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Software Architecture Considerations for the Use of 4.0 Technologies in Water Utilities

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Abstract: The global population is facing a water shortage as a result of the increasing concentration of people in certain areas, which puts great pressure on the operations of city waterworks. Water is a necessary resource for life, and most people take it for granted. City waterworks are required to provide sufficient potable water to all its residents 24/7. In order for this to be possible, the complex business of the waterworks consists of a large number of connected business processes, which should enable high-quality service, which often boils down to the problem of multi-factor optimization. The role of information systems is to ensure the smooth implementation of daily operations and the basis for making strategic decisions. It can be seen that the use of traditional information systems can only optimize the operation of city waterworks to a certain level. In this context, there is an area for the use of 4.0 technologies such as the Internet of Things, cloud computing, big data, and artificial intelligence. In this paper, we will consider the elements of software architecture that can make the operations of city waterworks more efficient.
Keywords: smart city; smart water utility; software architecture; industry 4.0

1 INTRODUCTION

Water is one of the most important resources on the planet. Fresh and usable water, which can be used for drinking, is very rare and makes up only 0.5% of the total 70% of water surfaces on Earth. About 2.3 billion people on the planet live in water scarcity and that number is expected to grow (United Nations, 2019). Trends show that the process of urbanization is unstoppable and that on a global level, around 55% of the population lives in urban areas. According to the United Nations in two related studies from 2014 and 2018, predictions are that about 70% of the world's population will live in urban areas by 2050. All this indicates that soon there will be an increasing fight for clean water (United Nations, 2014, 2019).

At the local and regional level, it is the water supply companies that provide water to the population. It is usual that they are part of the narrowest city infrastructure, so they need to follow the long-term development of the city. At the same time, a large number of water companies are also engaged in wastewater disposal services. They carry out their business through a set of complex, intertwined business processes, which extend from taking water from the source, its processing, and then distribution to the end consumers who use it. After the water is used, it goes into the sewage system, where it is taken away from the consumer, and after treatment, it ends up in the waterways.

Business requirements in city waterworks are usually such that they need to provide each citizen with a sufficient amount of water 24 hours a day, 7 days a week. Not all waterworks have the ability to provide drinking water for their citizens, but some of them do just that. This means that drinking water must meet the physical, chemical, biological and microbiological prescribed values of various parameters, which are determined by the standard and in accordance with health regulations. Because of this, the pressure on the operation of the city's waterworks is constantly increasing. There is a particular problem in countries such as Serbia, where the price of water is not determined by the market, but is part of social policy measures, which further limits business, but will not be the subject of this paper.

Traditional information systems applied in waterworks are: business, geographical and technical (Vesić, 2023). Each of them has its field of action. The business information system enables the implementation of the company's business functions: customer registration, installation, replacement, servicing and reading of water meters, consumption invoicing, material and financial accounting, warehouse operations, procurement, personnel records, etc. Technical information systems are systems for control and monitoring of industrial processes: monitoring the water level in reni wells at scattered sources, as well as drinking water tanks that will be delivered to consumers, data on the main parameters of the water supply network such as pressure and flow, data from pumping stations and pumps, data on the levels of chemicals in the purification process, etc. Geographic information systems integrate spatial data (where things are located) with all types of descriptive information (what things are there): data about pipelines and their characteristics such as pipe diameter, material, year of construction, section length, type of pipe, then data on connections and their characteristics, data on fittings, etc.

Many challenges that arise in water supply operations cannot be overcome or reduced to a satisfactory level by using traditional technologies. It is a space that opens up for Industry 4.0 technologies such as Internet of Things, cyber-physical systems, then Cloud, Fog and Edge computing, Big Data technologies, artificial intelligence and machine learning its special part.

These technologies should enable more efficient implementation of business operations in city waterworks. This actually means that it is necessary to enable business insights that did not exist until now, which can become the basis for decision-making that will contribute to the reduction of various anomalies that may arise in different parts of the business model of the city water supply. Therefore, it would be possible to carry out business process reengineering relying on Industry 4.0 technologies that can achieve a high degree of interoperability with existing IT in city water utilities.

