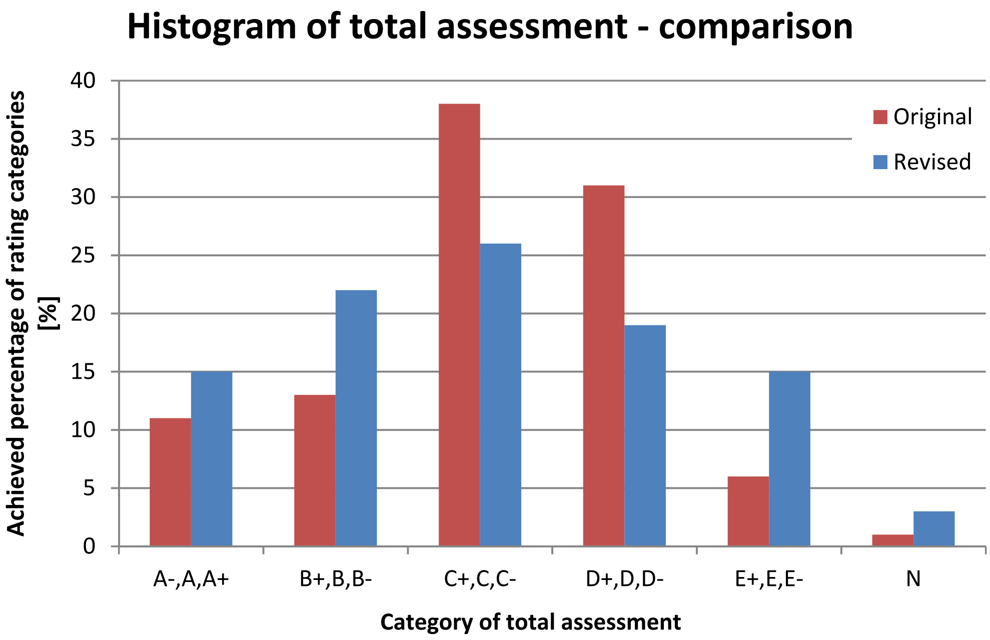

Fig. 2. Comparison of the achieved weight sensitivity assessment

2.2. TEAN module

The entire assessment methodology is developed for the 7 basic WDS structures. For each of these structures there is a set of indicators and factors designed within the relevant module for both basic parts of the assessed structure. In this chapter we present an example of the structure of indicators for the **TEAN** module - water distribution networks. The structure indicators, factors and their weights for the **Structural Technical part** as well as **Technological Operating part** of the assessed water network (pressure zone, district metering area) are presented in Table 2.

Table 2. Structure of indicators and factors and their weighs in the TEAN module

Structural Technical part			**weight**
	Structural Technical indicators		**0,40**
	ST1 - Average pipe material age		**0,50**
	F1-	Pipe age according to pipe material	0,75
	F2-	Pipe incrustation	0,25
	ST2 – Condition of valves in the network		**0,40**
	F1-	Valves	0,50
	F2-	Hydrants	0,35
	F3-	Other fittings	0,15
	ST3 – Condition of valve manholes		**0,10**
	F1-	Condition of valve manhole	1,00

Technological Operating part			**weight**
	Technological Operating indicators		**0,60**
	TO1 – Burst rate		**0,40**
	F1-	Average yearly pipe burst rate [pp.km^{-1}.year^{-1}]	0,50
	F2-	Burst dynamics	0,50
	TO2 – Water losses		**0,25**
	F1-	NRW percentage	0,30
	F2-	Unit NRW [m^3.km^{-1}.year^{-1}]	0,30
	F3-	Minimum night flow	0,20
	F4-	Economic loss level (ELL)	0,20
	TO3 – Quality of water in the network		**0,25**
	F1-	Water age time in the network [hours]	0,30
	F2-	Incrustation impact	0,30
	F3-	Transported water quality	0,20
	F4-	Effect of pipe materials	0,20
	TO4 – Pressure conditions in the zone		**0,10**
	F1-	Maximum hydrostatic pressure [m]	0,40
	F2-	Average hydrodynamic pressure [m]	0,30
	F3-	Hydrodynamic pressure fluctuation [m]	0,30

Table 3 gives an example of assessing the factors of Technological Operating indicator **TO2-Water losses**. For this indicator we propose 4 factors expressing various water losses indicators in the relevant water supply network and the borders of the point ranking.

