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APPLICATION OF COMPARATIVE ANALYSIS AND SAW METHOD FOR SELECTION OF A QUANTITY DRINKING WATER METERING SYSTEM

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Abstract

The numerous positive experiences from the use of the smart system for remote reading of drinking water serve as an incentive to analyze the possibility of applying the smart system in the Republic of North Macedonia. For this purpose, both the existing and the smart system were analyzed, with the most appropriate criteria being selected, both qualitative and quantitative, based on various practical and scientific findings. Each of the systems is described through all the established criteria, after which a comparative analysis of these two quantity drinking water metering systems was carried out, and the benefits of applying the smart system for measuring drinking water were determined.

Key words: *Existing system, Smart system, Water loss, Malfunctions, Expenses, Simple Additive Weights Method*

INTRODUCTION

Water suitable for human consumption is called drinking water or potable water. This natural resource is becoming increasingly rare in certain areas, and its availability represents a major social and economic problem. The lack of potable water to meet human needs occurs on all continents and, as stated by the World economic forum in 2019, it will represent one of the greatest global risks in the upcoming decade [1]. The shortage of potable water is manifested through partial or complete inability to meet the expressed demand, economic competition for the quantity or quality of water, disputes among users, irreversible depletion of groundwater, and negative impacts on the environment.

Two-thirds of the world's population live with the conditions of no water for at least one month each year [2]. More than two billion people live in countries where water supply is not findable. Half a billion people around the world face lack of water throughout the entire year. Half of the world's largest cities suffer from lack of water. Only 0.014% of the Earth's water is drinkable and easily accessible. Of the remaining water, 97% is seawater, and slightly less than 3% is difficult to access [3]. Technically, there is enough fresh water globally to meet humanity's needs. However, due to unequal distribution, further aggravated by climate change creating some very wet and some very dry geographical regions as well as the sharp increase in global demand for fresh water from industry in recent decades, humanity is facing a drinking water crisis.

If current trends continue, demand is expected to exceed supply by 40% by the year 2030 [4].

According to water quantities, our country falls within the areas with satisfactory water resources, with only a slight shortage felt during certain parts of the year, especially in the summer months, and particularly in Eastern Macedonia. Drinking water in all public utility companies in our country is bacteriologically and chemically safe, as confirmed by the daily analyses carried out by the expert teams of the Institutes for Health Protection in each city [5].

In 2024, it was estimated that Macedonia loses 146 000 000 m^3 of drinking water annually, almost half of the public utility companies (PUCs) operate at a financial loss, and for the majority of them, water loss exceeds 40% [6]. The current quantity drinking water metering system in our country consists of multi-jet horizontal and vertical water meters, as well as volumetric and industrial water meters. In this system, meter readings are done manually, which results in reduced accuracy, the inability to monitor consumption in real time, and the inability to detect excessive consumption or illegal connections. This makes the system inefficient and causes financial losses for the PUCs, especially when considering the wear and frequent malfunctions of the existing devices.

In recent years, a transition has begun from the old system to a new smart drinking water metering system, which significantly facilitates readings, increases user privacy, improves data transmission, reduces water losses, enables better management of water resources, and improves the financial performance of the PUCs.

The purpose of this paper is to determine the benefits and cost-effectiveness of introducing the smart system for measuring drinking water, using the municipality of Negotino (2400 households and 70 legal entities) as an example.

MATERIAL AND METHODS

Quantity drinking water metering systems

The term drinking water consumption measurement system refers both to the already existing system for measuring drinking water, which has been used for many years in almost all municipal enterprises, and the new, smart system, which significantly eases reading, data transmission within the system, as well as costs and water losses caused by the old system.

Existing System

The elements of the existing system for measuring drinking water are: multi-jet water meters (horizontal and vertical), volumetric water meters, and industrial (combined) water meters.

The multi-jet horizontal water meter (Figure 1. a) is of good quality and has a special locking mechanism. It is a dry water meter with multiple jets for residential applications, in sizes from 15 mm to 50 mm for cold/hot water. The principle of operation, tested over time, ensures accuracy and a wide flow range that maintains that level of accuracy. They must be installed horizontally with the dial facing directly upward to maintain accuracy. Pulse output with several selectable rates is available in most types. This allows the addition of a digital display for remote reading and, if necessary, the ability to reset to 0. These meters comply with the standards ISO4064 Class B for horizontal installation.