In the second chapter, we will analyze in more detail the operations of city waterworks through the value chain. In the third part, we will point out the challenges to the value chain. In the fourth unit, we will present some technological solutions of Industry 4.0 that can help in their business. In the conclusion, we will analyze the elements of the presented software architectures, and at the same time point out additional aspects of the application of these solutions and conclude with that.

2 BUSINESS MODEL OF WATER UTILITIES

Water companies have a complex business that is usually performed by a number of sectors, such as the water production sector, maintenance sector, water distribution sector, sewage sector, electro-mechanical plant sector, development and design sector, measurement and control sector, sales and billing sector, etc. In order to present the operations of such a complex system, which consists of a large number of subsystems, in a simpler way, the value chain model can be used. A value chain is a series of related activities that add value to an organization's products or services (Bocij et al., 2015, p. 52). There are two types of activities: primary activities and support activities (Stair & Reynolds, 2018, p. 47). Primary activities directly affect the production and distribution of the company's products and services and typically for production include: inbound logistics, operations, outbound logistics, marketing and sales, and services. Support activities include 4 basic areas of support activities: technological infrastructure, human resource management, accounting and finance, and procurement.

The value chain of water utilities is proposed by Ofwat, the regulatory body of England and Wales and it consists of (PwC, 2016):

- Water sources
- Raw water distribution
- Water treatment
- Treated water distribution
- Retail
- Sewage collection
- Sewage treatment
- Sludge treatment
- Sludge disposal

Water sources are used to supply raw water. They can be underground and above ground. With the increase in the number of inhabitants in cities, there is an increase in the need for water, so it is necessary to build a larger number of sources and thus increase capacities. Water sources can be scattered, i.e. they are not located in one location. City waterworks build their facilities to be able to draw water from underground and/or above-ground sources.

Raw water distribution aims to carry out its transport from the source of raw water to the water treatment plant. It consists of a complex of hydraulic elements such as pipes, pumping stations, etc., which work in synergy and need to deliver raw water from the water source to the factory for its processing. The task of the waterworks is to ensure the unhindered delivery of raw water to factories for processing, so it is necessary to carry out maintenance activities, as well as the construction and reconstruction of certain parts of the raw water distribution network.

In water processing plants, the technological process of obtaining clean drinking water is carried out by processing raw water. It can differ depending on the source that has been selected, considering that different sources have different degrees of impurity that need to be removed in the technological process. It is common for the technological procedure to consist of several stages, some of which are: preozonization, clarification, ozonization, filtration using double-layer filters, filtration using activated carbon, chlorination, UV disinfection, etc. After that, drinking water is stored in tanks.

Water distribution aims to deliver drinking water from the water treatment plant to the final consumers. It is a complex hydraulic system composed of pipes, valves, pumps, hydro towers and tanks. If the city is located on hilly terrain, then pumping stations are used to push the water to the appropriate height from where it is distributed to consumers by gravity.

End consumers, households and firms use water, which is charged in the sales process. Consumers have measuring devices, water meters, the reading of which determines the current consumption expressed in cubic meters, which is compared with the previous one, thus determining the amount of water consumed in the observed time period. Water utilities charge for the water used and in this way, they earn part of their income. In addition, the regulation regulates the handling of measuring devices and determines their correctness, replacement period, etc.

After use, the water goes into the sewage system, which has the task of collecting atmospheric and waste water in the process of collecting it, purifying it bringing it from the city territory and discharging it into water receivers. Atmospheric water is formed by precipitation such as snow, rain, and hail. Waste water includes the water used by the users, as well as the water produced in industrial processes and production activities, then water for washing streets, etc. The task of the city waterworks is to maintain the sewage infrastructure through a set of activities that it carries out.

Processing of atmospheric and wastewater is a step in which collected and delivered water is processed and its bad impact on the environment is reduced, which is actually a form of environmental protection. As the costs of this part of the sewage infrastructure are very high, the city's waterworks must decide in the long term to build factories dedicated to wastewater treatment. Due to insufficient financial resources, some city waterworks are not able to do this, so waste water is poured into river basins.

Sewage sludge is a by-product, which results from the treatment of municipal wastewater. Sludge treatment refers to various treatment processes before transporting the treated sludge to where it is collected for recycling or disposal. The most common processes used to treat sludge are anaerobic digestion (AD), lime stabilization and incineration.

