**THE POSSIBLE USE OF THE FMEA METHOD TO
ENSURE HEALTH SAFETY
OF MUNICIPAL WATER**

**MOŻLIWOŚCI WYKORZYSTANIA METODY FMEA
DLA ZAPEWNIENIA BEZPIECZEŃSTWA
ZDROWOTNEGO WODY WODOCIĄGOWEJ**

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Abstract: *The paper presents the adaptation of failure modes and effect analysis (FMEA) to assess risk associated with the possibility of tap water contamination. In the case of drinking water quality, occurring threats include pollution by hazardous substances that have an impact on life-threatening risk, health risk and environmental risk. The main aim of this paper is to develop a methodology to use the FMEA method for water supply system.*

Keywords: *water supply system, risk, FMEA*

Streszczenie: *W pracy zaprezentowano adaptację metody analizy przyczyn (rodzajów) i skutków uszkodzeń (FMEA) dla oceny ryzyka związanego z możliwością zanieczyszczenia wody wodociągowej. W wypadku jakości wody do spożycia, występujące zagrożenia obejmują zanieczyszczenia substancjami niebezpiecznymi, które mają wpływ na ryzyko zagrożenia życia, ryzyko zdrowotne i ryzyko środowiskowe. Głównym celem pracy jest opracowanie metodyki FMEA w odniesieniu do systemu wodociągowego.*

Słowa kluczowe: *system zaopatrzenia w wodę, ryzyko, FMEA*

1. Introduction

Failure modes and effects analysis (FMEA) it is a technique for determining the ways in which equipment can fail and the consequences of the failure on reliability and safety.

The purpose of failure modes and effect analysis (FMEA) is to analyse the possibility of system failures in the design and production stages. Components of the system have the possible failures assigned to them, then the frequency of occurrence and the possibility of detection are determined, and the potential effects and consequences are analysed (IEC 60812).

This method is an inductive method of risk analysis, which for the assumed failure of the component seeks the successive events and determines the possible final effects. FMEA can be applied at the level of systems, subsystems and components. FMEA was introduced in the 1960s for space flights. This method was used to verify the designs of spacecrafts in order to ensure maximum safety of astronauts.

The success of the method at NASA caused its usage in the aerospace industry. In the 1980s FMEA was successfully applied in the automotive and chemical industries, which resulted in its transfer to the ISO 9000 standards

The aim of the paper is to adapt the FMEA method to analyse the risk associated with consumption of tap water. Measurable qualitative result of FMEA for water supply system is a list of potential threats for health safety that can occur during tap water consumption.

2. The risk of water supply system

Safety of water supply system is defined as all conditions and actions that must be met at all stages of water production and supply, in order to ensure health benefits for humans. In light of the applicable law, the manufacturer - water supply company, is responsible for water health quality Risk (r) is the product of the likelihood of threat and its possible consequences (Chicken and Hayns 1989, MacGillivray et.al. 2006, Rak and Tchórzewska-Cieślak 2005).

$$r = P \cdot C \quad (1)$$

where:

P – the probability that a threat will occur (contamination of potable water),

C – measure of the possible consequences

As part of an evolving science on safety, the specialized techniques, called risk assessment, are being developed, based mainly on quantitative methods (ISO/IEC 2002, IEC 61882, Stewart and Melchers 1997). In the case of drinking water quality, occurring threats include pollution by hazardous substances that have an impact on life-threatening risk, health risk and environmental risk. The interaction between different types of risks are shown in Figure 1 (Szymczak, Szeszenia-Dąbrowska 1995).

Fig. 1 The interaction between individual risks

As you can see, the interaction between risks depends on the time of exposure. Life-threatening risk associated with the consumption of water is usually characterized by short time of exposure (incidental consumption of contaminated water, eg as a result of a terrorist attack, war, etc.). Health risk partially covers some areas of the two remaining risks. Health complications can occur as a result of consuming water that does not meet the requirements of the current standards (a well contaminated by flood, etc.). Environmental risk is the least documented from the medical point of view, and is associated with the degradation of aquatic.

Safety of water consumers can be secured by the following quality systems (Rak et al. 2005):

- Quality Management – QM,
- Hazard Analysis Critical Control Points – HACCP,
- Risk Analysis Biocontamination Control – RABC,

- Good Hygienic Practice - GHP ,
- Good Manufacturing Practice - GMP,
- Rapid Alert System for Food and Feed – RASFF.

GHP and GMP principles shall be implemented prior to the introduction of HACCP.