The vertical mechanical water meter is a type with multiple jet wings. This type of water meter requires vertical installation, with the direction of water flow being upward and downward, and it is easy to install, made from quality materials. Apart from the casing, the vertical water meter has the same components, mechanism, performance, and other parts as the horizontal water meter (Figure1.b).

a) b)

Figure 1. a) Horizontal and b) Vertical Multi Jet Water Meter DN15 for Residential areas

The volumetric water meter is a mechanical meter that accumulates water measurements based on fixed volume increments (Figure 2.a). It is most used in residential, commercial, and other areas. This type of water meter comes in several dimensions: DN15 (1/2"), DN20 (3/4"), DN25 (1"), DN32 (1-1/4"), DN40 (1-1/2").

The industrial water meter is widely used for main pipelines, industry, and irrigation fields. Made of stainless steel, cast iron, and ductile iron (Figure 2.b), these water meters range in size from DN50 to DN600 mm. An advantage of the industrial water meter is that the casing material has high wear resistance, with corrosion protection provided by epoxy resin.

The water temperature for all the previously presented types of water meters ranges from 0.1–40°C for cold water meters and 0.1–90°C for hot water meters.

a) b)

Figure 2. a) Volumetric Water Meters DN15(1/2"), b) Industrial Water Meters

Smart System

The components of the measuring instrumentation and the remote reading system, as well as the elements required for installing the smart drinking water metering system, are: vertical and horizontal multi-jet water meters (Figure 3), radio module (Clip ON) – attached to a multi-jet water meter with a wet mechanism (Figure 4.a), ultrasonic water meter (Figure 4.b), receiver with Bluetooth connection (Figure 5.a), optical device for programming ultrasonic water meters, handheld tablet for collecting and visualizing data (Figure 5.b).

a) b)

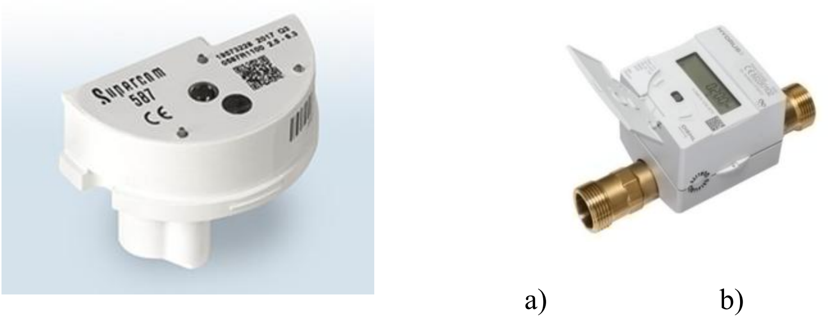
Figure 3. Horizontal (a) and vertical (b) domestic multi-jet water meter with wet mechanism

The radio module of the ultrasonic water meters is integrated into the meter itself, which prevents any kind of manipulation by the user. It is mounted directly onto the glass of the water meter without additional cables or screws. Data transfer is carried out through a one-way continuous radio system. The radio reading of the parameters takes place visually, also optically. Through programming with an optical device, the radio module allows activation of different alarm functions: leakage detection, minimum and maximum flow, and tampering recognition. The signal transmission time is less than 10 seconds, and the minimum data transmission range from the installation site of the modules, without additional amplifiers, is up to 400 m. This device has a protection class (protection against full immersion when installed in a chamber) of at least IP68, and the battery life is a minimum of 12 years. It also has the possibility of an upgrade to a GPRS system for data transmission and reading from a single location.

The ultrasonic water meter is a static cold-water meter with an ultrasonic volume measurement component, combined with hardware and software for measuring flow and water consumption, with the possibility of being integrated into an automatic remote reading system.

The reception of signals from the ultrasonic water meters is carried out via a Bluetooth connection, which is paired with a handheld computer – tablet. The receiver is used for reading the statuses of both multi-jet and ultrasonic water meters.