After processing, the sludge must be disposed of or recycled. This can be done in a number of ways: recycling by spreading on agricultural land, where it is used as a soil enhancer and fertilizer, then disposal by incineration and disposal in landfills. With this set of activities, the value chain ends.

It should be mentioned that some city waterworks do not include all the activities previously mentioned in the value chain. This usually refers to sewage treatment, sludge treatment, and sludge disposal. The main reason is insufficient investment in that part of the water infrastructure. As the awareness of environmental protection grows, so do the majority of city waterworks, supported by the state, invest efforts and large financial resources in these infrastructure segments as well. This is the most common case in capital cities, which can provide the largest volume of investment in that part of the water infrastructure.

3 CHALLENGES IN THE VALUE CHAIN OF WATER COMPANIES

In the value chain of water companies, there are many challenges in the primary activities. They can be presented in Table 1.

Table 1 Challenges in the Value Chain of Water Companies

	Activities	Challenges
Water sources	raw water extraction	source contamination
Raw water distribution	transfer of raw water to the processing plant	interruption of raw water transportation due to failure
		raw water contamination
Treated water distribution	transfer of drinking water from the tank to the consumer	interruption of the transport of drinking water
		contamination of drinking water
		water theft
Retail	water meter reading	accuracy and frequency of readings
	determination of breakdowns in consumption	breakdown at the water meter block
	classifying consumers into categories	checking whether the consumer fits his category
	consumer satisfaction with calculated consumption	impossibility of checking the fulfillment of obligations by the water company
Sewage collection	maintenance of atmospheric sewerage	the impossibility of determining the priority of drain maintenance in the situation of a significant change in atmospheric conditions
	separation of atmospheric and waste sewage	inability to control the separation of atmospheric and waste sewage

Although in reality there are many more challenges, in this paper we will focus on the following: the problem of contamination, the problem of non-revenue water, the problems of accuracy of readings and the problem of the impossibility of determining priorities in the maintenance of drains during weather changes.

3.1 Contamination Problem

The problem of contamination consists of the problem of contamination of the water source, then contamination of raw water and contamination of drinking water. Raw water that is captured from the source must have the appropriate quality in terms of physical, chemical, biological and microbiological parameters that it needs to meet. Depending on whether it is an underground or above-ground source, these parameters can vary. These variations can affect the technological process of water purification in which drinking water is obtained from raw water. It is directly related to the costs associated with the water treatment process. Therefore, in most waterworks, continuous sampling of raw water is carried out, its quality is checked, and if there is a risk of contamination, adequate actions are taken to prevent such raw water from entering the processing process. Source contamination is a major health and safety problem for every city and state, and for this reason, constant independent controls are carried out even by the state itself. The usual practice is to carry out the sampling in a manual way, where later each sample is checked with a series of necessary analyses and it is determined whether all the relevant parameters are satisfied. A similar principle applies to drinking water that needs to meet some other set of parameters. Both activities here aim to prevent health disasters.

3.2 Non-revenue Water Problem

The problem of non-revenue water, hereinafter referred to as NRW, refers to drinking water from which the company cannot generate revenue, and it is composed of a set of problems, some of which relate to leakage in the distribution network of the water supply system, then to the reading of the water meters themselves, theft of water and etc. The mentioned problems lead to the fact that there are losses of produced water delivered to the distribution system, which increase over the years. At the global level, the losses amount to 35 to 40%, while in Europe the average is 26% (AVK International A/S, n.d.). Because of this, most water utilities are constantly investing in the capital facilities of the water source, instead of directing the funds to the retention of the existing water in the system, which is known as the phenomenon of the "vicious cycle of NRW". (Frauendorfer & Liemberger, 2010, pp. 9–11). For a detailed understanding of the structure of water losses, a water balance is used, proposed by the International Water Association, which was simultaneously accepted by a large number of water utilities (Babić & Djukić, 2011), Table 2.

Table 2 NRW Structure (Babić & Djukić, 2011, p. 27)

<table>
<tr><td rowspan="10">System Input Volume (corrected for known errors)</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

Most water supply companies make efforts to reduce the share of NRW by repairing faults, reconstructing the distribution network, creating basic balancing zones, placing measuring equipment at certain points and collecting data from those devices, implementing manual fault detection, purchasing new and repairing old water meters, introducing illegal consumers into the system. These activities are most often not integrated and are carried out by different organizational units in isolation from all others that should influence the reduction of NRW.