Table 3. Example of the point assessment of TO2 Water losses indicator factor

TO2 – Water losses			
F1 – NRW percentage		F2 – Unit NRW (m^3.km^{-1}.year^{-1})	
0	Not assessed.	0	Not assessed .
1	< 12	1	< 3000
2	12-20	2	3000 - 7000
3	> 20	3	> 7000
F3 – Minimum night flow		F4 – Economic loss level (ELL)	
0	Not assessed.	0	Not assessed.
1	$Q_{min} \leq$ theoretical $Q_{t,min}$	1	< 0,8
2	$Q_{min} < 1,25*Q_{t,min}$	2	0,8 - 1,3
3	$Q_{min} \geq 1,25*Q_{t,min}$	3	> 1,3

2.3. TEA Water application

The proposed methodology was implemented with the aim of its programming into a web application, which allows for continuous access to information on the technical condition of the relevant infrastructure and the possibility of easy data entry. This makes the data on the technical condition of the water supply infrastructure available basically anytime and anywhere to the designated persons. The application is project-oriented, which means that we can set access rights for the individual projects to different users with various rights. The application makes it possible to enter and attach documents in various formats (doc, pdf, jpg) to the specific structures and technical indicators and generate printed sets with the final assessment. Currently, the application is tested as a working version and we expect that in the second half of 2016 it will be available to potential users. For more detailed information visit www.teawater.cz.

3. Case study

The proposed methodology has been tested on a variety of imaginary and real WSS. One of the case studies for the **TEAN module** was to assess selected pressure zones of the water supply system in the city of Brno. The presented pressure zone, which has been in operation since 1984, covers one neighbourhood in Brno. The pressure zone supplies a total of 5,650 inhabitants, the pipe material of the pressure zone consists of 80% grey cast iron, size ranging from DN 80 to DN 400. The total network length is 6.32 km. The final assessment of the technical condition of the water supply network in this pressure zone based on the proposed methodology by TEAN module is shown in Table 4.

Table 4. Final assessment of the water pressure zone – TEAN module

B+	**ASSESSMENT OF THE PRESSURE ZONE**			
	B	**ST Structural technical part**		
		1	ST1	Average pipe material age
		3	ST2	Condition of valves in the network
		1	ST3	Condition of valve manholes
	B	**TP Technological operating part**		
		2	TO1	Burst rate
		1	TO2	Water losses
		3	TO3	Quality of the water in the network
		3	TO4	Pressure conditions in the zone

4. Conclusions

The submitted methodology presents the results of the efforts to develop a simple but still efficient methodology for primarily assessment of the technical condition of water supply infrastructure. The individual modules are used for assessment and semi-quantitative categorisation of the technical condition of the specific components and structures of the water supply systems. The outputs of this methodology can also serve as the basis for comparative analyses, repairs planning, renewal planning, development of renewal financial plans or as the basis for further detailed structural-technological surveys, etc. The proposed methodology can interpret the technical condition of the relevant infrastructure, reveal potential hot spots and rank the operated structures described above as per the defined technical condition categories.

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References

[1] AlL-Barqawi H, Zayed, T. Infrastructure Management: Integrated AHP/ANN Model to Evaluate Municipal Water Mains' Performance, J. Infrastruct. Syst. 14:4 (2008) 305-318.

[2] F. Barák, Výhledy českého vodárenství po roce 2015. *Sovak: časopis oboru vodovodů a kanalizací* 2015 (in Czech), 21:4 (2015) 1-3.

[3] H. Alegre, S.T. Coelho, Infrastructure Asset Management of Urban Water Systems, Water Supply System Analysis - Selected Topics, Dr. Avi Ostfeld (Ed.), ISBN: 978-953-51-0889-4, InTech; 2012. DOI: 10.5772/52377. Available from: http://www.intechopen.com/books/water-supply-system-analysis-selected-topics/infrastructure-asset-management-of-urban-water-systems

[4] H. Alegre, M.C. Almeida, Strategic asset management of water and wastewater infrastructures, IWA Publishing, 2009. ISBN 97843391869

[5] T.L.Saaty, K. Peniwati, Group Decision Making, RWS Publications, 4922, Ellsworth Avenue, Pittsburgh, PA 15213, 2008.

[6] G.M. Heywood, J.P. Lumbers, M.A. Starr, A common framework for capital investment planning. In: G.M. Heywood, J.P. Lumbers, M. Starr, Capital maintenance planning common framework: review of current practice, Water Industry Research, London, UK, 2006. ISBN 1840573953.

[7] US EPA, Condition Assessment Technologies for Water Transmission and Distribution Systems, Publication No. EPA/600/R-12/017, 2012.