Compatibility of the receiver with Bluetooth connection is required for reading the statuses from the radio modules of multi-jet water meters with accuracy class R80, as well as compatibility with ultrasonic water meters that have an integrated radio module. One-way communication with the radio modules is also required for reading the radio signal from compact-type modules.



a) b)

Figure 4. a) Radio module (Clip On), b) Ultrasonic water meter

The optical device for programming ultrasonic water meters is paired with a handheld computer – tablet and is used for programming and adjusting the parameters of the ultrasonic water meters. The handheld tablet for data collection and visualization must be compatible with the licensed software of the optical device and the Bluetooth receiver. It is used for programming, configuring, and reading the statuses of radio modules in multi-jet water meters, as well as reading the statuses from radio modules of ultrasonic water meters. The handheld tablet is applied in radio reading systems and must include an installed licensed software package for radio reading. It should operate on a Windows operating system. The operating temperature range of the tablet is from a minimum of -10°C to a maximum of +50°C, with an operating humidity from 10% to 90%. The protection class is at least IP65.

a) b)

Figure 5. a) Bluetooth connector, b) Handheld tablet

Method of Comparative Analysis

The comparative analysis method is a method that applies comparison of identical or related facts, phenomena, processes, and relationships, in order to determine their similarities and differences. This method enables researchers to enrich their knowledge and reach new conclusions. Comparison between two things, phenomena, or events is conducted by first identifying their common aspects and then pointing out their differences. The comparison should emphasize both what is shared and what is distinct, which demonstrates the cognitive role of this method [7, 8].

The main goal of the comparative analysis method is empirical generalization and verification of the hypothesis. Through this, unknown aspects can be understood based on what is already known. This makes it possible to explain and interpret phenomena, generate new knowledge, and highlight the uniqueness of familiar phenomena and similar cases.

Comparative analysis is a suitable method for studying the possibilities and contributions of this topic. Simply put, without comparative analysis it is not possible to form a standpoint, concept, judgment, or conclusion in any form.

The criteria for comparing the old and new systems for drinking water measurement are divided into quantitative and qualitative. Quantitative criteria can be measurable, numerical data used for comparison or analysis. Qualitative criteria are non-measurable, descriptive characteristics that relate to the quality, nature, and properties of the object under analysis. Practice has shown that the most realistic picture in any analysis is obtained by combining both quantitative and qualitative criteria.

The quantitative criteria for evaluating the existing and smart drinking water metering system are the costs, which are represented by investment and operating costs, while the following qualitative criteria have been adopted: accuracy and possibility for integration with other systems, shortages, reduction of consumption, and water losses, and acceptability by the population.

Investment Costs

Investment costs are lower in the existing drinking water metering system because they involve lower initial costs for procurement and installation. These systems are often less complex and require less advanced technology, which makes them more affordable. Training for use and maintenance of the old systems is also cheaper, since the systems are simpler and do not require advanced training.

The investment costs for the existing drinking water metering system were calculated using the example of the Municipality of Negotino (2400 households and 70 legal entities). These costs include procurement, transport, installation of the required multi-jet water meters, reading equipment, and staff training. The total investment cost for this scale of installation amounts to 9 230 252 MKD. On the other hand, the initial costs for procurement and installation (investment costs) of modern measurement systems, which often include digital water meters, intelligent sensors, and remote monitoring capability, are higher.

The investment costs for the smart drinking water metering system were also calculated using the example of the Municipality of Negotino (2400 households and 70 legal entities). These costs include procurement, transport, installation of the required multi-jet water meters prepared for radio reading and ultrasonic water meters with internally integrated radio modules, a complete set of equipment for remote reading, programming, and configuration of radio modules, including handheld tablets together with PCs with installed software packages for reviewing and visualizing water meter data for remote reading, as well as staff training. The total investment cost for this scale of installation amounts to 25 053 972 MKD [9, 10, 11].

Operational Costs

The components considered as the basis for defining the operational costs of both quantity drinking water metering systems include:

- Costs for meter reading – daily wages for reading the meter data on a monthly basis,
- Repair costs – including both material expenses and labor costs,
- Non-revenue water (NRW) – the unbilled quantity of drinking water due to system losses.