It is common for water utilities to have organizational units that deal with the reduction of NRW, and one of their key activities is the creation of the so-called mathematical model of the distribution system. That model can be represented in the form of a graph where pipes form the edges of the graph and valves form the nodes of that graph. In that model, the expected values of pressure and water flow are precisely known at certain points. When those values deviate from those expected in the observed period, then manual activities are carried out that should determine where the anomalies arise, i.e., losses in the distribution network i.e., in the observed balancing zone. This is done by assigning a task to another organizational unit to determine where the anomaly occurs, where they then go to that region and use special equipment to determine where the anomaly is located. This is quite inefficient, especially in a situation where we have a large number of changed parts of the distribution network, so with each change, it is necessary to make an adjustment, i.e., calibration of the mathematical model. At the same time, this model is good insofar as there are geographically distributed points where pressure and flow values are measured. Although a good part of these devices are connected to the IT infrastructure via SCADA, there are also devices that collect data, the so-called loggers, from which these data are periodically downloaded and, through batch procedures, are loaded into software through which the analysis of the mathematical model of the water supply network is performed. Due to the great complexity of the water supply distribution system, where a good part of it is determined by the nature of water movement, i.e. laws of fluid mechanics, it is very difficult to manage the optimization of the water distribution system in terms of loss reduction, because there are a large number of different interwoven operational activities that are applied in the traditional management of the water distribution network.

3.3 The problem of Accuracy and Frequency of Readings

This problem can be seen as a special problem when reducing NRW. Water meters are used in the reading process, which are mechanical devices that break down over time. For this reason, it is necessary to ensure the continuous maintenance of a large number of water meters at the level of the entire city, which can be measured in hundreds of thousands of devices. In addition, in some facilities, there are no so-called direct connections, but water is calculated as a share of the total consumption. Therefore, new work procedures have been introduced in some waterworks, through which the total consumption of a larger facility, such as, for example, the shopping centre calculates through the main water meter, and all stores within it have their own local water meters where control is carried out. The business rule applies here that the sum of consumption on all local water meters should be equal to the consumption on the main water meter. It is customary to determine the customer's consumption in the period based on two consecutive readings and to issue invoices based on this.

Problems arise because water meters break down over time and then show measurement errors. In addition, part of the errors occur in the recording of the state of the water meter, where a decade ago the consumption was entered manually in the reading book. Since that time, PDA devices have been used to record consumption. Errors in consumption occur on the basis of incorrect input by the person in charge of reading the water meter.

Part of the problem arises when a large number of people are connected to one main water meter, and at the same time, they have their own local water meters where the sum of their consumption does not match the total consumption, which may be a sign that there is illegal consumption or that the distribution network does not meet the prescribed standards.

Most water utilities read the water meters several times a year, and this can be a big problem if, in the meantime, there are certain malfunctions that are small or invisible to the eye. Once the consumer receives the bill, he is no longer in a position to take any action to reduce the bill.

3.4 The Problem of the Impossibility of Determining Priorities in the Maintenance of Street Gutters During Weather Changes

In the case of storm sewers, it is important to monitor the level of rainwater in the downspouts, in order to be able to react in time and prevent water from spilling onto the street and thus prevent endangering the safety of people in traffic. It often happens that drains get clogged, due to careless citizens who throw various forms of waste into them, as well as drain overflows due to huge amounts of rainfall.

In a situation where there is a large amount of precipitation, the city's waterworks, which may be responsible for the maintenance of the sewage network, may be in trouble, because they have no knowledge of which group of drains will fill up the fastest and spill onto the roadway. That is why it is difficult to prioritize the maintenance of those drains, and instead of preventive maintenance, the maintenance of the sewage network is carried out reactively.