Fig. 2 Systems to ensure safety of municipal water supply system.

3. Monitoring of water supply system

One of the main activities undertaken by the water supply system operators to ensure reliable and safe supply of water to consumers is to carry out complex monitoring of all system components, from an intake to the consumer collection points. Complex water supply system monitoring includes:

- quantitative monitoring of water (measuring of flow rate and flow velocity, pressure measurement in water network),
- qualitative monitoring of water (examinations of physical, chemical and bacteriological indicators of water quality),
- technical monitoring of all the elements constituting the system (inspections of pipelines, the technical examination of materials, endurance test).

Methods of monitoring and classification of surface and underground waters are regulated by relevant legislation (Dz. U. z dnia 9 września 2008 r., Dz. U. Nr 204, poz. 1728, Dz.U. 2008 nr 143 poz. 896, DZ.U. nr 81,poz.685).

Table 1 shows the classification of surface and underground waters, depending on the quality, according to mentioned above regulations .

Table 1 The classification of surface / underground waters.

Class of water quality	Water quality
I	very good
II	good
III	moderate
IV	poor
V	bad

Depending on the limits of water quality indicators, which, because of water contamination, must be subjected to the standard treatment processes, in order to obtain drinking water in accordance with regulations issued by the Minister of Environment of 27 November 2002 on requirements to be met by surface waters used to supply the population with water intended for human consumption, three categories of waters are established:

- A1 - water requiring simple physical treatment, in particular, filtration and disinfection;
- A2 - water requiring standard physical and chemical treatment, in particular, pre-oxidation, coagulation, flocculation, decantation, filtration, disinfection (final chlorination);
- A3 – water requiring intensive physical and chemical treatment, in particular, oxidation, coagulation, flocculation, decantation, filtration, adsorption on activated carbon, disinfection.

The regulation of the Minister of Health of 29 March 2007 on the quality of water intended for human consumption ((Dz. U. nr 61, poz. 417) defines: the requirements for the quality of water intended for human consumption, a method for assessing the suitability of water, the minimum frequency of water testing and sites of water sampling, the study of water, water quality monitoring program, a method for surveillance of materials and products used in the water treatment and distribution, supervision of laboratories performing tests on water quality, a method of informing consumers about the quality of water and the proceedings before the authorities of the State Sanitary Inspection if water does not meet the quality requirements.

The proposed division of the water quality indicators, depending on the impact of exceeding the limit values for the health of water consumers, is as follows:

- group I - includes microbiological indicators,
- group II - includes chemical indicators, the key parameters of water quality, significant in view of their importance to the health safety of water and health risks, if their limit values are exceeded,
- group III - includes the other water quality parameters that may affect water quality and safety of health, but do not belong to group II,
- group IV - includes water quality parameters which characterize the pollutants that can get into water from building materials or as by-products of water disinfection, so called secondary water pollution,
- group V - includes the physical and chemical water quality indicators which affect consumer acceptance of water quality (colour, turbidity, taste, odour, iron, manganese).

4. The use of the FMEA method to analyse the risk of failure in water supply system

The FMEA procedure in relation to water supply system is carried out in the following stages (Rak and Tchórzewska-Cieślak 2005):

- defining the system and its decomposition into subsystems, objects and elements,
- identification of internal and external functions,
- identification of possible threats and determination of their impact on the entire system operation,
- classification of threats severity,
- identification of methods for detection and prevention of threats,
- evaluation and assessment of risk associated with various types of threats.

The practical course of conduct involves:

- giving identifiers to elements, objects and subsystems,
- determining their functions in the system,
- identifying types and symptoms of threats and methods for identification,
- identifying the causes of failures,
- determining the effects of failures and creating a ranking of criticality of failures,
- ways to prevent failures.

The concept of FMEA is as follows:

The FMEA methodology boils down to the following findings:

- the potential possibilities of the occurrence of undesirable events (failures),
- the possible health effects for consumers,
- identifying the causes,
- classification of the possible undesirable events (failures) in relation to health risks,
- projects for preventive actions.

Risk assessment shall be based on the following risk priority number (RPN):

$$RPN = S \cdot O \cdot D \quad (2)$$

where:

- S – point weight for threat severity rating, (contamination of tap water),
- O – point weight for the frequency of threat occurrence rating, (contamination),
- D – point weight for the possibility of threat detection rating, (contamination).

The point scale 1-10 is used for the individual RPN parameters.