The operational costs of the existing drinking water metering system are high. Manual data processing is required (writing down readings and entering them), which can be time-consuming and prone to human error. The old measurement system often requires greater maintenance due to worn-out components and mechanical parts, making repairs frequent and expensive, especially if spare parts for older models are no longer produced. The unbilled quantity of drinking water due to system losses in our country amounts to around 62% of the total supplied water. The total operational costs of the existing system on a monthly level for the same scope (2400 households and 70 legal entities) amount to 48 323 069 MKD [9, 10, 11].

The operational costs of the smart drinking water metering system are lower. Meters equipped with radio-reading modules can be read in two ways: by walking (manual mobile reading) from a moving vehicle or via an upgraded stationary network that transmits the data directly to the office. This reduces the time required for this activity. In these systems, modern and durable materials are used (non-corrosive alloys, special plastics) that have a longer service life, which means that maintenance and repair costs are usually lower. The unbilled quantity of drinking water due to losses in the system can be minimized in the smart system. This is possible only if all defects and illegal connections are removed – which the system is able to detect and report. The total operational costs of the smart system on a monthly level for the same scope (2400 households and 70 legal entities) amount to 99 422 MKD.

Accuracy and Possibility for Integration with Other Systems

The existing system has limited precision and relies on mechanical methods, which can cause measurement errors. The influence of temperature, pressure, and chemical composition of the water can lead to incorrect readings. Accuracy can be limited due to mechanical parts and variations in water flow, affecting the repeatability of measurements. Additionally, the technological capabilities of older systems are not designed to support new technologies; they lack automation, and many old water and sewer systems are unable to collect data automatically, while manual data processing is time-consuming and resource-intensive. Integration of new water measurement technologies with old systems can be challenging, so integration must be carried out carefully and in phases.

Modern systems often use electronic or digital technologies that offer higher accuracy and the possibility for automatic calibration. They often have built-in sensors for external factors, which help them adjust and provide accurate measurements under varying conditions. Digital technologies provide greater precision, with minimal variation between repeated measurements. These systems often offer options for integration with IT technology, allowing real-time monitoring and data analysis.

Shortages, Reduction of Consumption, and Water Losses

Shortages and losses of drinking water are a serious problem in many regions of the world and can have various causes and consequences. The main causes of drinking water shortage are: climate change (droughts, changes in precipitation patterns), excessive consumption (especially in agriculture and industry), population growth, poor water resource management (inefficient policies), pollution (industrial waste, wastewater, agrochemicals), and others.

Reducing water consumption is possible only if efforts are made to raise public awareness of the importance of drinking water and the need for its rational use, through workshops and training for the population, interactive lessons in kindergartens and schools, creating flyers and posters, using print and electronic media for this purpose, and more.

The causes of water losses in the old system include: leakage from outdated water pipes, leakage in connections and reservoirs, damaged infrastructure, inaccurate measurement of consumption (malfunctioning water meters), illegal connections to the water network, and losses due to lack of monitoring and control.

In the new smart meter system, notifications can be received for leaks or abnormal consumption, which can potentially lead to financial savings for the utility company and encourage the population to reduce irrational water use.

Acceptability by the population

If the public is well informed about the benefits of smart water measurement, such as better resource management, cost savings, and the ability to monitor water consumption in real time, there is a higher likelihood of acceptance of the system. When local governments and utility companies take an active role in implementation, offering incentives, public presentations, and user support, acceptance will be higher. This approach helps address any skepticism.

In the existing drinking water metering system, privacy can be compromised during meter readings, since meters are often located inside homes, and the meter reader must access the meter to record consumption.

As with other "smart" technologies, concerns often exist about data privacy and security. People may fear that their water consumption data could be misused by utility companies. However, transparency in how data is used and strong security measures can mitigate these concerns.

RESULTS AND DISCUSSION

Comparative Analysis

Based on the defined criteria and the evaluation of the existing and smart system for measuring drinking water according to all criteria, as given in the previous chapter, a comparative analysis can be made for each criterion separately, as well as a general conclusion of this analysis.

The investment costs are lower in the existing drinking water metering system, since it has lower initial costs for procurement and installation (these systems are often less complex and require less advanced technologies, which makes them cheaper). On the other hand, the initial costs for procurement and installation of the smart system, which often include digital water meters, intelligent sensors, and the possibility for remote monitoring, are higher, which may cause rejection by the public utility companies.