4 INDUSTRY 4.0 SOLUTIONS IN OVERCOMING CHALLENGES IN THE VALUE CHAIN OF WATER COMPANIES

A smart city is a vision that enables the integration of many different technological solutions and manages the most diverse city assets: local government information systems, schools, libraries, transportation systems, hospitals, power plants, law enforcement agencies and other services in that community (Musa, 2016). The goal is to provide citizens with a higher level of quality of life through the use of technology that increases the efficiency of services and meets their needs. In order for the aforementioned vision to be feasible, it presupposes the application of new generation technologies better known as Industry 4.0, which unite: the Internet of Things, cloud computing, cyber-physical systems, big data technologies, etc. which serve planning, construction, management, integrated industrialization, computerization, modernization and sustainable development of cities (Safiullin et al., 2019). With these technologies, a vision came to life.

Although water utilities have traditional IS in the form of business, geographic and technical, they have limited opportunities to overcome challenges in the value chain of primary activities. At the same time, it is a big problem if the aforementioned IS are not integrated, but act as isolated entities, which in many ways makes daily operational activities more difficult, and makes the challenges greater. As water pipes are the most important part of the city's infrastructure, it is assumed that some solutions offered by Industry 4.0 can help solve problems in their value chain. What is specific about these solutions is that they can either increase the efficiency of the company's existing business processes or make some business processes automated or semi-automated, which was not possible with earlier ICT solutions.

4.1 Industry 4.0 Solutions in Overcoming Contamination Problem

The quality of water is very important for citizens, and it needs to be continuously checked, whether it is raw water that is taken from the source or drinking water that is delivered to consumers.

Advances in sensor and wireless communication technologies make it possible to implement a solution to monitor water quality at sources. In his research, Paska states that such a solution requires a large number of sensors and that it is therefore important that the downward trend in the price of sensors continues (Paska, 2018). The implemented solution was implemented in Stockholm during 2017 and 2018, where the parameters: pH, temperature, conductivity, dissolved oxygen and redox potential were measured on Lake Melleren. The sensors communicate with the cloud-based Ericsson IoT platform over the LTE network. In the first phase of the research, the data collected from the sensors was unsatisfactory, because not much could be concluded about the contamination of the source. Therefore, it was decided to apply multivariate analysis and artificial intelligence in the next phase in order to provide a reliable solution for monitoring the quality of the raw water at the source.

The authors (AlMetwally et al., 2020) propose a low-cost water quality monitoring system, which allows for additional filtration. It uses sensors for temperature, pH, and turbidity, where if the water is not of satisfactory quality, it is directed to the filters and then to the distribution system. The sensors connect to an SBC, such as an Arduino or Raspberry Pi, and have the ability to send data to the Cloud.

Research results (Lakshmikantha et al., 2021) show that the water quality monitoring system consists of a number of sensors, the most important of which are: temperature, turbidity, pH, conductivity, humidity, and CO_2, which are connected to the controller. The controller is an Arduino uno ATMEGA328. Through the WiFi module, the controller sends data to the Cloud where processing takes place, and if something is not right, users are notified on their mobile phone or PC.

4.2 Industry 4.0 Solutions in Overcoming the Problem of Non-revenue Water

The problem of non-revenue water is extensive and here we will focus on the part related to leaks and failures in the water distribution network. Water utilities usually use sensors in a technical information system, implemented as a SCADA system. SCADA has very expensive sensors that connect to PLCs. Considering that water distribution networks are very long, the installation of SCADA sensors is unprofitable. There is room for relatively inexpensive IoT sensors that can be embedded and form a wireless sensor network. The problem of fault detection consists of two mutually related problems, namely detection that should answer the question: Has a fault occurred? And localization: Where did the failure occur?

The paper presents the architecture, which consists of a wireless sensor network, where each sensor would be installed in the pipe of the distribution system (Difallah et al., 2013). The sensors measure two parameters: pressure and flow. All the nodes of that network address the local workstation, which processes the data, and at the same time forwards it to the central server, which stores the data in a string-based database. Both on the server, as well as on local stations, anomaly detection is performed by stream processing. As a detection algorithm, it uses LISA spatial statistics, extended by time parameters. The proposed solution enables anomaly detection locally and globally.

