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Methodology for the estimation of the technical condition in the case of water treatment plants

Tomáš Kučera[a,]*, Ladislav Tuhovčák[a], Renata Biela[a]

[a]*Brno University of Technology, Faculty of Civil Engineering, Institute of Municipal Water Management, Žižkova 17, Brno, 602 00, Czech Republic*

Abstract

The paper presents the methodology for determining the operating and technical indicators for a preliminary assessment of the elements of water supply system (WSS) such as water treatment plants. The necessary data and system of technical indicators (TI) evaluation using the multi-objective optimization and Failure Mode and Effects Analysis (FMEA) are defined. The proposed methodology allows for the selection and ranking of WSS critical elements for more detailed analyses and suggestions of the type of renewal, including the estimated financial costs. Water treatment plants can be assessed by means of the specific part of the methodology. With respect to the water treatment plants the authors of the methodology realize that it is hard to generalize the entire audit since there are many types of water treatment plants as well as technological elements used. The proposed set of assessment indicators is based on the function of the water treatment plant, i.e. production of drinking water in the required quantity and quality. When assessing the technical condition of the water treatment plant this facility may not be viewed simply in structural and technical terms but it is absolutely necessary and much more important to assess it in technological terms.

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Keywords: water supply; water treatment plants; technical condition

* Corresponding author. Tel.: +420-541-147-723; fax: +420-541-147-728.
E-mail address: kucera.t@fce.vutbr.cz

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1. Introduction

The basic mission of water companies is to supply safe drinking water which meets the quality requirements laid down by legislation. The most important issue when managing and planning the operation of a drinking water distribution system is to satisfy consumer requirements. A reliable distribution system means ensuring water of the required quality and pressure at any time for all consumers. A considered bonus is a water supply that enjoys consumer trust [1]. However besides this prime objective, water companies focus on how to operate the entire water supply system cost-effectively and sustainably. They endeavour to focus on the design and construction of new elements of water supply to achieve better efficiency and effective functioning of existing systems. In addition, the current condition of individual components of the system and its behaviour needs to be assessed constantly. Only detailed knowledge of the present condition of the system makes it possible to make a meaningful plan of investments or partial repairs.

As a consequence of the attempts to assess these systems some assessment systems have been developed based, for example, on a system of performance indicators (PI). Among the most important PI systems are systems developed under the heading of International Water Association [2] and a series of other projects [3,4,5,6,7,8,9].

2. Methodology

The assessment of the technical condition of water treatment plants is part of the complex water supply system assessment methodology. All components of the system are considered from withdrawal structures, water treatment plants, tanks and pumping stations to individual water mains.

The design of a single concept of methodology of a preliminary assessment of the technical condition of elements of water mains is based on the method FMEA (Failure Mode and Effects Analysis). The FMEA is a method of analysing reliability which makes it possible to determine faults with major consequences affecting the function of the system and its elements.

2.1. Principle of assessment

In contrast to the standard FMEA method the proposed methodology is enhanced by a further level – factors (F). The technical indicators are not assessed directly here, but a set of proposed factors for each individual technical indicator is used for their assessment. A single four-point assessment system is proposed for each individual factor with specifications and a recommendation for a specific points assessment of each factor. A sort of verdict that is valid for the assessed element complies with each points assessment. In addition, the weight of each factor is determined as part of the assessment of the relevant indicator. Factors are the single level into which data are entered in the assessment, and assessments at higher levels are calculated from data entered at the level of factors.

The selected points assessment of factors is as follows:

- 0 – factor is not assessed, there is insufficient information for assessing this factor;
- 1, 2 or 3 – whereas value 1 means the most favourable condition, in contrast value 3 is the least favourable condition in the assessment of the factor

The assessment of the analysed water supply system or its part is divided into two basic parts:

- Structural and technical – total structural and technical indicators,
- Technological and operational – total of technological and operational indicators which have no direct link to the structural and technological condition of the analysed structure.

Thus this involves a multi-criteria assessment. The proposed methodology [10] of assessment of the condition is based on the weighted sum method. It is particularly important in the weighted sum method to set the weighting of the individual factors and indicators. The weighting in the proposed methodology was set on the basis of findings and experience of the research team also obtained from consultations with water company workers.

2.2. Approach to the assessment of water treatment plants

Water treatment plants play an important role in water supply systems for the supply of water both in the aspect of the quantity of supplied water and in its quality and quantity. While the importance of the quantitative aspect prevails in the distribution networks, in the case of water treatment plants the qualitative aspect of water supply also increases in importance.