The operational costs of the existing drinking water metering system are high, since manual data processing is required, frequent defects occur due to worn-out components, and there is a large amount (62%) of unbilled drinking water. Whereas these costs in the smart system are much lower because the reading of the water meters is done remotely, the materials applied are modern and durable, and the unbilled amount of drinking water can be reduced to a minimum if all defects and illegal connections are eliminated, which this system can report. This cost is on a monthly level and has a huge impact on the financial operations of the public utility companies, which gives a great advantage to the smart system compared to the existing one.

The existing system has limited accuracy and the use of mechanical methods, which may cause errors in measurement, while the integration of new drinking water measurement technologies with old systems can be a challenge. Therefore, the integration should be carried out carefully and in phases. On the other hand, smart systems often use electronic or digital technologies that provide greater accuracy and the possibility of automatic calibration, and they also offer integration options with IT technology, which allows real-time monitoring and data analysis. This indicates that public utility companies will have much greater benefits in their operations if they install a smart drinking water metering system.

Regarding the quantitative criterion of shortage, reduction of consumption and losses of drinking water, the general conclusion is that public utility companies must continuously replace the worn-out parts of the system, promptly monitor losses and abnormal consumption, detect illegal connections, and analyze the data obtained from the field. This will lead to an improvement in the financial operations of these companies. Considering both proposed systems in relation to this criterion, a much greater advantage is given to the smart system, since it has the ability to provide leakage notifications and allows better management of water resources.

In the existing drinking water metering system, during the very process of meter reading, the privacy of the population is compromised, since water meters are often located inside households. However, as a system that has been applied for a long time and is familiar to users, it is more widely accepted. To achieve greater acceptance of the smart system, it is necessary to inform the population about the benefits of smart water measurement, such as better water resource management, cost savings, and the ability to monitor water consumption in real time.

Table 1. Comparative analysis of the existing and smart drinking water metering system

Tag	Criterion	Existing system	Smart system
C_1	Investment costs	9 230 252 MKD (low purchase prices)	24 991 159 MKD (high purchase prices)
C_2	Operating costs	48 323 069 MKD/month (high, due to slow readings, frequent malfunctions and unbilled water)	99 422 MKD/month (low, due to faster reading, more durable materials and the ability to minimize unbilled water)
C_3	Accuracy and possibility of integration with other systems	Limited accuracy, human errors, mechanical influences. Poor integration with IT systems, difficult to upgrade	High accuracy, automatic calibration, real-time data. High integration with IT technologies, the possibility of embedding on sensors
C_4	Shortage, reduction in consumption and losses of drinking water	Large losses (62%), non-functional water meters, illegal connections, leaks	Reduced losses, leak alarms, better water resource management
C_5	Acceptability by the population	Violation of privacy during reading	Greater transparency and control are needed, as well as education of the population to increase acceptability.

From Table 1, it is clearly seen that the existing system is cheaper in the short term but uneconomical and inefficient in the long run, whereas the smart system is expensive to install but enables significant savings and improvement in the financial operations of the public utility companies, greater accuracy in measurement, reduction of drinking water losses, while its acceptance by the population depends on how much the public utility companies will inform them and on their transparency and control in operations.

Simple Additive Weights (SAW)

The Simple Additive Weighting (SAW) method is often known as the weighted addition method. The basic concept of the SAW method is to find a weighted sum of the performance ratings for each alternative on all criteria (Fishburn, 1967) (MacCrimmon, 1968). The SAW method requires a decision matrix normalization process (X) to a scale that can be compared with all existing alternative ratings [12, 13].

This SAW method requires the decision-maker to determine the weight for each criterion. The total score for the alternatives is obtained by adding up all the multiplication results between the rating (which can be compared across criteria) and the weight of each criterion. The rating of each criterion must be dimension-free in the sense that it has passed the previous matrix normalization process [14].

The rating of each attribute must be dimension-free in the sense that it has passed the previous matrix normalization process.

The quantification of qualitative criteria in the simple additive weights (SAW) method is made according to Table 2 [15].