One of the problems in the detection of anomalies in infrastructure networks, such as the water distribution network, is the selection of the algorithm needed to recognize the anomaly. In extensive research, the authors provide an overview of a large number of algorithms that can be used (Chan et al., 2018). Anomaly detection algorithms can be roughly grouped into: statistical, classification, model-based, predictive, clustering-based, spatio-temporal, etc. Some of them are: Nonlinear Kalman Filter, Predictive Kalman Filter, ANN, SPC, Weighted Least Squares With Expectation-Maximization, Deep Belief Neural Network, Bayesian inference system, Graph-Based Localization, Ensemble CNN-SVM, Pattern Matching, Associative Artificial Neural Networks, K-nearest neighbors, Bayesian Classifier, Multiclass SVM, Graph Partitioning Algorithm with Flow Balancing Equation, RuLSIF – Relative unconstrained Least-Squares Importance Fitting, k-means, PCA, Linear Prediction Coefficient Filter - LPCF, Multivariate Nearest Neighbor - MVNN, etc.

What is not stated is the fact that each of the presented algorithms requires a different architectural setup. Some solutions are on-premise, but can also be used on the cloud, while some solutions that require the processing of streams as one of the scenarios of BigData technologies, can be used exclusively on the cloud platform.

In the scenarios of anomaly detection on the water distribution network, there is a large number of variations in the proposed solutions at different levels of the software architecture. For example, the authors propose a system that includes the Internet of Things, which has audio sensors in it, where the use of AI algorithms such as neural networks, specifically convolutional neural networks, achieves detection (Rezwanul Islam et al., 2023). The proposed solution also shows the specific selection of the sensors themselves, the SBU and the required chipset.

4.3 Industry 4.0 Solutions in Overcoming the Problems of Accuracy and Frequency of Readings

As in many industries, of which electricity production and consumption stand out, smart meter technologies have revolutionized the process of reading and acquiring data. The progress from AMR to AMI technologies contributed a lot to this.

The authors (Joy Okoli & Kabaso, 2024) give an overview of the technologies used in the formation of a smart water grid. They indicate that there are a number of different IoT solutions. LPWAN technologies, such as e.g. LoRaWAN and NB-IoT due to their ability to have a long communication range and low power consumption are proving to be very important in performing communication from the Edge layer to the central server. They differentiate three different architectural layers: the measurement layer, the communication layer and the communication layer. In the mentioned way, information about consumption reaches both the water company and the user himself, which ensures much greater trust compared to the previous manual readings of consumption and their recording in PDA devices.

In practice, pilot research involving IoT is also carried out, where pre-prepared modules are placed on top of the existing analogue metering infrastructure and thus enable remote consumption readings. These modules establish communication via LoRa or NB-IoT technologies. They usually contain a large number of alarms that allow them to be installed for many years, such as a magnet attack alarm, an alarm for disconnecting the module from an analogue water meter, an overconsumption alarm, a leak alarm, etc. The readings that arrive at the server are usually stored in a database that can support time series as well as the volume of data from multiple devices. Most often, with the use of ETL, that data is transferred to some other database that is related, from where the data is consumed by the WEB API and forwarded to different clients in JSON format. Web or mobile applications consume this data and display consumption data from the water meter. If there is a high speed of data arrival from many devices, it may happen that traditional technologies that work in on-premise mode are not sufficient, especially in the part where it is necessary to receive data from the Edge layer. Then it switches to cloud mode, which enables scalability and the use of technologies such as Apache Kafka, Amazon Kinesis, RabbitMQ, etc.

4.4 Industry 4.0 Solutions in Overcoming the Problem of the Impossibility of Determining Priorities in the Maintenance of Street Drains

By installing sensors in sewer drains at a certain height, it is possible to monitor how much water is inside the drain. After the water level exceeds a certain threshold, the sensor can notify the local gateway, which further forwards the information to the Cloud.

At an early stage, one such solution is offered by Fujitsu (Fujitsu, n.d.). It is a combination of IoT, Cloud, Web services based on the REST convention.

5 CONCLUSION

The research indicates that IoT, Cloud Computing, Big Data and AI technologies can significantly contribute to solving or reducing unwanted effects on the operation of city waterworks. Depending on the problem for which a software solution is applied, the software architecture can differ to a greater or lesser extent. What can be singled out as an invariable part of those architectures are the layers that are differentiated into: the sensing layer, local gateway layer, backend layer and frontend layer (Vesić, 2025).

In the sensing layer, sensors acquire all relevant data such as: pressure, flow, water quality parameters, etc. In addition, for certain scenarios, it is possible to implement wireless sensor networks, through which data on a phenomenon can be collectively transmitted, especially where there are spatially distributed observation objects. The sensing layer passes its data to the local gateway layer.