Table 2 presents the criteria for evaluating threat severity (parameter S).

Table 3. presents the criteria for evaluating the frequency of potential threats occurrence (parameter O).

Table 4. presents the criteria for evaluating the threat detection (parameter D)

Table 2. The criteria and point weights for threat severity (contamination) – S

Type of water in source	Descriptive scale of the possible threat	The potential threat effects	Point weight
surface water and groundwater out of class and without category	Almost certain microbiological contamination (eg, bacteriological faecal contamination), possible excess of quality indicators for water from group II	very dangerous	10
surface water class 5 or 4, corresponding to category A3 and groundwater class 5	Very high probability of microbiological contamination, possible excess of quality indicators for water from group II	dangerous	9
	High probability of microbiological contamination, possible excess of quality indicators for water from group III	very serious	8
surface water class 4 or 3, corresponding to category A2 and groundwater class 4	Moderately high probability of microbiological contamination, possible excess of quality indicators for water from group III	serious	7
	Average probability of microbiological contamination, possible excess of quality indicators for water from group IV	average	6
surface water class 2, corresponding to category A2 and groundwater class 3	Low probability of microbiological contamination, possible excess of quality indicators for water from group IV	little	5
	Very low probability of microbiological contamination, possible excess of quality indicators for water from group V	very little	4
surface waters class 1, corresponding to category A1 and groundwater class 2	Slight probability of microbiological contamination, possible excess of quality indicators for water from group V	slight	3
	Very slight probability of microbiological contamination, possible excess of quality indicators for water from group V	very slight	2
groundwater class 1 (relic, triassic and older) does not require treatment	Almost impossible microbiological and / or chemical contamination	almost none	1

Table 3 The evaluation criteria and point weights for the frequency of threat occurrence – O.

Occurrence	Frequency estimation	Point weight
Almost certain	every day	10
Very often	once a month	9
Often	once every six months	8
Moderately often	once a year	7
Average	every 2 years	6
Seldom	every 5 years	5
Very seldom	every 10 years	4
Slight	every 25 years	3
Very slight	every 50 years	2
Almost impossible	every 100 years	1

Table 4 The evaluation criteria and point weights for the probability of threat detection – D.

Detectability	Probability	Point weight
Nearly impossible	$\leq 0,3$	10
Very little	0,5	9
Negligible	0,7	8
Very low	0,8	7
Low	0,9	6
Average	0,95	5
Medium high	0,98	4
High	0,99	3
Very high	0,999	2
Almost certain	$\geq 0,9999$	1

The criteria for risk assessment are as follows:

- $RPN \leq 40$ - tolerable risk,
- $40 < RPN \leq 100$ - controlled risk,
- $RPN > 100$ - unacceptable risk.

Application example:

- For the threat severity parameter:
 - surface water class 2, corresponding to the category A2, the low probability of microbiological contamination, possible excess of quality indicators for water from group 2C $\Rightarrow$ potential effects: little $\Rightarrow$ threat weight : $S = 5$
- For the frequency of occurrence parameter:

- occurrence: average $\Rightarrow$ estimated frequency: every two years $\Rightarrow$ frequency weight: $O = 6$
- For the detection parameter:
 - detestability: high $\Rightarrow$ probability of threat detection: $0.99 \Rightarrow$ detection weight: $D = 3$

Risk priority number is: $RPN = S \cdot O \cdot D = 5 \cdot 6 \cdot 3 = 90$, which corresponds to the controlled risk category.

Conclusions

- The following sequence of risk reduction is preferred: $S \rightarrow O \rightarrow D$
- Risk analysis is a key phase of the process of water supply safety management. It consists of threats identification and qualification of their consequences and frequency. Sources of information about the operation of water supply facilities are in the determined form (standards, regulations, orders) and sometimes in the probabilistic form (field tests, modelling, simulation).
- The determination of undesirable events that threaten the safety of the operation of water supply lies in the choice that takes into account the effects of failures. The possibility of adapting the FMEA method, based on the expert's method, was found.
- The qualitative result of the FMEA is a list of potential threats to health safety which can occur when municipal water is consumed. The significance of threat is determined by the point weight S . The quantitative result of the FMEA is risk estimation through the point weights O and D . The final result of the FMEA is the determination of the risk priority number RPN .
- The FMEA method is one of the first systemic approach to the analysis of undesirable events. It can be carried out starting from the level of a single element of the system (bottom-up) or from the level of the whole system towards its constituent elements (top-down).

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