Table 2. Quantification of qualitative criteria in the Simple Additive Weights (SAW) method

Type of criteria	bad	good	average	very good	excellent
C_{max}	1	3	5	7	9
C_{min}	9	7	5	3	1

Table 3. Weight of the criteria and value/rating on alternatives

Criteria	Criterion Weight	Alternatives	
		Existing system– A_1	Smart system – A_2
		Value/Rating	Value/Rating
$C_1 \rightarrow min$	0.20	9 230 252 MKD	24 991 159 MKD
$C_2 \rightarrow min$	0.35	48 323 069 MKD/month	99 422 MKD/month
$C_3 \rightarrow max$	0.20	5	9
$C_4 \rightarrow min$	0.15	9	3
$C_5 \rightarrow max$	0.10	5	7

The formula for carrying out the normalization is as follows [16]:

$$R_{ij} = \begin{cases} \frac{X_{ij}}{maxX_{ij}}, & for\ C_i \rightarrow max \\ \frac{minX_{ij}}{X_{ij}}, & for\ C_i \rightarrow min \end{cases} \tag{1}$$

Where Rij is a normalized performance rating; Xij is the attribute value of each criterion; Max Xij is the greatest value of each criterion; Min Xij is the smallest value of each criterion; Rij is the normalized performance rating of the alternatives Ai on criteria Cj; i = 1,2,…, m and j = 1,2,…, n.

The preference value for each alternative (Vi) is given as:

$$V_i = \sum_{j=1}^{n} W_j \cdot R_{ij} \tag{2}$$

Where Vi is the ranking for each alternative, Wj is the weighted value of each criterion; A larger Vi value indicates that the alternative Ai is preferred.

Table 4. Ranking by Simple Additive Weighting (SAW) method

Criteria C_j	Criterion Weight W_j	Alternatives - A_i			
		Existing system– A_1		Smart system – A_2	
		Normalized performance rating - R_{ij}	Ranking – V_1	Normalized performance rating - Rij	Ranking – V_2
C_1	0.20	1.0000	0.2000	0.3693	0.0739
C_2	0.35	0.0021	0.0007	1.0000	0.3500
C_3	0.20	0.5556	0.1111	1.0000	0.2000
C_4	0.15	0.3333	0.0500	1.0000	0.1500