The local gateway layer aims to enable data transfer to the backend layer. That is his primary task. Also, he can perform some additional activities that are important to be done as early as possible, which can be very significant in the case of water contamination problems, i.e. early detection of contamination is possible. Additional activities would include collecting and analyzing data from a specific group of sensors that would address that server. For the realization of this task, a suitable technology can be Fog Computing, which would collect data from local gateways and carry out their preprocessing due to the need to remove noise in the data, and then processing through which local anomalies can be detected. A local anomaly may or may not be based on AI concepts, and it largely depends on the specific scenario. Depending on the amount of data that arrives and the time in which it arrives, Big Data frameworks such as e.g. Spark, are in the streaming scenario. In this sense, it is possible to define a time interval of observation, the so-called A window in which an anomaly detection algorithm is implemented, and if the data arriving from the sensor in that interval is processed by the algorithm and it is determined that an anomaly exists, it is possible to undertake all activities to mitigate its effect or to remove it entirely. In Spark, the mentioned algorithms can be programmed in Python, Scala, and Java. Also, other programming languages such as C# and .NET through certain libraries have the ability to work with this Big Data framework. Therefore, the layer of the local gateway can be viewed only as Edge Computing, but also as Edge Computing extended Fog Computing. The architectural solution largely depends on which problem from the value chain of water supply is being solved, as well as what the other limitations are: domain, technological, financial, legal, etc.

It is the backend layer that needs to accept data from the local gateway layer. Depending on the specific scenario, it is possible that the volume of data is large and therefore it is necessary to first store it in a broker (we mentioned some alternatives earlier), and then to process and store the data additionally. In this way, it is possible to gain an insight into each individual region but also to have an overall picture of the system, which is very important for the business operations of city waterworks, which are usually organized by region. In addition to the mentioned activities performed by the backend layer, it is necessary to enable an API that could forward data to all clients, regardless of whether they are desktop, web or mobile. For the aforementioned reasons, Web service technologies are used, most often based on the REST standard. Many different technologies, software frameworks and programming languages can be used on this layer. The most common case is that the choice of Cloud vendor Amazon, Azure or others will determine their choice.

The frontend layer shows the user data and problems that occur in the infrastructure of the city's water supply. This layer communicates with the BackEnd layer and consumes data. Usually, the mentioned interfaces should be organized in such a way as to enable the display of changes that are in real-time or close to real-time. That is why SPA frameworks are used in Web applications that enable this. They are mainly organized as JavaScript frameworks, but they can also use WebAssembly technologies, such as e.g. .NET Blazor.

What has been observed in many manuscripts is that the authors are focused on how existing problems in water supply companies can be solved by using smart solutions. What is much less talked about is how to integrate traditional IS: business, geographical and technical with new smart solutions, and this is very important, especially for those scenarios that require data exchange or the initiation of business processes through existing systems. If we have anomaly detection, users would like to see perhaps some additional data on their interface about the place where the anomaly occurred, e.g. how old are the pipes, what is their diameter, what material are they made of, or who does the water meter read, and that can't be obtained unless integration with the traditional IS used in water companies is performed.

This type of integration should pay special attention to complementing the data from smart technologies with data from the geographic information system, which can enable better localization and quick response in certain scenarios, such as, for example, the maintenance of the water distribution network. As the GIS contains a database of the elements of the water distribution network, it can, through an API or in some other way, forward data on which valve scheme needs to be closed in order to localize a fault or possibly contaminated drinking water. In this way, unwanted consequences can be reduced and efficiency in the management of the water distribution network can be increased

In addition, it should be borne in mind that many of these systems can be legacy, which can further complicate the problem of integrating traditional and smart solutions. Therefore, in the backend layer, it is necessary to carry out the adequate architectural design for all these systems to work in harmony as a single entity, i.e. from the outside they looked like a system of systems. This may include a hybrid cloud scenario where data exchange would be achieved about on-premise traditional systems and smart systems that are more cloud-oriented.