The assessment of the technical condition needs to be considered comprehensively both in structural and technical terms and in operational and technological terms while it is necessary to take into account the quantity and the quality of the produced water.

With respect to the water treatment plants the authors of the methodology realize that it is hard to generalize the entire audit since there are many types of water treatment plants as well as technological elements used.

The proposed set of assessment indicators is based on the water treatment plant function, i.e. production of drinking water in the required quantity and quality. When assessing the technical condition of the water treatment plant this facility may not be viewed simply in structural and technical terms but it is absolutely necessary and much more important to assess it in technological terms. It is obvious that the resulting product – drinking water – must meet the prescribed indicator values but the production process efficiency may differ.

The indicators and factors related to the structural condition of water treatment plants are designed similarly to the water intake structures. The assessment of these indicators focuses on the condition of the tank and wall surfaces (concrete and masonry structures), the condition of windows and doors, ventilation and thermal insulation, etc.

Technically speaking, it is recommended that the proposed assessment indicators should be used to monitor the individual pipelines (e.g. progress of corrosion), functionality of closing and control elements as well as the age of pumps and other machinery. What is difficult is to determine the service life of these components. In general, the described methodology considers a limit service life works of 10–15 years for the machinery.

In the technological part of the assessment we focus mainly on the efficiency of drinking water production, the technical condition is then evaluated both in terms of the water treatment plant as a whole, and specifically for the crucial process units. These indicators include the treatment plant performance usability examining the ratio between the actual average treatment plant output and the projected output. The favourable ratio is considered at 90–100%. If the plant capacity is not fully utilized or if the plant is overloaded in hydraulic terms, the efficiency of technological processes is adversely impacted (design flow rate values, surface load and retention time are not followed). An indicator monitoring internal water consumption is used to follow the volume of water used to operate the process units (flushing water, sludge extraction, rinsing, etc.). A good situation in terms of internal water consumption is in the range of 3–5%, a value above 10% is considered unsatisfactory [11,12,13].

In addition to quantitative indicators, qualitative indicators have also been proposed to monitor compliance with the requirements for drinking water quality and the number of exceeded limit values, as well as the standard of the measurement and monitoring equipment at the plant and the degree of automation.

As regards the indicators assigned to the individual technological stages, removal efficiency is evaluated along with the retention time in the clarifiers, filtration rate and net unit production.

With respect to the efficiency, it is quite difficult to give an assessment verdict and some of the decisions must be left to be made by each individual assessor. However, the proposed methodology generally recommends the efficiency of removing suspended solids during sedimentation at over 80% to be considered as being very good. Similarly, with respect to filtration it is recommended as very good efficiency if the turbidity values in the effluent reach 1.0 NTU.

3. System of proposed indicators of water treatment plants

As has already been said, the system of the assessment of the technical condition is based on indicators that are further divided into factors. And in the case of water treatment plants part of the indicators applying to the structural and technical part and the operational technological part have been prepared.

Both these parts need to be assessed with an equal degree of effort however. But in the opinions of the authors, the operational and technological part methodology needs greater attention in the case of water treatment plants. It is for this reason that it is recommended assigning greater weight in the methodology to this part by up to 70% as opposed to 30% for the structural and technical part.

In the structural and technical part, individual components of structural constructions are assessed such as buildings but also components of technological units. Here the authors particularly have in mind concentre, steel and other tanks. Structural and technical parts are assessed using three indicators:

- Condition of structural construction,
- Condition of technological elements,
- Protection of a structure from external forces.

As regards structural assessment, we present as an example one of the factors for the walls of a buildings:

0 Not assessed;
1 Dust-free execution, no visible defects (cracks, mould, dampness);
2 Dust treatment, thin cracks, local occurrence of mould and attached organisms, isolated dampness;
3 Peeling surface, distinct cracks, greater areas of mould and attached organisms, marked dampness, water seepage.

As described above in the principle of methodology, assessment takes place by choosing a valid (most applicable) verdict at the level of individual factors. The factor then acquires the value stated in the chosen verdict. Structural openings (windows, doors, covers) as well as pipe entries through walls, railings and other elements.

In structural and technical terms, the level of structural protection is also monitored against external forces. Factors were incorporated into this indicator on how the structure was secured against entry of authorised persons (e.g. functionality of locks or conditions of window bars). In the case of water treatment plants, air contamination and exposure of the water surface to sunlight is also unacceptable – such factors are also found in the described methodology. We state one of the factors here "Ventilation"

0 Not assessed;
1 The structure is ventilated by functional air ducts, ventilation is equipped with an air filter, secured against the penetration of animals and rain;
2 Some of the air ducts do not function, lack an air filter, ventilation is secured against the entry of animals or the air ducts are not protected against rain;
3 Ventilation of the structural has limited function, lacks an air filter or is not secured with adequate protection against the entry of animals or the air ducts are not protected against the rain.