C_5	0.10	0.7143	0.0714	1.0000	0.1000
Total Ranking			**0.4333**		**0.8739**

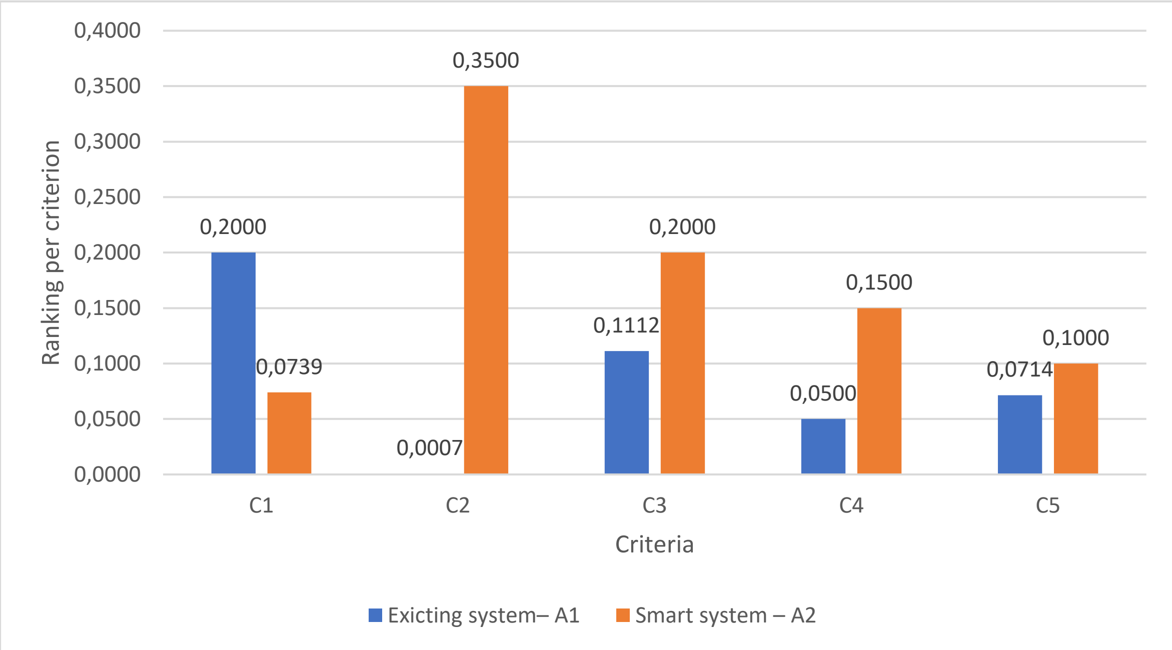


Diagram 1. Ranking per each of the criterion

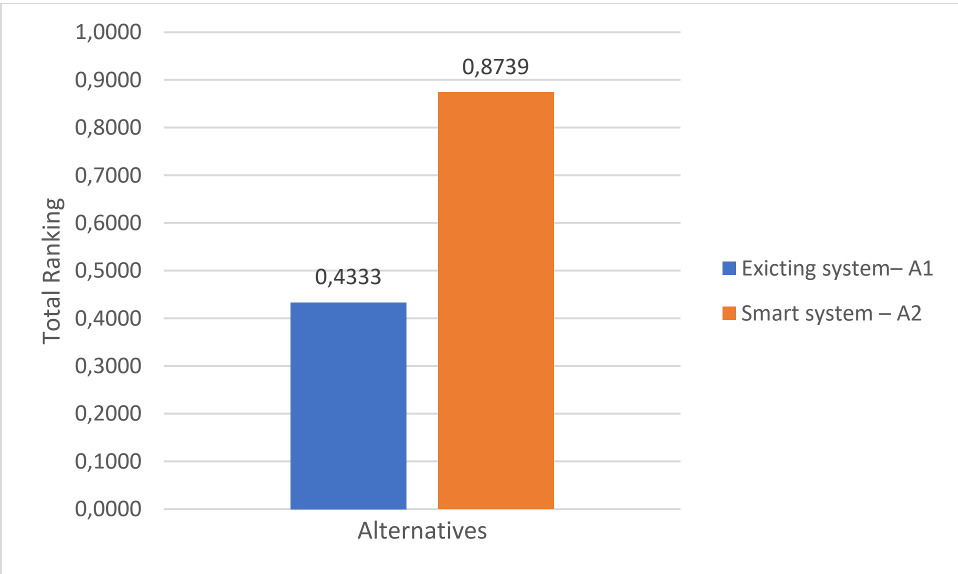


Diagram 2. Total ranking for the existing and smart drinking water metering system

From Table 4 and Diagram 2, it can be seen that the total ranking of the existing drinking water metering system has a value of 0.4333, which is much lower than that of the smart system, which amounts to 0.8739. This shows that even with this analysis using the Simple Additive Weighting (SAW) method, the advantage lies with the smart drinking water metering system.

In Diagram 1, the individual ranking per each of the applied criteria for the two adopted alternatives is presented, where it can be noted that only in Criterion 1 – Investment Costs does Alternative 1 (the existing system) have an advantage, while for all other criteria the advantage belongs to the smart system.

CONCLUSION

Smart quantity drinking water metering systems could be considered an important tool for the planning and operations of public utility companies. These systems record water consumption and transmit the information to the companies for monitoring and billing; they also provide greater measurement accuracy and reduce drinking water losses, since consumption is monitored in real time and all illegal connections and abnormal consumption are detected. When it comes to public acceptance, it depends on how much the utility companies will inform the public and how dedicated they will be to transparent and accountable operations.

In terms of costs, the smart system has higher investment costs, but the monthly operational costs are much higher in the existing system, which negatively affects the financial performance of the public utility companies. The analyses in this paper showed a significant advantage of smart drinking water metering systems, therefore as a general conclusion it can be stated that public utility companies should:

- inform the population about the importance and benefits of the smart system, through workshops, flyers, and use of media space;
- install the smart drinking water metering system;
- use the data on leakages and illegal connections to eliminate such occurrences;
- regularly renew the worn-out water supply network;
- operate transparently and accountably;
- use the collected data from the smart system for better management of water resources, cost savings, and the ability to monitor water consumption in real time.

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