6 REFERENCES

[1] AlMetwally, S. A. H., Hassan, M. K., & Mourad, M. H. (2020). Real Time Internet of Things (IoT) Based Water Quality Management System. *Procedia CIRP*, *91*, 478–485. https://doi.org/10.1016/j.procir.2020.03.107

[2] AVK International A/S. (n.d.). *Water in the world – local and global challenges*. Water in the world – local and global challenges

[3] Babić, B., & Djukić, A. (2011). Estimation of Water Balance and Water Losses in Water Utilities-Experiences from the Belgrade Waterworks. *Water Research and Management*, *1*(4), 27–34.

[4] Bocij, P., Greasley, A., & Hickie, S. (2015). *Business Information Systems: Technology, Development and Management for the E-Business* (5th ed.). Pearson Education Limited.

[5] Chan, T. K., Chin, C. S., & Zhong, X. (2018). Review of Current Technologies and Proposed Intelligent Methodologies for Water Distributed Network Leakage Detection. *IEEE Access*, *6*, 78846–78867.

https://doi.org/10.1109/ACCESS.2018.2885444
[6] Difallah, D. E., Cudre-Mauroux, P., & McKenna, S. A. (2013). Scalable anomaly detection for smart city infrastructure networks. *IEEE Internet Computing*, *17*(6), 39–47. https://doi.org/10.1109/MIC.2013.84
[7] Frauendorfer, R., & Liemberger, R. (2010). *The Issues and Challenges of Reducing Non-Revenue Water*. Asian Development Bank.
[8] Fujitsu. (n.d.). *Fujitsu Develops Technology for Low-Cost Detection of Potential Sewer System Overflows*. Retrieved June 30, 2020, from https://www.fujitsu.com/global/about/resources/news/press-releases/2015/0210-03.html
[9] Joy Okoli, N., & Kabaso, B. (2024). Building a Smart Water City: IoT SmartWater Technologies, Applications, and Future Directions. *Water*, *16*(4). https://doi.org/10.3390/w16040557
[10] Lakshmikantha, V., Hiriyannagowda, A., Manjunath, A., Patted, A., Basavaiah, J., & Anthony, A. (2021). IoT based smart water quality monitoring system. *Global Transitions Proceedings*, *2*(2), 181–186. https://doi.org/10.1016/j.gltp.2021.08.062
[11] Musa, S. (2016). Smart Cities - A Roadmap for Development. *Journal of Telecommunications System & Management*, *5*(3). https://doi.org/10.4172/2167-0919.1000144
[12] Paska, D. (2018). Digitalized water and smart cities - how can telecommunication networks be used for environmental resilience? *ITU Journal: ICT Discoveries*, *2*, 1–8. https://xilirprojects.com/wp-content/uploads/2019/11/ITU2018-3.pdf
[13] PwC. (2016). *Balance of Risk: Risk and reward across the water and sewerage value chain*. http://www.ofwat.gov.uk/wp-content/uploads/2015/12/rpt_com201512pwcrisk.pdf
[14] Rezwanul Islam, M., Azam, S., Shanmugam, B., & Mathur, D. (2023). An Intelligent IoT and ML-Based Water Leakage Detection System. *IEEE Access*, *11*. https://doi.org/10.1109/ACCESS.2023.3329467
[15] Safiullin, A., Krasnyuk, L., & Kapelyuk, Z. (2019). Integration of Industry 4.0 technologies for "smart cities" development. *International Scientific Conference "Digital Transformation on Manufacturing, Infrastructure and Service."* https://doi.org/10.1088/1757-899X/497/1/012089
[16] Stair, R. M., & Reynolds, G. W. (2018). *Principles of Information Systems* (13th ed.). Cengage Learning.
[17] United Nations. (2014). *World Urbanization Prospects The 2014 Revision - highlits*.
[18] United Nations. (2019). *World Urbanization Prospects 2018 - highlights*.
[19] Vesić, S. L. (2023). Use of Data Warehouse in Water Companies. *SETI V - International Scientific Conference SCIENCE, EDUCATION, TECHNOLOGY AND INNOVATION*.
[20] Vesić, S. L. (2025). Software architectures for smart water utilities. In M. Gligorijević (Ed.), *International Scientific and Professional Conference "ALFATECH" Smart Cities and modern technologies* (pp. 181–187). ALFA BK University. https://doi.org/10.46793/ALFATECHproc25.181V

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