There is considerable experience in the Czech Republic with flooding so one of the factors also applies to securing the water treatment plant structure against flooding – hundred-year flooding is taken into account.

Assessment in structural and technical terms is an integral part of the methodology however greater importance is placed here on the operational and technological part thereby highlighting the qualitative aspect of water supply. The following items were included in this group:

- Scope of the water treatment technology;
- Separation technology;
- Further processes;
- Pump technology;
- Measuring, monitoring and manipulation;
- Efficiency of operation and safety.

In the 'Scope of the water treatment technology' indicator the technology line is also monitored for whether it corresponds in its composition to the intensity of raw water pollution. An assessment is made of whether any limit values for the quality of drinking water as specified by legislation have or have not been exceeded or whether it is expected that they could be exceeded in the near future. The factor called legislation has the following composition of verdicts:

0 Not assessed;

1 All standard indicators of the quality of drinking water are below the specified limit and no exemption is made regarding the quality of drinking water;
2 An exemption is made regarding the quality of drinking water or it is expected that after the amendment of the requirements for drinking water, water will not be produced conforming to the indicator with the threshold indicator (TI);
3 Some of the indicators with the highest threshold indicator (HTI) reach such values that these values will not be satisfactory after an amendment to legislation.

One of the important monitored factors is also the frequency of the unsatisfactory results of analyses. This factor is conceived as follows:

0 Not assessed;
1 The limit values of HTI indicators are not exceeded; TI indicators are exceeded at a max. of up to 1%;
2 The limit values of TI indicators is exceeded by 1–2%, in HTI indicators up to 1%;
3 The limit values of TI indicators is exceeded by more than 2%, in HTI indicators over 1%;

Note: Two types of limit values for quality drinking water indicators are introduced in Czech legislation. The threshold indicator (design. TI) applies to health non-hazardous indicators such as iron. The second type is the highest threshold indicator (design. HTI) which can be interpreted as health hazardous indicators such as arsenic and lead.

The indicator with the highest weighted value in the entire methodology concerns separation technologies. Here an in-depth assessment is necessary as regards knowledge of the course of the separation process. The assessment cannot go without a detailed analysis of documentation and supporting calculations. Facts such as 'Process parameters' are assessed which have the following composition of assessment verdicts:

0 Not assessed;
1 The key parameters of separation processes are satisfactory (the values need to be verified for example of surface load, Reynolds number, filtration rate, retention time, …);
2 The key parameters of separation processes have unfavourable values only in extraordinary situations (such as during short-term increased performance of the water treatment plant);
3 The key parameters of separation processes are constantly unsatisfactory (values need to be verified for example of the surface load, Reynolds number, filtration rate and others).

and also for example the 'Construction of separation units' factor whose value is selected from these verdicts:

0 Not assessed;
1 The technical equipment in which separation processes are taking place is fully satisfactory in terms of construction (such as adequately constructed inlet and outlet, appropriate raking device, working pump with adequate performance);
2 The technical equipment in which separation processes are taking place has certain construction defects, however these have no major impact on the quality of water at the outlet from the equipment;
3 The technical equipment in which separation processes are taking place has major construction or other defects that have a noticeable impact on the quality of water at the outlet from the equipment.

The water treatment plant assessment methodology was comprehensively conceived therefore the list of assessment factors also contains such an item as the utility of the performance of the water treatment plant in terms of its proposed values, smooth operation of the water treatment plant or outflow of chemicals. These items decidedly contribute to the overall assessment of the water treatment plant however they have a smaller impact on the result of the assessment.

4. Conclusions

The described assessment methodology of the water treatment plant's technical equipment is part of the comprehensive pack for the assessment of entire water supply systems (withdrawal structures, pumping stations, tanks, etc.). The construction of the methodology for a water treatment plant was not that simple because a water treatment plant contains a great number of different elements ranging from structural, technological to electronic. In addition, each of the more than 3,000 water treatment plants in the Czech Republic is unique. So it is difficult to adopt some universal assessment rules in which the entire assessment role can be generalised. Despite this the assessment methodology was construed whose outputs can serve as a basis for comparative analysis, planning of repairs, planning renovation, drawing up of renovation financing plans or as a basis for a further detailed structural and technological survey, etc.

The proposed methodology can interpret the technical condition of the assessed infrastructure and above all draw attention to the critical points in the system of drinking water production.

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